NATIONAL INVENTORY REPORT 1990–2024: GREENHOUSE GAS SOURCES AND SINKS IN CANADA

CANADA'S SUBMISSION TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE



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Rapport d'inventaire national 1990–2024 : Sources et puits de gaz à effet de serre au Canada

FOREWORD

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC) on December 4, 1992. Multiple international agreements were introduced under the UNFCCC, the most recent one being the Paris Agreement which Canada ratified on October 5, 2016. Under the Convention, national inventories of sources and sinks of greenhouse gases (GHGs) must be submitted to the UNFCCC annually by April 15 of each year. This report is part of Canada's annual inventory submission to the UNFCCC.

Previously, up to the 2023 edition, this inventory was prepared and submitted in accordance with the UNFCCC Reporting Guidelines, adopted through Decision 24/CP.19. Since 2024, Canada's national GHG inventory complies with the modalities, procedures and guidelines (MPGs) for the transparency framework for action and support referred to in Article 13 of the Paris Agreement (Decision 18/CMA.1). The reporting guidelines require Parties to develop their national inventories using the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. The reporting guidelines also require inventory reports to provide detailed and complete information on estimates development, including the formal arrangements supporting their preparation and any significant changes to inventory preparation and submission procedures. The reporting guidelines also commit Parties to improve the quality of emission and removal estimates on an ongoing basis.

In addition to the description and explanation of inventory development and national arrangements, the present National Inventory Report analyzes trends in emissions and removals. The report also describes the several improvements incorporated in this edition of the inventory, along with the subsequent recalculations.

This report represents the efforts of many years of team work and builds on the results of previous reports, published in 1992, 1994, and yearly from 1996 to 2025. Ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce their uncertainties as far as practicable.

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Overall coordination of Canada's National Inventory Report was led by Raphaëlle Pelland St-Pierre. Compilation of centralized emission data and tables, uncertainty estimates and key category analyses were led by Amélie Amiot and Pegah Bauco. The coordination and submission of the CRTs was led by Catherine Robert. Layout of the National Inventory Report for publication was led by Marida Waters. Translation services were provided by Dalila Benmeddour and Kim Thibault. Credit is given to the ECCC Digital Communications Web team for webpage development. Additionally, we would like to thank Monique Murphy for the methane emissions gridded maps.

Other contributors

We would like to acknowledge Richard Holt and Navin Sundar of the Cross Sectoral Energy Division of ECCC for implementing the Marine Emissions Inventory Tool as well as the Analysis and Modelling Division of ECCC for providing socio-economic data used in the data extrapolation and provincial disaggregation processes for several Industrial Process and Product Use (IPPU) categories. In addition, we would like to recognise the contribution from the Mining and Processing Division of ECCC, specifically Alain Gingras and Vincent Roy for their support in collecting historical activity data for the inclusion of emissions from the production of iron ore pellets.

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LIST OF COMMON ABBREVIATIONS AND UNITS

Abbreviations

AAC ..... Aluminium Association of Canada
AAFC ..... Agriculture and AgriFood Canada
AWMS ..... Animal Waste Management System
BCER ..... British Columbia Energy Regulator
BCOGC ..... British Columbia Oil and Gas Commission
CAC ..... criteria air contaminant
CAPP ..... Canadian Association of Petroleum Producers
CBM-CFS3 ..... Carbon Budget Model of the Canadian Forest Sector version 3
CCS ..... carbon capture and storage
CCTUS ..... carbon capture, transport, use and storage
CEEDC ..... Canadian Energy and Emissions Data Centre
CEPA 1999 ..... *Canadian Environmental Protection Act, 1999*
CEPEI ..... Canadian Energy Partnership for Environmental Innovation
CFC ..... chlorofluorocarbon
CFS ..... Canadian Forest Service
C-NLOER ..... Canada-Newfoundland and Labrador Offshore Energy Regulator
COA ..... *Census of Agriculture*
CRT ..... Common Reporting Tables
DE ..... digestible energy
DOC ..... degradable organic carbon (Waste sector)
DOC ..... dissolved organic carbon (LULUCF sector)
DMI ..... dry matter intake
DOM ..... dead organic matter
ECCC ..... Environment and Climate Change Canada
EF ..... emission factor
EFW ..... energy from waste
EO ..... Earth Observation
EOR ..... enhanced oil recovery
FRD ..... facility-reported data
GDP ..... gross domestic product
GHG ..... greenhouse gas
GHGRP ..... Greenhouse Gas Reporting Program
GWP ..... global warming potential
HCFC ..... hydrochlorofluorocarbon
HFC ..... hydrofluorocarbon
HWP ..... harvested wood products

ICSR ..... Industrial Chemicals and Synthetic Resins

IEA ..... International Energy Agency

IPCC ..... Intergovernmental Panel on Climate Change

IPPU ..... Industrial Processes and Product Use

LDAR ..... Leak Detection and Repair

LMC ..... Land Management Change

LTO ..... landing and takeoff

LULUCF ..... Land Use, Land-Use Change and Forestry

MCF ..... methane conversion factor

MMV ..... Measurement, Monitoring and Verification

MPGs ..... modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement

MSW ..... municipal solid waste

N/A ..... not available

NFCMARS-HWP ..... National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products

NIR ..... National Inventory Report

NMVOC ..... non-methane volatile organic compound

NRCan ..... Natural Resources Canada

ODS ..... ozone-depleting substance

OECD ..... Organisation for Economic Co-operation and Development

PFC ..... perfluorocarbon

QA ..... quality assurance

QC ..... quality control

RESD ..... *Report on Energy Supply and Demand in Canada*

RU ..... reconciliation unit

SCR ..... selective catalytic reduction

SLC ..... Soil Landscapes of Canada

SMR ..... steam methane reformation

SOC ..... soil organic carbon

StatCan ..... Statistics Canada

UOG ..... upstream oil and gas

VKT ..... vehicle kilometres travelled

UNFCCC ..... United Nations Framework Convention on Climate Change

Chemical Formulas

C ..... carbon

$CaCO_3$ ..... calcium carbonate; limestone

CaO ..... calcium oxide; lime; quicklime; calcined limestone

CF_4 ..... carbon tetrafluoride; perfluoromethane

C_2F_6 ..... carbon hexafluoride; perfluoroethane

CH_4 ..... methane

CO ..... carbon monoxide

CO_2 ..... carbon dioxide

CO_2 eq ..... carbon dioxide equivalent
H_2S ..... hydrogen sulphide
Mg ..... magnesium
$MgCO_3$ ..... magnesite; magnesium carbonate
MgO ..... magnesia; magnesium oxide
N ..... nitrogen
NF_3 ..... nitrogen trifluoride
NH_3 ..... ammonia
NH_4^+ ..... ammonium
NH_4NO_3 ..... ammonium nitrate
N_2O ..... nitrous oxide
N_2O-N ..... nitrous oxide emissions represented in terms of nitrogen
NO_3^- ..... nitrate
NO_x ..... nitrogen oxides
SF_6 ..... sulphur hexafluoride
SiC ..... silicon carbide

Notation Keys

IE ..... included elsewhere
NA ..... not applicable
NE ..... not estimated
NO ..... not occurring

Units

bbl ..... barrels
g ..... gram
Gg ..... gigagram
GWh ..... gigawatt-hour
ha ..... hectare
kg ..... kilogram
kha ..... kilohectare
km ..... kilometre
kt ..... kilotonne
kWh ..... kilowatt-hour
m ..... metre
Mg ..... megagram
Mha ..... million hectares
ML ..... megalitre
Mt ..... megatonne
PJ ..... petajoule
TJ ..... terajoule
t ..... tonne
TWh ..... terawatt-hour

EXECUTIVE SUMMARY

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ES.1. Key Points

- In 2024, Canada's greenhouse gas (GHG) emissions (excluding the Land Use, Land-Use Change and Forestry [LULUCF] sector) were 685 megatonnes of carbon dioxide equivalent (Mt CO_2 eq),[1] a decrease of 78 Mt (-10%) from 2005, and a decrease of 2.2 Mt (-0.3%) from revised 2023 emissions.
- The most notable trends in Canada's emission profile between 2005 and 2024 were from Electricity as well as Oil and gas sources. Emissions from Electricity decreased by 66 Mt (-57%) over this period driven by the phase-out of coal-fired electricity generation. Oil and gas emissions increased by 10 Mt (5.1%), although emissions peaked in 2014 at 230 Mt and have since decreased by 22 Mt (-9.6%) to 208 Mt in 2024, consistent with measured decreases of fugitive methane sources in recent years.
- Methane emissions reached their lowest reported levels in 2024 at 105 Mt CO_2 eq, decreasing by 47 Mt (31%) since 2005 and by 39 Mt (27%) since 2012.[2] This was driven by the Oil and Gas sector, which accounted for almost 80% of the decline. Since the peak of Oil and Gas methane emissions in 2014, emissions have decreased by 46%, largely in response to federal and provincial regulations designed to reduce methane emissions.
- The emissions intensity for the entire Canadian economy (GHG per gross domestic product [GDP]) has continued to decline; in 2024 it had declined by 48% since 1990 and by 37% since 2005.
- As with every National Inventory Report (NIR) edition, improvements have been implemented resulting in revisions to previously published data. Overall, this edition of the inventory shows an upward revision of 4.3 Mt in 2005 and a downward revision of 7.0 Mt in 2023, compared with the previously published inventory in 2025. Enhanced methods use Canadian-specific studies and knowledge, facilitate the adoption of new scientific data and better reflect evolving technologies and industry practices.
- Canada's NIR is a scientific report representing Canada's historical emissions since 1990, which, along with other publications such as Canada's Biennial Transparency Report (BTR), informs and supports decision-making to reduce GHG emissions and combat climate change, as reflected in the 2030 Emissions Reduction Plan.
- Consistent with Canada's Nationally Determined Contribution, reporting of progress towards emission reduction targets combines emissions from four sectors of Canada's NIR – Energy, Industrial Processes and Product Use (IPPU), Agriculture and Waste – with the accounting contribution from the LULUCF sector, calculated and reported separately in Canada's BTR. Information on the LULUCF accounting approach can be found in Canada's BTR and Canada's GHG and Air Pollutant Emissions Projections Reports. The 2026 NIR is a joint submission with Canada's second BTR under the Paris Agreement.

1 National totals presented in Canada's official GHG inventory do not include LULUCF sector emissions or removals.

2 Recognizing Canada's policy target of a 75% methane emission reduction from a 2012 base year by 2030.

ES.2. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty established in 1992 to cooperatively address climate change issues. The ultimate objective of the UNFCCC is to stabilize atmospheric GHG concentrations at a level that would prevent dangerous interference with the climate system. Canada ratified the UNFCCC in 1992, and the Convention came into force in 1994. To strengthen the global response to climate change, multiple international agreements were introduced under the UNFCCC. The most recent one is the Paris Agreement, a legally binding international treaty with the overarching goal to limit the global average temperature rise to well below 2°C and pursue efforts to limit the increase to 1.5°C. Canada, recognizing the significance of collective action, ratified the Paris Agreement in 2016, and the Agreement entered into force the same year. Since then, Canada adopted 2005 as the base year for its GHG emission reduction targets.

To achieve its objective and implement its provisions, the Paris Agreement sets out several guiding principles and commitments. Specifically, Article 13 establishes an enhanced transparency framework for action and support. It commits all Parties to develop, periodically update, publish and make available to the Conference of the Parties their national inventories of anthropogenic emissions by sources, and removals by sinks, of seven GHGs.

Canada's official GHG inventory is prepared and submitted annually to the UNFCCC in accordance with the modalities, procedures and guidelines (MPGs) for the transparency framework for action and support referred to in Article 13 of the Paris Agreement, adopted through Decision 18/CMA.1 in 2018.[3] The annual inventory submission under the UNFCCC consists of the NIR and Common Reporting Tables (CRTs), submitted by April 15 of each year.

The GHG inventory includes emissions and removals of carbon dioxide (CO_2), and emissions of methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) in five sectors (Energy, Industrial Processes and Product Use [IPPU], Agriculture, Waste, and Land Use, Land-Use Change and Forestry [LULUCF]). The GHG emission and removal estimates contained in Canada's GHG inventory are developed using methodologies consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. In line with the principle of continuous improvement, the underlying data and methodology for estimating emissions are revised over time; hence, total emissions in all years are subject to change as both data and methods are improved (see section ES.8).

In 2021, Canada formally submitted its enhanced Nationally Determined Contribution (NDC) to the UNFCCC, committing to cut its GHG emissions by 40%-45% below 2005 levels by 2030 (see The NIR: Scientific Evidence for Decision Makers box that follows). Canada submitted its NDC for 2035 to the UNFCCC in February 2025. With this new NDC, Canada commits to reducing GHG emissions by 45%-50% below 2005 levels by 2035. Since 2005 was adopted as a base year for Canada's targets, many of the metrics in this report are presented in that context, in addition to the 1990 base year as required by the MPGs. In keeping with the reporting requirements, the GHG inventory reports annual emissions from 1990 up to and including the year ending 15 ½ months prior to its submission to the UNFCCC in April (e.g., 2024 for the 2026 edition of the inventory).

Consistent with Canada's Nationally Determined Contribution, progress towards Canada's targets is measured by combining information from Canada's NIR to its LULUCF contribution in accordance with Canada's approach to LULUCF accounting, which is reported separately in Canada's First Biennial Transparency Report submitted to the UNFCCC and Canada's GHG and Air Pollutant Emissions Projections Reports.

Section ES.3 of this Executive Summary provides an overview of the latest information on Canada's net anthropogenic GHG emissions and links this information to relevant indicators of the Canadian economy. Section ES.4 outlines the major trends in emissions by IPCC sectors over the 2005–2024 period.

For the purposes of analyzing economic trends and policies, emissions have been allocated to the economic sector from which they originate. Section ES.5 presents Canada's emissions broken down by the following economic sectors: Oil and Gas, Electricity, Transport, Heavy Industry, Buildings, Agriculture, and Waste and others.[4] Throughout this report, the word "sector" generally refers to activity sectors as defined by the IPCC for national GHG inventories, except when the expression "economic sectors" is used in reference to the Canadian context.

Section ES.6 summarizes GHG emissions for Canada's 13 subnational jurisdictions. Section ES.7 gives an overview of the key category analysis and results. Section ES.8 presents an overview of the improvements incorporated into this inventory, as well as planned improvements for future editions. Finally, section ES.9 provides some detail on the components of this submission and outlines key elements of its preparation.

3 Previously, this inventory was prepared and submitted in accordance with the revised *Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention, Part I: UNFCCC Reporting Guidelines on Annual Inventories* (UNFCCC Reporting Guidelines), adopted through Decision 24/CP.19 in 2013. Since 2024, reporting is done using the MPGs.

4 Others includes Coal Production, Light Manufacturing, Construction and Forest Resources.

The NIR: Scientific Evidence for Decision Makers

Canada's first national climate plan, the Pan-Canadian Framework on Clean Growth and Climate Change, was developed in collaboration with provinces and territories and with input from Indigenous peoples, and released in 2016. In December 2020, the Government of Canada released the Strengthened Climate Plan, which included 64 new or strengthened federal policies, programs and investments to cut emissions. In 2021, Canada submitted its enhanced 2030 target to the UNFCCC and enacted the *Canadian Net-Zero Emissions Accountability Act* (CNZEAA). These documents provide the foundation of Canada's approach to reaching a GHG emissions reduction of 40%-45% below 2005 levels by 2030, as committed to in Canada's Nationally Determined Contribution (NDC), and setting Canada on a path to reaching net-zero emissions by 2050.

Consistent with Canada's NDC, progress towards Canada's targets is measured by combining information from Canada's NIR to its LULUCF contribution in accordance with Canada's approach to LULUCF accounting, which is reported separately in Canada's Biennial Transparency Report (BTR) and in Canada's GHG and Air Pollutants Emissions Projections for the years when a BTR is not produced.

Pursuant to the CNZEAA, the 2030 Emissions Reduction Plan (ERP) includes key measures to achieve the 2030 target, an interim GHG emissions objective for 2026, an overview of relevant sectoral strategies, a timetable for the implementation of measures, and a summary of key cooperative measures or agreements with provinces and territories. Building on the 2030 ERP, Canada's Methane Strategy (2022) outlines measures to further reduce domestic methane emissions by more than 35% by 2030, compared with 2020 levels.

In February 2025, consistent with the Paris Agreement, Canada submitted its 2035 NDC to the United Nations Framework Convention on Climate Change (UNFCCC), committing to achieve GHG emissions reductions of 45%-50% below 2005 levels. The 2035 NDC builds on Canada's existing 2030 target, which aims to reduce emissions by 40-45% below 2005 levels. As required by the CNZEAA, Canada will release the 2035 ERP, setting out detailed policies and initiatives to meet the target, by the end of 2029.

The official national GHG inventory relies on the best available scientific methods and most dependable data to estimate GHG emissions from Canada's entire economy, including the adoption of new technologies and changes in practices or behaviours. Inventory inputs are updated annually to incorporate the effects of policies and measures, in addition to the influence of independent, real-world factors such as market conditions or unexpected events. Methods are constantly enhanced as scientific understanding improves.

Thus Canada's official national GHG inventory, along with other regular publications such as the greenhouse gas and air pollutant emissions projections and Canada's Biennial Transparency Report, provides robust scientific evidence supporting the decision makers who strive to reduce Canada's GHG emissions and combat climate change.

ES.3. Overview of National GHG Emissions (1990–2024)

Canada accounts for approximately 1.4% of global GHG emissions (Climate Watch, 2026 for the year 2022), making it the 11th largest emitter. While Canada is one of the highest per capita emitters, per capita emissions have declined since 2005 from 24 t CO_2 eq/capita to 17 t CO_2 eq/capita in 2024 (StatCan, n.d.[a]).[5]

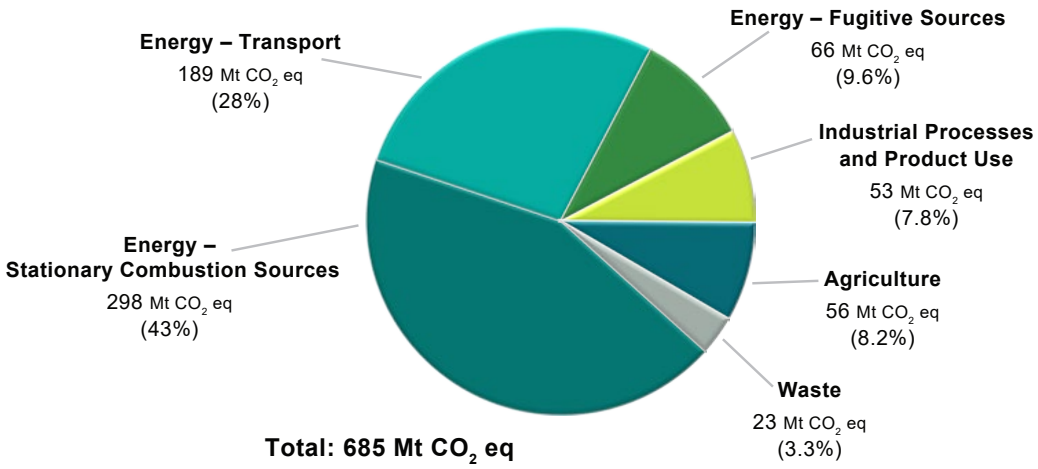
Emission Breakdown by Sector (2024)

In 2024, Canada's GHG emissions were 685 Mt CO_2 eq, excluding the LULUCF sector.[6] The Energy sector (consisting of Stationary Combustion Sources, Transport and Fugitive Sources) emitted the largest share (81%) of Canada's total GHG emissions (Figure ES–1). The remaining emissions were generated by the Agriculture and IPPU sectors, with contributions from the Waste sector. When included with emissions from other sectors, LULUCF sector emissions corresponded to 0.6% of the national total in 2024.

5 Throughout this report, data are presented as rounded figures. However, all calculations (including the ones to obtain percentages) have been performed using unrounded data.

6 Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO_2 eq.

Figure ES–1 **Breakdown of Canada's Emissions by Intergovernmental Panel on Climate Change Sector (2024)**

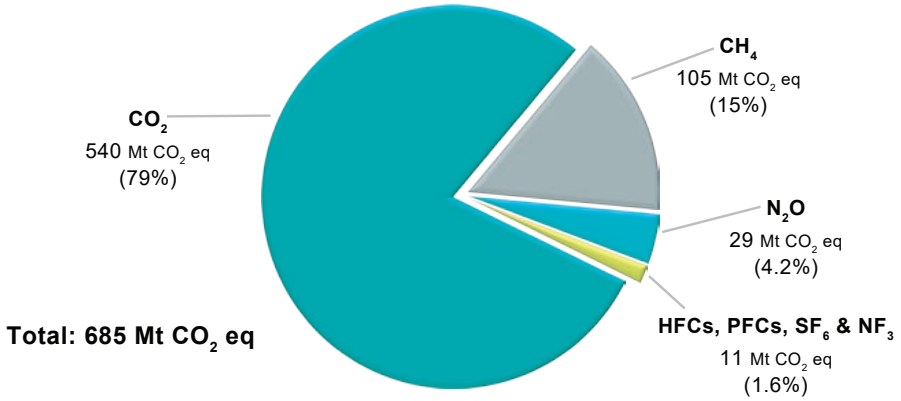


Note: Totals may not add up due to rounding.

Emission Breakdown by GHG (2024)

Canada's emissions profile is similar to most industrialized countries, in that CO_2 is the largest contributor to total emissions, accounting for 540 Mt or 79% of total emissions in 2024, as shown by the largest part of Figure ES–2. Most CO_2 emissions in Canada result from the combustion of fossil fuels. CH_4 emissions in 2024 amounted to 105 Mt or 15% of Canada's total and were the second-largest contributor. These emissions consist largely of fugitive[7] emissions from oil and natural gas systems (46 Mt), agriculture (31 Mt) and landfills (19 Mt). Emissions of N_2O accounted for 29 Mt or 4.2% of Canada's emissions in 2024, which mostly arise from agricultural soil management (18 Mt). Emissions of synthetic gases (HFCs, PFCs, SF_6 and NF_3) accounted for less than 2% of national emissions.

Figure ES–2 **Breakdown of Canada's Emissions by GHG (2024)**



Note: Totals may not add up due to rounding.

7 Includes flaring, venting and unintentional release of GHGs during the extraction, processing, transformation and delivery of fossil fuels to the point of final use.

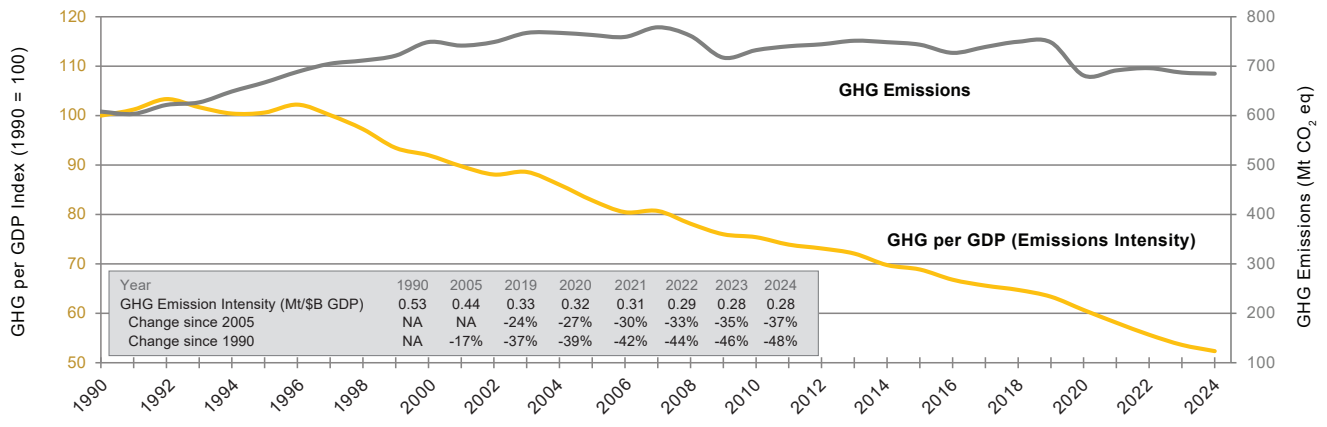
Changes in Total Emissions (1990–2024)

After fluctuations in recent years, overall, Canada's GHG emissions in 2024 have decreased by 78 Mt or 10% since 2005. In general, year-to-year fluctuations are superimposed over trends observed over a longer period. During the period covered in this report, Canada's economy grew more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (GHG per GDP) has continued to decline; in 2024 it had declined by 48% since 1990 and by 37% since 2005 (Figure ES–3). The decline in emissions intensity can be attributed to factors such as fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.

Over the last 10 years (2015–2024), total emissions decreased by 59 Mt or 7.9%. Since 2015, significant decreases occurred from Oil and Natural Gas Fugitive Sources (-33 Mt or -34%) as well as Public Electricity and Heat Production (-25 Mt or -31%). These decreases can be explained mostly by methane emission reductions from conventional oil and gas activities (more specifically from decreased venting) as well as the phase-out of coal-fired electricity generation and increased electricity generation from renewable sources. In contrast, from 2015 to 2024, Oil and Gas Extraction combustion emissions increased by 12 Mt (12%), mainly attributed to continued production growth in Canada's oil sands operations. Emissions from some transport sources increased as well, notably Light-Duty Gasoline Trucks by 6.2 Mt (13%) and Other Transportation[8] by 3.4 Mt (6.8%). The increase from Light-Duty Gasoline Trucks is related with an increase in the off- and on-road vehicle fleet, leading to more kilometres driven overall, whereas for the Other Transportation category, this coincides with increased transport of natural gas in pipelines.

When observing long-term emission trends, large-scale events can have a significant impact on a portion of the time series analyzed and should be considered. The years 2020 and 2021 were marked by the COVID-19 pandemic. This coincides with an abrupt decrease of 67 Mt (9.0%) in total GHG emissions between 2019 and 2020, with almost half from Transport (-32 Mt or -15%). The year after, between 2020 and 2021, emissions increased slightly by 10 Mt (1.5%) and between 2021 and 2022 they continued to increase by 4.5 Mt (0.7%), while remaining below their 2019 pre-pandemic levels. Finally, between 2022 and 2024, emissions decreased by 11 Mt (1.6%). Impacts of the pandemic, more pronounced in 2020, are now harder to distinguish in the latest years. Notwithstanding the abrupt decrease between 2019 and 2020, and recent year changes, the general breakdown of emissions by IPCC sector has not substantially changed over time (Figure ES–4).

Figure ES–3 **Canadian GHG Emissions and Indexed Trend Emissions Intensity (excluding Land Use, Land-Use Change and Forestry)**

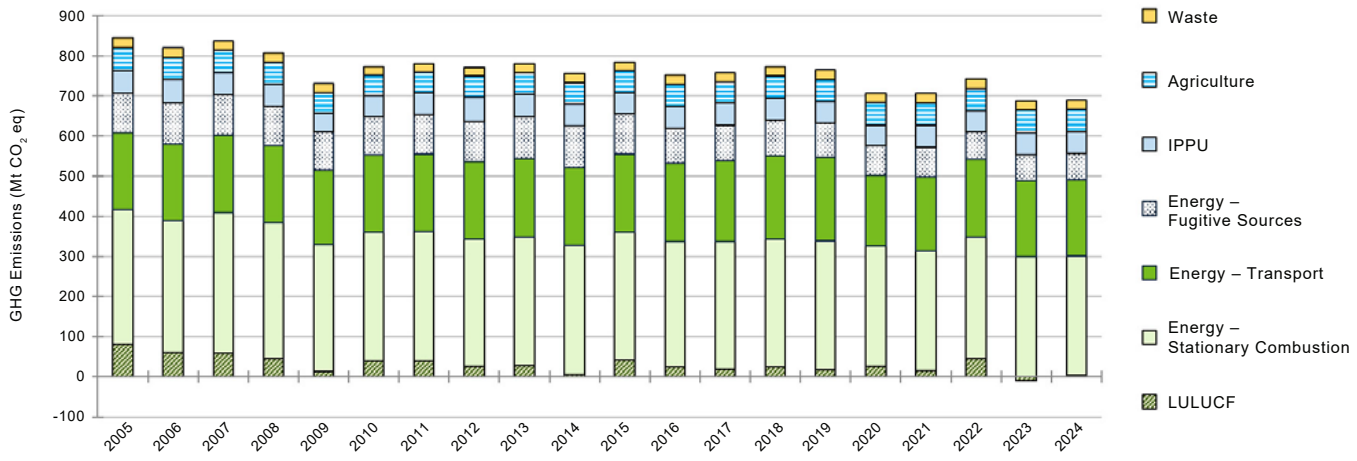


Year	1990	2005	2019	2020	2021	2022	2023	2024
GHG Emission Intensity (Mt/$B GDP)	0.53	0.44	0.33	0.32	0.31	0.29	0.28	0.28
Change since 2005	NA	NA	-24%	-27%	-30%	-33%	-35%	-37%
Change since 1990	NA	-17%	-37%	-39%	-42%	-44%	-46%	-48%

Notes:
NA = Not applicable
GDP data source = StatCan (n.d.[b])

8 Other Transportation includes consumption of fuels (excluding the biogenic CO_2 emissions from ethanol and biodiesel) by mobile combustion devices not licensed to operate on roads, as well as pipeline transportation and distribution of crude oil, natural gas, refined petroleum and other products.

Figure ES–4 **Trends in Canadian GHG Emissions by Intergovernmental Panel on Climate Change Sector (2005–2024)**



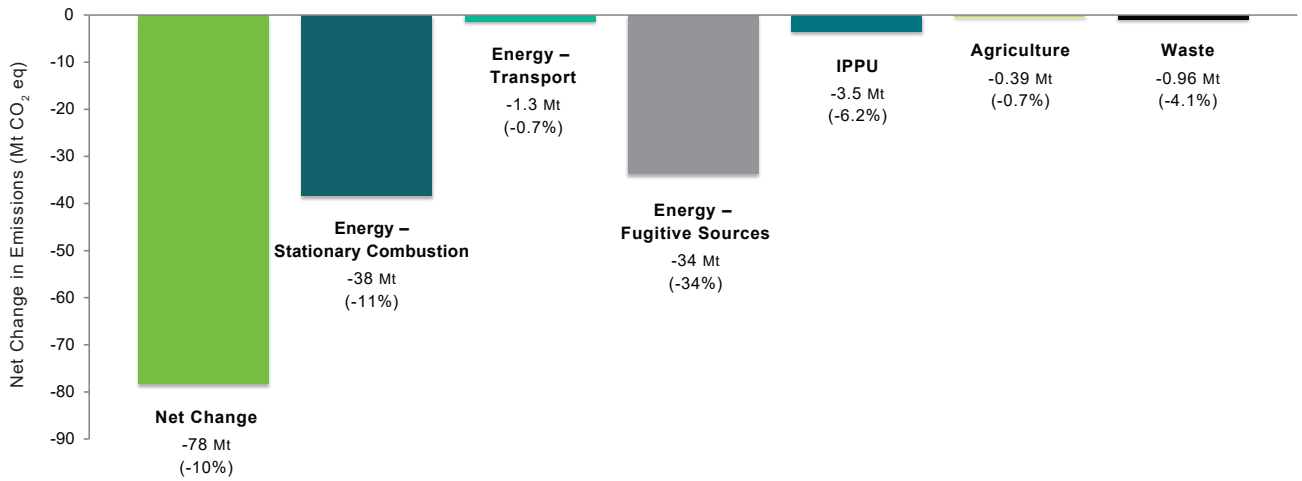
ES.4. GHG Emissions and Trends by Intergovernmental Panel on Climate Change Sector

Trends in Emissions (2005–2024)

Over the 2005–2024 period, total emissions are down by 78 Mt or 10% with decreases in emissions from all IPCC sectors. The Energy sector dominated, with emission decreases of 38 Mt (11%) from Stationary Combustion Sources, 34 Mt (34%) from Fugitive Sources and 1.3 Mt (0.7%) from Transport (Table ES–1). Over the same period, emissions are down by 3.5 Mt (6.2%) in the IPPU sector and 0.96 Mt (4.1%) in the Waste sector. Agriculture sector emissions have remained relatively stable with a decrease of 0.39 Mt (0.7%) (Figure ES–5).

Chapter 2 provides more information on GHG emissions trends since 1990 and 2005 and their drivers.[9] Further breakdowns of emissions and a complete time series can be found at open.canada.ca.

Figure ES–5 **Changes in Emissions by IPCC Sector (2005–2024)**



9 The complete NIR can be accessed here: canada.ca/ghg-inventory.

Energy – 2024 GHG Emissions (552 Mt)

In 2024, GHG emissions from the IPCC Energy sector (552 Mt) were 12% lower than in 2005 (626 Mt). Within the Energy sector, emissions increased by 46 Mt (73%) from Oil and Gas Extraction, 3.6 Mt (7.2%) from Other Transportation, 1.4 Mt (35%) from Mining and Quarrying, and 1.3 Mt (57%) from Agriculture and Forestry. These emissions were offset by decreases of 65 Mt (53%) from Public Electricity and Heat Production, 34 Mt (34%) from Fugitive Sources, 8.7 Mt (19%) from Manufacturing Industries, 8.4 Mt (19%) from the Residential category, 5.4 Mt (27%) from Petroleum Refining, and 4.1 Mt (3.3%) from Road Transportation.

Stationary Combustion Sources (298 Mt)

From 2005 to 2024, stationary combustion emissions from Oil and Gas Extraction increased 46 Mt (73%), consistent with a 254% rise in crude bitumen and synthetic crude oil production from Canada's oil sands operations.

Decreasing electricity generation from coal and refined petroleum product (RPP) usage (by 84% and 77%, respectively) and an increase in the amount of low-emitting generation in the mix[10] were the largest drivers of the 65 Mt (53%) decrease in emissions associated with Public Electricity and Heat Production between 2005 and 2024. Since 2005, reduced consumption of more GHG-intensive fossil fuels (coal and RPPs), accounted for 50% of the decrease in emissions from Public Electricity and Heat Production. Significant emission reductions in GHG-intensive fossil fuels occurred in Ontario (99%), Alberta (98%), Manitoba (91%), New Brunswick (58%), Nova Scotia (57%), and Saskatchewan (38%). Emission fluctuations over the period reflect variations in the mix of electricity generation sources. Since 2005, the increase in electricity generated from low-emitting sources accounted for 29% of the decrease in emissions.

The 8.4 Mt (19%) decrease in emissions in the Residential category between 2005 and 2024 is largely driven by energy efficiency improvements, with smaller decreases due to warmer weather and reduced consumption of light fuel oil offset by an increase in population and floor space.

GHG emissions from fuel consumption in Manufacturing Industries decreased by 8.7 Mt (19%) between 2005 and 2024, consistent with a 16% decrease in energy use (StatCan, n.d.[c]). The decrease occurred in Other Manufacturing (-4.1 Mt or -25%), Pulp and Paper (-2.8 Mt or -33%), Cement (-1.7 Mt or -34%), Non-Ferrous Metals (-0.88 Mt or -23%), and Iron and Steel (-0.42 Mt or -8.4%), in contrast with an increase in Chemicals (1.2 Mt or 15%).

Since 2005, one petroleum refinery in Alberta has permanently closed (2012), while four others either converted to terminal facilities or renewable energy production facilities including one in Ontario (2005), Quebec (2010), Nova Scotia (2013), and Newfoundland and Labrador (2020) contributing to the decrease of 5.4 Mt (27%) in Petroleum Refining Industries emissions.

Transport (189 Mt)

Most transport emissions in Canada are related to Road Transportation, which includes personal transportation (light-duty vehicles and trucks) and heavy-duty vehicles. The general growth trend in road transportation emissions through the time series is largely due to an increase in driving: more cars and trucks on the road are using more fuel and therefore generating greater emissions, despite continued reductions in the emissions produced by each individual vehicle. Further, despite a reduction in kilometres driven per vehicle, the total population of the vehicle fleet in 2024 had increased by 37% since 2005 leading to more kilometres driven overall. Also contributing to more vehicle kilometers driven over this time period, within the total vehicle population, was a decrease in the number of light-duty vehicles (i.e., cars); and an increase in the number of heavy-duty vehicles that typically contribute more vehicle kilometers travelled per vehicle.

From 2005 to 2019, emissions from Transport have generally increased. From 2019 to 2020, the start of the COVID-19 pandemic, Transport emissions decreased below 2005 levels as travel from aircraft and light-duty on-road vehicles decreased. From 2021 to 2024, as travel demand returns to pre-pandemic levels, Transport emissions increased by 4.9 Mt, bringing them 1.3 Mt below 2005 levels and still below pre-pandemic levels in 2019.

Fugitive Sources (66 Mt)

Fugitive Sources are comprised of flaring, venting and unintentional emissions from fossil fuel production (coal, oil and natural gas) with emissions from the oil and gas industry generally accounting for approximately 98% of total fugitive emissions in Canada. Since 2005, almost 230 000 productive oil and gas wells have been drilled and the annual number of producing wells has increased by 2%. Crude oil and natural gas production has also increased by 60%, mostly due to Canada's Oil Sands. Even with the increased output and activity, emissions from Fugitive Sources have decreased by 34 Mt (34%). This includes a 5.6% increase from 100 Mt in 2005 to a peak in 2014 of 105 Mt. Since 2014, emissions have decreased by 38 Mt (37%) as a result of measures to increase the conservation of natural gas (comprised mainly of CH_4) and federal and provincial measures to reduce methane emissions from the upstream oil and gas industry. The reduction of emissions coinciding with increased production highlights the reduction in emission intensities that have been achieved (see Chapter 2 for more details).

10 The mix of electricity generation sources is characterized by the amount of fossil fuel versus hydro, other renewable sources and nuclear sources. In general, only fossil fuel sources generate net GHG emissions.

CO_2 Transport and Storage (0.65 kt)

Carbon capture involves the capture of anthropogenic CO_2 from industrial processes or fuel combustion sources. The captured CO_2 is transported to, and injected at, long-term storage (LTS) facilities or enhanced oil recovery (EOR) sites. Injection into LTS began in 2015, and in 2024 approximately 1.0 Mt of captured CO_2 was placed in geological formations for LTS. EOR use of industrial captured CO_2 began in 2000, and in 2024 about 3.3 Mt of captured CO_2 was injected to support EOR operations, of which approximately 870 kt was imported from the United States. At 2024 year-end, a cumulative total of 10.4 Mt of captured CO_2 was placed in LTS and 58.3 Mt was injected for EOR.

Due to the increase in activity associated with this category, fugitive emissions from CO_2 capture, transport, use and storage increased from 0.09 kt in 2005 to 0.65 kt in 2024. See Chapter 3, section 3.4, for more details on carbon capture and storage volumes and associated emissions.

Industrial Processes and Product Use – 2024 GHG Emissions (53 Mt)

The IPPU sector covers non-energy GHG emissions that result from manufacturing processes and use of products, such as limestone calcination in cement production and the use of HFCs and PFCs as replacement refrigerants for ozone-depleting substances (ODSs). Emissions from the IPPU sector contributed 53 Mt (7.8%) to Canada's 2024 emissions.

Between 2005 and 2024, process emissions from most IPPU categories decreased. Lower cement and lime production, and closures or indefinite idling of multiple facilities contributed to an emission decrease of 1.3 Mt (13%). Emissions from the Iron and Steel Industry decreased by 1.3 Mt (12%) during the period because of the closure of a facility in 2013. The Aluminium Industry also saw a decline in its process emissions of 2.3 Mt (28%), largely due to the implementation of technological improvements and the shutdown of older smelters using Søderberg technology. The closure of primary magnesium plants in 2007 and 2008 as well accounted for 1.1 Mt (79%) of the overall decrease. Another emission decrease of 2.3 Mt (100%) came from the 2009 closure of the sole Canadian adipic acid plant located in Ontario.

A notable exception to the overall decrease in IPPU emissions was the 4.9 Mt (101%) increase in emissions from the use of HFCs to replace chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) since 2005. However, since 2018, HFC emissions have decreased by 2.0 Mt (17%), primarily due to a reduction in HFC imports, coinciding with the implementation of federal regulations gradually phasing down HFCs.[11]

Agriculture – 2024 GHG Emissions (56 Mt)

The Agriculture sector covers non-energy GHG emissions related to the production of crops and livestock. In 2024, emissions from Agriculture accounted for 56 Mt, or 8.2% of total GHG emissions for Canada, including 30% and 76% of national CH_4 and N_2O emissions, respectively.

The main drivers of the emission trend in the Agriculture sector are the fluctuations in livestock populations and the application of inorganic nitrogen fertilizers to agricultural soils mainly in the Prairie provinces. Since 2005, fertilizer use has increased by 108%, while major livestock populations peaked in 2005, then decreased sharply until 2011. As a result, emissions in 2024 are roughly equivalent to 2005, though the contribution of emissions from crop production has increased relative to the livestock sector. In 2024, emissions from livestock feed consumption and digestion (enteric fermentation) accounted for 47% of total agricultural emissions, and the application of inorganic nitrogen fertilizers accounted for 19% of total agricultural emissions.

Waste – 2024 GHG Emissions (23 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from Waste contributed 23 Mt (3.3%) to Canada's total emissions in 2024.

The primary sources of emissions in 2024 for the Waste sector are Landfills (19 Mt or 85% of total emissions from this sector), including municipal solid waste (MSW) and industrial wood waste disposal. Wastewater Treatment and Discharge accounted for 2.6 Mt (12%) of the Waste sector emissions. Other sources include Biological Treatment of Solid Waste (composting) (2.7%), and Incineration and Open Burning of Waste (0.7%).

Between 2005 and 2024, CO_2 eq emissions from MSW landfills decreased by 6.0%. Of the 33 Mt CO_2 eq of CH_4 generated by MSW landfills in 2024, 18 Mt CO_2 eq (56%) were emitted to the atmosphere, while 12 Mt CO_2 eq (37%) were captured by landfill gas collection facilities and flared or used for energy (compared to 30% in 2005). The remaining 2.0 Mt (6.2%) is assumed to be oxidized through landfill cover materials.

11 The Ozone-depleting Substances and Halocarbon Alternative Regulations can be accessed here: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2016-137/.

The Key Contribution of Facility Data to GHG Estimates

Greenhouse gas emission estimates associated with industrial activity in Canada largely rely on data reported by facilities to Canada's federal, provincial and territorial governments.

Since 2004, Environment and Climate Change Canada's (ECCC) Greenhouse Gas Reporting Program (GHGRP) has been collecting and publishing facility-reported GHG emissions information annually. For example, industrial process emissions reported to the GHGRP are directly incorporated in the NIR's IPPU sector for cement, lime, aluminium and magnesium production, as are volumes of CO_2 captured, transported, injected and stored in geological reservoirs. Flaring data reported by petroleum refineries is also incorporated into the NIR, while facility-level data reported to the GHGRP by oil sands operators is used to facilitate the disaggregation of oil and gas emission estimates. Emissions from waste incineration and industrial wastewater are also directly included in the NIR. Work is ongoing to integrate more facility-reported data in the national GHG inventory. Technical specifications of industrial fuel and raw material reported to the GHGRP are also used to verify and improve the quality of industrial process emission estimates. More information on the use of GHGRP data is provided in Chapter 1, Table 1–6.

The national energy balance compiled by Canada's statistics agency presents annual energy supply and demands by regions following North American Industry Classification Systems (see Annex 4 for more detail). The national energy balance is largely based on facility data collected by Statistics Canada and is the key data source used to estimate fuel combustion emissions for space heating to electricity generation and industrial, manufacturing and transportation activities. Statistics Canada also collects facility data on behalf of ECCC on chemical and petrochemical production.

Inventory estimates of fugitive emissions in Canada's upstream oil and gas sector rely heavily on volumetric data reported by individual oil and gas facilities to Petrinex, operating under a Crown-Industry governance structure, for the provinces of Alberta, Saskatchewan, British Columbia and Manitoba. These data are also used to assess and collect royalties and inform provincial regulations and legislation.

Finally, other activity data are also collected from suppliers via legislated reports on hydrofluorocarbon (HFC) imports and exports as well as through targeted, periodic surveys on the use of fluorinated gases, landfill gas collection, incineration, wastewater methane recovery, composting and anaerobic digestion.

Inventory experts work diligently with providers of industrial and other activity data to ensure the accuracy, consistency and completeness of reported data and their alignment with inventory reporting requirements.

Land Use, Land-Use Change and Forestry – 2024 (Net GHG Source of 4.4 Mt)

The LULUCF sector reports anthropogenic GHG fluxes between the atmosphere and Canada's managed lands, including those associated with land-use change and fluxes of carbon from Harvested Wood Products (HWP) production and use, which are closely linked to Forest Land.

In this sector, the net flux is calculated as the sum of CO_2 and non-CO_2 emissions to the atmosphere and CO_2 removals from the atmosphere. In 2024, this net flux amounted to a net source of 4.4 Mt.

Net fluxes from the LULUCF sector over recent years have fluctuated between net removals of 8.7 Mt in 2023 and net emissions of 81 Mt in 2005. Fluctuations are driven by the variability in crop yields and by variations in carbon storage in HWP and emissions and removals from Forest Land, which are closely tied to forest harvest rates.

Estimates from the forest sector are split between anthropogenic emissions and removals associated with forest management and HWP, and emissions and removals resulting from the natural cycles of disturbances in managed forests (wildfires and insects). The combined net flux from Forest Land and HWP fluctuated from a net source of 90 Mt in 2005 to a net sink of 1.0 Mt in 2024. This was a result of decreases in harvest rates and longer-term effects of disturbance history—natural and anthropogenic—on the overall age structure of the Canadian managed forest. In 2024, an additional 0.63 Mt CO_2 eq of carbon was sequestered to the global pool of HWP coming from Canadian Forests; however 64% of carbon in the HWP pool, that was disposed of or consumed as bioenergy, was associated with short-lived products.

In most years, Cropland contributed to net removals ranging from 1.9 Mt (1991) to 40 Mt (2014). Net emissions occurred due to drought in recent years—specifically 2002, 2003 and 2022—that resulted in low yields and consequently carbon loss from soils as decomposition rates were higher than carbon input rates to soils. Net removals have increased, on average, as a result of improved soil management practices including conservation tillage and an overall gradual increase in crop productivity resulting from improved and more intensive practices such as the reduced use of summer fallow. Interannual variability occurs throughout the time series, reflecting weather-related impacts to crop production. Since 2005, a decline in net removals from a decrease in perennial land cover has largely offset removals resulting from increasing yields and there is, subsequently, no clear trend.

The conversion of forests to other land uses is a prevalent practice in Canada and is mainly due to resource extraction and cropland expansion. Emissions resulting from forest conversion in the years 2005 to 2024 have fluctuated around 20 Mt annually with the lowest emissions occurring in 2010.

Using Aerial Measurements to Improve Inventory Estimates

In accordance with the MPGs and IPCC guidance on the preparation of national inventories, inventory methods rely on understanding and quantifying emissions and removals by individual source categories and greenhouse gases. This approach is generally referred to as “bottom-up.”

Other approaches to estimating emissions have recently emerged, based on inverse modelling of GHG emissions or removals derived from measurements of atmospheric gas concentrations. These approaches are referred to as “top-down.” The measurement technologies used to develop “top-down” inventories vary widely, from satellites to small aircraft and drones to towers to ground-based vehicles, all of which have different advantages and technical limitations to consider. The 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Vol 1, chap 6) provides guidance on the use of “top-down” estimates to validate inventory estimates and improve their accuracy (IPCC, 2019).

While differences in the results from “bottom-up” and “top-down” approaches (e.g., Chan et al., 2020; MacKay et al., 2021; Conrad et al. 2023a; MacKay et al., 2024) are unavoidable due to differing methods, data sources, level of detail, and other confounding factors, recent advancements in measurement techniques have been successful in the creation of source-resolved methane emission inventories based on aerial measurements for Canada’s major oil and gas producing provinces (Johnson et al., 2023; Conrad et al., 2023a, b).

These aerial measurement-based inventories have been partially included in this inventory, improving the accuracy of methane emission estimates for the oil and gas sector in Canada. See Annex 3.2, section A3.2.2.1.5 for more details on the methodology used to incorporate aerial measurements into the inventory estimates. ECCC continues to work with researchers to improve the integration of “bottom-up” inventory methods and remote measurements with the goal of further improving the accuracy of inventory estimates in future editions of this report. Advances in reconciling “top-down” and “bottom-up” estimates could also lead to improvements in other inventory sectors, such as waste and agriculture.

Table ES–1 Canada's GHG Emissions by Intergovernmental Panel on Climate Change Sector, Selected Years

GHG Categories		GHG Emissions (Mt CO_2 eq)						
		2005	2019	2020	2021	2022	2023	2024
TOTAL[a, b]		**763**	**748**	**681**	**691**	**696**	**687**	**685**
ENERGY		**626**	**616**	**549**	**558**	**563**	**554**	**552**
a.	**Stationary Combustion Sources**	**336**	**322**	**299**	**300**	**303**	**298**	**298**
	Public Electricity and Heat Production	123	70	62	62	58	59	57
	Petroleum Refining Industries	20	15	14	14	15	14	15
	Oil and Gas Extraction	63	105	101	104	105	106	109
	Coal Production	0.36	0.55	0.45	0.52	0.52	0.56	0.53
	Biofuel Manufacturing	0.15	1.0	0.84	0.80	0.77	0.79	0.81
	Mining and Quarrying	3.9	5.4	4.9	5.3	5.8	5.2	5.3
	Manufacturing Industries	47	42	39	39	40	39	38
	Construction	1.4	1.4	1.4	1.4	1.6	1.5	1.6
	Commercial and Institutional	32	38	35	33	35	33	32
	Residential	43	41	38	37	39	35	35
	Agriculture and Forestry	2.2	3.3	3.1	3.2	3.3	3.2	3.4
b.	**Transport**	**190**	**208**	**176**	**184**	**192**	**190**	**189**
	Aviation	7.7	8.6	4.7	5.6	7.7	8.4	8.1
	Road Transportation	122	132	111	116	120	119	118
	Railways	6.5	6.5	6.0	5.8	5.8	5.8	5.8
	Marine	4.0	4.0	3.8	2.9	3.3	3.3	3.4
	Other Transportation	50	57	50	53	55	53	53
c.	**Fugitive Sources**	**100**	**85**	**74**	**74**	**68**	**66**	**66**
	Coal Mining	1.5	1.6	1.4	1.4	1.4	1.6	1.4
	Oil and Natural Gas	98	84	72	73	67	64	65
d.	**CO_2 Transport and Storage**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
INDUSTRIAL PROCESSES AND PRODUCT USE		**57**	**54**	**52**	**54**	**53**	**55**	**53**
a.	**Mineral Products**	**10**	**8.9**	**8.3**	**9.0**	**8.4**	**8.9**	**8.5**
b.	**Chemical Industry**	**10**	**6.2**	**5.9**	**5.7**	**5.7**	**5.6**	**5.6**
c.	**Metal Production**	**21**	**16**	**15**	**16**	**16**	**17**	**16**
d.	**Production and Consumption of Halocarbons, SF_6 and NF_3**	**4.8**	**12**	**11**	**11**	**11**	**10**	**10**
e.	**Non-Energy Products from Fuels and Solvent Use**	**10**	**11**	**11**	**12**	**12**	**13**	**12**
f.	**Other Product Manufacture and Use**	**0.51**	**0.62**	**0.66**	**0.66**	**0.61**	**0.65**	**0.68**
AGRICULTURE		**57**	**55**	**57**	**56**	**56**	**55**	**56**
a.	**Enteric Fermentation**	**35**	**27**	**27**	**27**	**27**	**26**	**26**
b.	**Manure Management**	**9.0**	**8.3**	**8.3**	**8.3**	**8.2**	**8.1**	**8.2**
c.	**Agricultural Soils**	**12**	**17**	**18**	**17**	**18**	**18**	**18**
d.	**Field Burning of Agricultural Residues**	**0.05**	**0.05**	**0.06**	**0.04**	**0.05**	**0.05**	**0.05**
e.	**Liming, Urea Application and Other Carbon-Containing Fertilizers**	**1.4**	**2.7**	**3.0**	**3.1**	**2.8**	**3.1**	**3.4**
WASTE		**23**	**23**	**23**	**23**	**23**	**23**	**23**
a.	**Landfills**	**21**	**20**	**20**	**20**	**20**	**20**	**19**
b.	**Biological Treatment of Solid Waste**	**0.33**	**0.50**	**0.51**	**0.60**	**0.61**	**0.61**	**0.61**
c.	**Incineration and Open Burning of Waste**	**0.35**	**0.17**	**0.16**	**0.15**	**0.17**	**0.16**	**0.15**
d.	**Wastewater Treatment and Discharge**	**2.2**	**2.6**	**2.6**	**2.5**	**2.5**	**2.6**	**2.6**
LAND USE, LAND-USE CHANGE AND FORESTRY		**81**	**16**	**26**	**14**	**46**	**- 8.7**	**4.3**
a.	**Forest Land**	**145**	**36**	**36**	**29**	**15**	**1.3**	**- 1.2**
b.	**Cropland**	**- 20**	**- 12**	**- 10**	**- 14**	**24**	**- 21**	**- 3.6**
c.	**Grassland**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
d.	**Wetlands**	**7.0**	**5.6**	**5.6**	**6.0**	**5.7**	**5.5**	**5.4**
e.	**Settlements**	**5.1**	**5.0**	**4.7**	**4.6**	**4.5**	**4.6**	**4.3**
f.	**Harvested Wood Products**	**- 57**	**- 18**	**- 10**	**- 11**	**- 3.0**	**0.73**	**- 0.63**

Notes:
Totals may not add up due to rounding.
0.00 Indicates emissions were truncated due to rounding.
a. National totals calculated in this table do not include emissions and removals reported in LULUCF.
b. This summary data is presented in more detail at open.canada.ca.

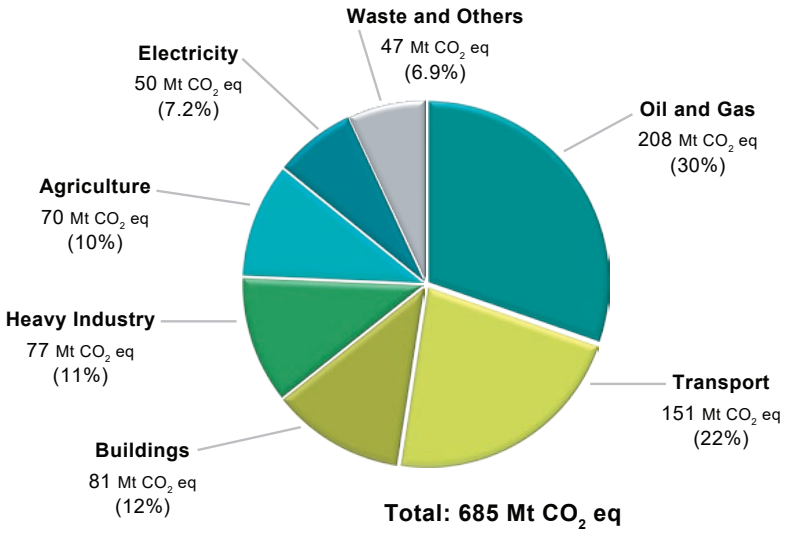
ES.5. Canadian Economic Sectors

For the purposes of analyzing economic trends and policies, and in addition to what is required by inventory reporting requirements, emissions have been allocated to the economic sector from which they originate. In general, a comprehensive emission profile for a specific economic sector has been developed by reallocating the relevant portion of emissions from various IPCC subcategories. For example, emissions associated with the oil and gas industry are present in the Stationary Combustion Sources, Transport, Fugitive Sources, and Non-Energy Products from Fuels and Solvent Use IPCC subsectors and are combined into the Oil and Gas economic sector. This reallocation simply recategorizes emissions under different headings and does not change the overall magnitude of Canadian emission estimates.

Overall, GHG emissions trends in Canada's economic sectors are consistent with those described for similar IPCC sectors (Figure ES–6). The most notable trends in Canada's emission profile between 2005 and 2024 were from Electricity as well as Oil and Gas sources, with Electricity decreasing by 66 Mt and Oil and Gas increasing by 10 Mt. Over the same period, in addition to Oil and Gas sources, Agriculture is the only other sector that showed emission increases (Table ES–2). The emission trends in Oil and Gas are mainly due to the production growth in Canada's oil sands operations (59 Mt) offset by methane emission reductions from conventional oil and gas activities (-43 Mt). Emissions from Electricity decreased, driven by the phase-out of coal-fired electricity generation. Emissions from Heavy Industry, Waste and others, and Buildings also decreased over this period. From 2005 to 2020, Transport emissions generally increased. After a notable decrease in 2020, emissions in this sector increased before stabilizing in recent years at levels below those of 2005.

Further information on economic sector trends can be found in Chapter 2, section 2.4. Additional information on the IPCC and economic sector definitions are available in Chapter 1. A detailed crosswalk table between both can be found in the national GHG data files by economic sector at open.canada.ca.

Figure ES–6 **Breakdown of Canada's GHG Emissions by Economic Sector (2024)**



Note: Totals may not add up due to rounding.

Table ES–2 **Canada's GHG Emissions by Economic Sector, Selected Years**

Economic sector	GHG Emissions (Mt CO_2 eq)							Change (Mt CO_2 eq)	Change (%)
	2005	2019	2020	2021	2022	2023	2024	2005–2024	2005–2024
NATIONAL TOTAL	**763**	**748**	**681**	**691**	**696**	**687**	**685**	**-78**	**-10%**
Oil and Gas	198	223	203	209	206	204	208	10	5.1%
Electricity	116	62	54	52	49	51	50	-66	-57%
Transport	156	169	141	147	153	152	151	-4.8	-3.1%
Heavy Industry	89	80	77	79	80	79	77	-11	-13%
Buildings	85	94	88	85	88	83	81	-3.3	-3.8%
Agriculture	66	69	70	70	70	69	70	3.6	5.4%
Waste and Others	54	51	48	49	50	49	47	-6.4	-12%

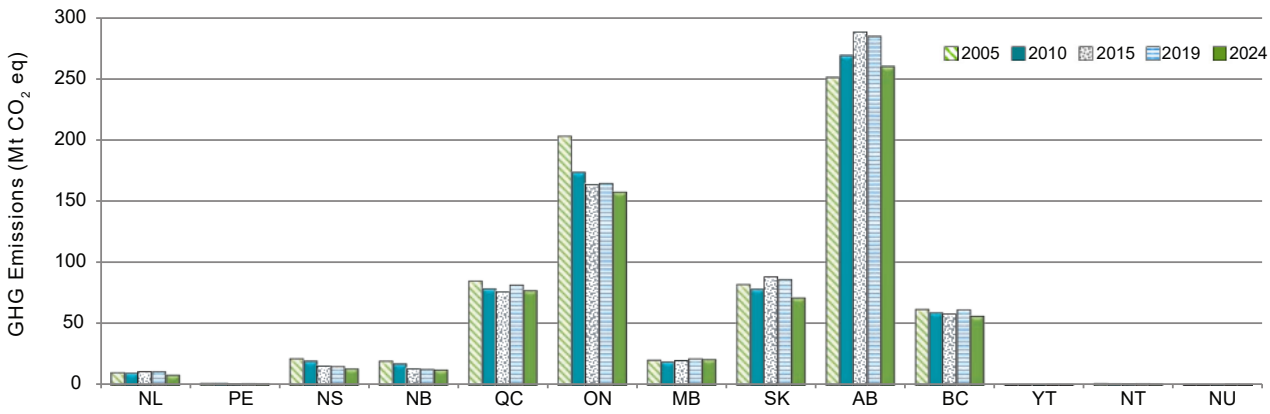
Notes:
Totals may not add up due to rounding.
Additional detail in section 2.4 of Chapter 2.

ES.6. Provincial and Territorial GHG Emissions

Emissions vary significantly by province and territory because of factors such as population, energy sources and economic structure. All else being equal, economies based on resource extraction will tend to have higher emission levels than service-based economies. Likewise, provinces that rely on fossil fuels for electricity generation emit relatively higher amounts of GHGs than those using hydroelectricity (Figure ES–7).

Historically, Alberta and Ontario have been the highest-emitting provinces, representing 38% and 23% of the national total in 2024, respectively. Since 2005, emission patterns in these two provinces have diverged. Those in Alberta have increased by 9.0 Mt (3.6%) since 2005, primarily because of the expansion of oil and gas operations offset by the closure of coal-fired power plants. In contrast, Ontario's emissions have decreased by 46 Mt (22%) since 2005, owing primarily to the closure of coal-fired electricity generation plants. Overall, emissions have decreased in eight provinces and one territory between 2005 and 2024, while emissions of two provinces and two territories have increased (Table ES–3).

Figure ES–7 **GHG Emissions by Province and Territory in 2005, 2010, 2015, 2019 and 2024**



Note: The year 2019 has been included and 2020 excluded, as significant emission drops happened during the first pandemic year and do not represent emission trends of the time series.

Table ES–3 **Greenhouse Gas Emissions by Province and Territory, Selected Years**

Province and Territory	GHG Emissions Totals (Mt CO_2 eq)									Change (Mt CO_2 eq)	Change (%)
	2005	2010	2015	2019	2020	2021	2022	2023	2024	2005–2024	2005–2024
CANADA	**763**	**732**	**743**	**748**	**681**	**691**	**696**	**687**	**685**	**-78**	**-10%**
NL	11	10	11	11	9.1	8.2	8.3	8.1	8.6	-2.1	-19%
PE	1.9	1.8	1.5	1.6	1.6	1.6	1.6	1.5	1.5	-0.40	-21%
NS	22	20	16	16	14	14	14	13	14	-8.3	-38%
NB	20	18	14	13	11	12	13	11	13	-7.2	-36%
QC	85	79	77	82	75	78	79	78	78	-7.8	-9.1%
ON	203	174	164	165	149	152	158	160	158	-46	-22%
MB	21	19	21	22	21	21	22	21	21	0.56	2.7%
SK	83	79	89	87	75	77	75	73	72	-11	-13%
AB	251	269	289	285	265	267	262	260	260	9.0	3.6%
BC	62	59	58	62	58	59	60	58	57	-5.6	-9.1%
YT	0.56	0.65	0.53	0.69	0.59	0.65	0.66	0.67	0.72	0.16	28%
NT	1.7	1.5	1.6	1.4	1.2	1.3	1.4	1.4	1.3	-0.37	-22%
NU	0.64	0.65	0.69	0.90	0.78	0.83	0.84	0.88	0.93	0.28	44%

Note:
Totals may not add up due to rounding.

ES.7. Key Category Analysis

The 2006 IPCC Guidelines (IPCC, 2006) define procedures for selecting estimation methods and defining which are most suited to national circumstances, considering the available knowledge and resources. Identifying and prioritizing methodology improvements is a good practice that can be facilitated by the identification of key categories, ensuring the most efficient use of available resources. This annual analysis is required by the MPGs. Key categories are prioritized because their estimates have a significant influence on the national total, in terms of the absolute level of emissions, the trend assessment, or both. For the 1990–2024 GHG inventory, level and trend key category assessments were performed according to the Tier 1 approach (IPCC, 2006).

The categories that have the strongest influence on the national trend (excluding LULUCF) are:

1. Fuel Combustion – Energy Industries – Gaseous Fuels, CO_2
2. Fuel Combustion – Energy Industries – Solid Fuels, CO_2
3. Fuel Combustion – Transport – Road Transportation, CO_2

The categories that have the strongest influence on the national trend (including LULUCF) are:

1. Fuel Combustion – Energy Industries – Gaseous Fuels, CO_2
2. LULUCF – Forest Land Remaining Forest Land, CO_2
3. Fuel Combustion – Energy Industries – Solid Fuels, CO_2

Details and results of the key category level and trend assessments are presented in Annex 1 of this report.

ES.8. Inventory Improvements

Continuous improvement is good inventory preparation practice (IPCC, 2006) and essential to ensure Canada's inventory estimates are based on the best available science and data. Recalculations of inventory estimates often result as part of continuous inventory improvement activities, including refinements of methods, updates to activity data, inclusion of categories previously not estimated, correction of errors, or compliance with recommendations arising from reviews conducted under the UNFCCC. ECCC continuously consults and works with experts in federal, provincial and territorial agencies; industry; academia; research institutions; and consultants to improve inventory quality. Improved understanding and refined or more comprehensive data are used to develop and integrate more accurate methods. The implementation of methodological improvements leads to the recalculation of previous estimates to maintain a consistent trend in emissions and removals.

The 2026 edition of the GHG inventory incorporates methodological improvements in the estimation of multiple emission sources. Notably and among others, refinements occurred in Transport to improve the percentage of renewable fuels used in on-road and off-road gasoline and diesel. Furthermore, key parameters in the Fugitive Emissions Model were revised to better reflect the Leak Detection and Repair (LDAR) requirements under provincial methane regulations in

Alberta. Additionally, a country-specific method has been developed to estimate the emissions and removals associated with wetland management and land-use change for oil and gas activities in Alberta's oil sands region. Finally, new sources of emissions were included in the 2026 GHG inventory, for example, the iron ore pelletization source and methane emissions from Flooded Land. Overall, without the LULUCF sector, the recalculations resulted in a 4.3 Mt upward revision in 2005 and a -7.0 Mt downward revision in 2023. The improved methods use Canadian-specific studies and knowledge, adopt the most up-to-date activity data and better reflect evolving technologies and industry practices. Chapter 8 of the present report provides greater detail on the impacts of current inventory improvements on the overall emission trends.

Improvements to inventory estimates are anticipated in future editions of this report. For example, amongst several planned improvements, in the Energy sector for Transport, the migration to the United States Environmental Protection Agency's (U.S. EPA) MOtor Vehicle Emission Simulator 5 (MOVES5) model is planned. Also related to the Energy sector, a liquefied natural gas (LNG) export terminal operated by LNG Canada came online in 2025. Development of combustion and fugitive emissions for this new segment of the Canadian oil and gas industry is planned. Improvements expected in the LULUCF sector include tracking of emissions and removals resulting from agricultural drainage, improvements to woody biomass estimates using age and species groups, integration of tillage and crop productivity impacts in soil organic carbon estimation, and the growth of urban trees. Refer to Chapter 8 for details on the planned improvements and for a complete list covering all sectors. For additional detail on LULUCF planned improvements of methods related to Forests, refer to the *Improvement Plan for Forest and Harvested Wood Products Greenhouse Gas Estimates*.

ES.9. National Inventory Arrangements

Environment and Climate Change Canada is the single national entity with responsibility for preparing and submitting the national GHG inventory to the UNFCCC and for managing the supporting processes and procedures. The inventory arrangements for the preparation of the inventory include, amongst others: formal institutional arrangements on data collection and estimate development; a quality management system, including a method change process to peer review and approve planned improvements; the identification of key categories and generation of quantitative uncertainty analysis; a process for performing and tracking recalculations following improvements and activity data updates; procedures for third-party reviews and official approval; and a working archive system. Information regarding the national inventory arrangements are presented in Chapter 1.

Structure of Submission

As per the MPGs, the annual submission of Canada's official GHG inventory comprises the NIR and CRTs. The CRTs are a series of standardized data tables containing mainly numerical information. The NIR contains the information to support the CRTs, including a comprehensive description of the methodologies used in compiling the inventory, data sources, institutional arrangements, and quality assurance and quality control procedures.

The NIR, in accordance with MPG requirements, includes:

- Chapter 1: an overview of Canada's legal, institutional and procedural arrangements, along with cross-cutting information for producing the inventory, and a description of Canada's GHGRP and how the facility-reported data are integrated in the inventory.
- Chapter 2: an analysis and breakdown of Canada's GHG emission trends by IPCC and Canadian economic sectors.
- Chapters 3 to 7: descriptions and additional analysis of emission estimates for each sector.
- Chapter 8: a summary of the recalculations, and implemented and planned improvements.
- Annexes 1 and 2: a key category analysis and uncertainty assessment.
- Annex 3: estimation methodologies details.
- Annex 4: Canada's energy balance.
- Annex 5: information on ozone and aerosol precursors.
- Annexes 6 and 7: emission factors and details on the GHG intensity of electricity generation, respectively.

This material is available on the Government of Canada's Open Data website in various formats, in addition to summary tables of GHG emissions at the national level and for each provincial and territorial jurisdiction, sector and gas.

The complete NIR, in PDF format, can be accessed through Canada's official greenhouse gas inventory main webpage. ECCC is streamlining NIR content, including a transition away from heavy amounts of data in the PDF format of the report to greater data availability in various formats on open.canada.ca. If you have any questions or would like to share views on this, please contact us at ges-ghg@ec.gc.ca.

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CHAPTER 1

NATIONAL CIRCUMSTANCES, INSTITUTIONAL ARRANGEMENTS, AND CROSS-CUTTING INFORMATION

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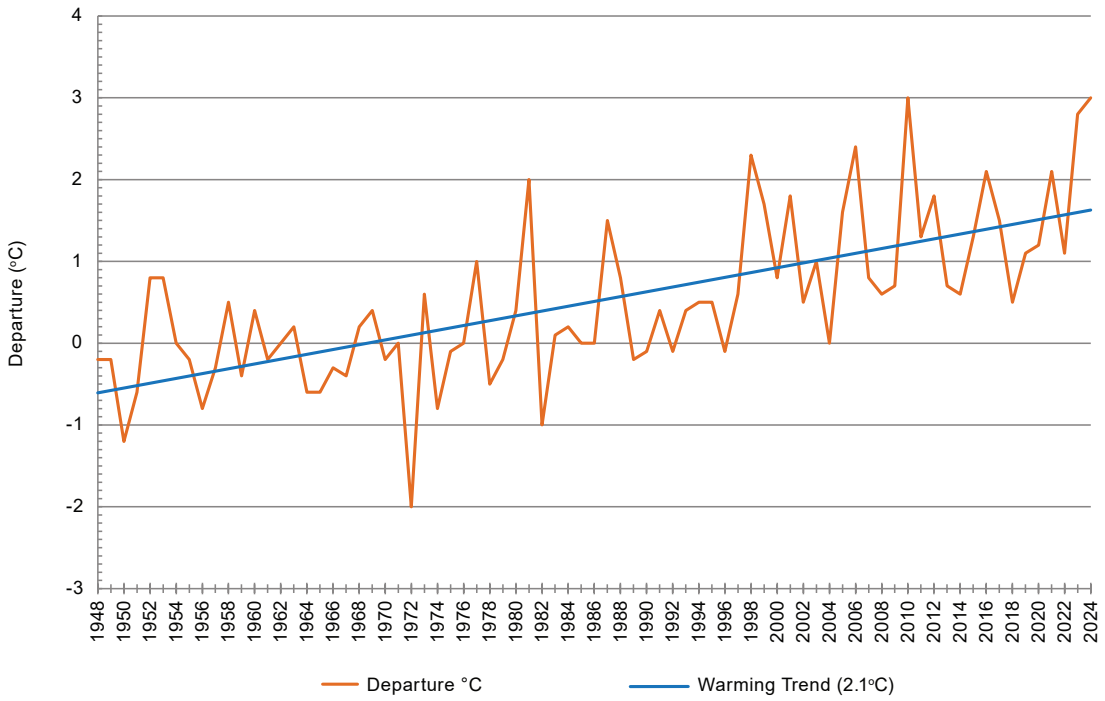
1.1. Greenhouse Gas Inventories and Climate Change

Climate change is a defining challenge of the 21st century. It is a worldwide problem, and tackling it requires global action. Comprehensive assessment reports prepared by the Intergovernmental Panel on Climate Change (IPCC), based on the most recent science, have concluded that human activities have unequivocally caused global warming. Global surface temperatures in 2011-2020 reached 1.1°C higher than the 1850–1900 period (IPCC, 2023). Governments around the world have recognized that climate-related risks grow with the magnitude of warming and associated climate change. Therefore, they have committed to working together to limit global warming.

Climate change has caused widespread and rapid changes, impacting human and natural systems. It has caused substantial damage and increasingly irreversible losses to ecosystems (IPCC, 2023). Atmospheric concentrations of GHGs have increased significantly since pre-industrial times across the globe. In fact, since 1750, the concentration of atmospheric carbon dioxide (CO_2) has increased by 151%; methane (CH_4) by 265%; and nitrous oxide (N_2O) by 125% (WMO, 2024). Observed increases in well-mixed GHG concentrations since around 1750 are undeniably caused by GHG emissions from human activities over this period (IPCC, 2023).

In Canada, the impacts of climate change may be observed through the increases in extreme weather events, higher risk and severity of forest fires and pest infestations, reductions in freshwater resources and Arctic ice, and the acceleration of glacial melting. Canada's national average temperature for 2024 was 3.0°C above the baseline average (defined as the mean over the 1961–1990 reference period) (see Figure 1–1). Based on preliminary data, the year 2024 was tied as the warmest year since nationwide recording began in 1948, matching the previous record of 3.0°C set in 2010. Apart from 1996 and 2004, temperature departures above the baseline average have been observed in the previous three decades. The warming trend indicates that average annual temperatures across the nation have warmed up by 2.1°C over the past 77 years (ECCC, 2025). Canada's climate is warming and will continue to warm rapidly. It is warming at a rate that is already two times faster than the global average. Looking only at the Canadian North, this rate stands at three times faster than the global average. Emissions must be reduced to limit the extent of climate change and avoid ecological and socio-economic tipping points, while keeping in mind that climate change impacts will continue even after global net-zero emissions are achieved (ECCC, 2023a).

Figure 1–1 **Annual Canadian Temperature Departures and Long-Term Trend, 1948–2024**



Note:
Source: ECCC (2025)

1.1.1. Background to Canada's National Greenhouse Gas Inventory

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC) in December 1992, which came into force in March 1994. The ultimate objective of the UNFCCC is to stabilize atmospheric GHG concentrations at a level that would prevent dangerous interference with the climate system. To strengthen the global response to climate change, multiple international agreements were introduced under the UNFCCC. The most recent one is the Paris Agreement, a legally binding international treaty with the overarching goal to limit the global average temperature rise to well below 2°C and pursue efforts to limit the increase to 1.5°C. Canada, recognizing the significance of collective action, ratified the Paris Agreement in 2016, and the Agreement entered into force the same year.

To achieve its objective and implement its provisions, the Paris Agreement sets out several guiding principles and commitments. Specifically, Article 13 of this agreement establishes an enhanced transparency framework (ETF) for action and support. It requires all Parties to gather and share information on GHG emissions, national policies, best practices and progress towards their emissions targets among other items. Precisely, it also commits the signatories to develop, periodically update, publish, and make available to the Conference of the Parties (COP) their national inventories of anthropogenic[1] emissions by sources, and removals by sinks, of seven direct GHGs. The GHGs covered in this inventory are emissions and removals of carbon dioxide (CO_2), and emissions of methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

1 Anthropogenic refers to human-induced emissions and removals that occur on managed lands.

Canada, as a developed Party under the UNFCCC, is required by the Convention to submit its national GHG inventory every year. In addition, all Parties under the Paris Agreement ETF are required to submit to the UNFCCC a Biennial Transparency Report (BTR)[2] every two years. In support of Article 13, Decision CMA.1 of FCCC/Cp/2018/L.13 established the modalities, procedures, and guidelines (MPGs) for the transparency framework for action and support including the requirements for National Inventory Reports. A suggested general outline of the National Inventory Report (NIR) was also established in Decision 5/CMA.3 in 2021.

Canada's annual NIR submission is comprised of an inventory report and a set of data tables, referred to as the Common Reporting Tables (CRTs), to be submitted together by April 15 of each year under the Paris Agreement and UNFCCC. This edition of the NIR documents Canada's annual GHG emission estimates for the 1990−2024 period based on international agreed-upon reporting requirements and formats.[3] The 2024 edition was the first to be submitted under the Paris Agreement.[4] Refer to section 1.2.4 for more details on the inventory submission structure.

1.1.2. Metrics and Global Warming Potentials

Since 2005 was adopted as a base year for Canada's Nationally Determined Contribution (NDC) and emission reduction targets, many of the metrics in this report are presented in that context, in addition to the 1990 base year as required by the MPGs. The IPCC defines GHGs as "gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect" (IPCC, 2021). Each type of GHG has a unique atmospheric lifetime and heat-trapping potential.[5] The radiative forcing[6] effect of a gas in the atmosphere is a quantification of its ability to cause atmospheric warming. Direct radiative forcing occurs when the gas itself is a GHG, whereas indirect forcing occurs when atmospheric condition and non-GHG species chemically transform to a GHG, such as carbon monoxide (CO) to carbon dioxide (CO_2), or when a gas influences the atmospheric lifetimes of other gases.

Global warming potential (GWP) is defined as the time-integrated change in radiative forcing due to the instantaneous release of 1 kg of the substance, expressed relative to the radiative forcing caused by the release of 1 kg of CO_2. A GHG's GWP value accounts for the instantaneous radiative forcing caused by an incremental concentration increase, as well as the lifetime of the gas. It is a relative measure of the warming effect that the emission of a radiative gas (i.e., a GHG) might have on the surface atmosphere.

The GWP concept was developed to allow a comparison of the ability of each GHG to trap heat in the atmosphere relative to CO_2, as well as characterize GHG emissions by how much CO_2 is required to produce a similar warming effect over a given period. This is the carbon dioxide equivalent (CO_2 eq) value and is calculated by multiplying the amount of the gas by its associated GWP. This normalization to CO_2 eq enables the quantification of total national emissions expressed as CO_2 eq.

Since GWP values are based on background conditions for GHG concentrations and climate, they need to be adjusted on a regular basis to reflect the increase in gases already present in the atmosphere and changing atmospheric conditions. The IPCC develops and updates the GWPs for all GHGs generally every 6 to 7 years. In accordance with the MPGs of the ETF under the Paris Agreement (Annex to Decision 18/CMA.1) and consistent with Decision 5/CMA.3 paragraph 25, this report uses the 100-year GWP values from the IPCC Fifth Assessment Report (AR5) (IPCC, 2014) as shown in Table 1–1.

2 The BTR includes information on progress towards Nationally Determined Contributions (NDCs), policies and measures, climate change impacts and adaptation, levels of financial, technology development and transfer and capacity-building support, and areas of improvement. It also summarizes some of the information presented in the NIR.

3 For ease of reference please refer to the following documents:
- Paris Agreement: https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf
- MPGs: https://unfccc.int/sites/default/files/resource/l23_0.pdf?download
- Guidelines for the operationalizing of the MPGs (i.e., suggested reporting structure): https://unfccc.int/sites/default/files/resource/CMA2021_L10a2E.pdf

4 Previously, this inventory was prepared in accordance with the revised *Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention, Part I: UNFCCC Reporting Guidelines on Annual Inventories* (UNFCCC Reporting Guidelines), adopted through Decision 24/CP.19 in 2013 and was submitted under the Convention.

5 Definitions of the seven GHGs presented in this inventory can be found in IPCC, 2021.

6 The term "radiative forcing" refers to the amount of heat-trapping potential of any given GHG. It is measured in units of power (watts) per unit of area (metres squared).

Table 1–1 **IPCC Global Warming Potentials (GWPs)**

GHG	Formula	100-Year GWP[a]	Atmospheric Lifetime (years)
Carbon dioxide	CO_2	1	Variable
Methane[b,c]	CH_4	28	12.4
Nitrous oxide	N_2O	265	121
Sulphur hexafluoride	SF_6	23 500	3 200
Nitrogen trifluoride	NF_3	16 100	500
Hydrofluorocarbons (HFCs)			
HFC-23	CHF_3	12 400	222
HFC-32	CH_2F_2	677	5.2
HFC-41	CH_3F	116	2.8
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1 650	16.1
HFC-125	CHF_2CF_3	3 170	28.2
HFC-134	CHF_2CHF_2	1 120	9.7
HFC-134a	CH_2FCF_3	1 300	13.4
HFC-143	CH_2FCHF_2	328	3.5
HFC-143a	CH_3CF_3	4 800	47.1
HFC-152	CH_2FCH_2F	16	0.40
HFC-152a	CH_3CHF_2	138	1.5
HFC-161	CH_3CH_2F	4	0.18
HFC-227ea	CF_3CHFCF_3	3 350	38.9
HFC-236cb	$CH_2FCF_2CF_3$	1 210	13.1
HFC-236ea	CHF_2CHFCF_3	1 330	11
HFC-236fa	$CF_3CH_2CF_3$	8 060	242
HFC-245ca	$CH_2FCF_2CHF_2$	716	6.5
HFC-245fa	$CHF_2CH_2CF_3$	858	7.7
HFC-365mfc	$CH_3CF_2CH_2CF_3$	804	8.7
Perfluorocarbons (PFCs)			
PFC-14	CF_4	6 630	50 000
PFC-116	C_2F_6	11 100	10 000
PFC-218	C_3F_8	8 900	2 600
PFC-31-10	C_4F_{10}	9 200	2 600
PFC-318	c-C_4F_8	9 540	3 200
PFC-41-12	n-C_5F_{12}	8 550	4 100
PFC-51-14	n-C_6F_{14}	7 910	3 100
PFC-91-18	$C_{10}F_{18}$	7 190	2 000
PFC-c216	c-C_3F_6	9 200	3 000

Notes:
a. Source: Table 8.A.1 in IPCC (2013).
b. The GWP for methane includes indirect effects from enhancements of ozone and tratospheric water vapour.
c. Fossil methane has been excluded as agreed upon per UNFCCC Decision 5/CMA.3.

1.2. Canada's National Circumstances and Institutional Arrangements

Canada's inventory arrangements for estimating anthropogenic emissions from sources, and removals by sinks, of all seven GHGs include the institutional, legal and procedural arrangements necessary to ensure that Canada meets its reporting obligations. The institutional arrangements include formal agreements with contributors, often in the form of data-sharing agreements, describing the latter's roles and responsibilities in the preparation of the national GHG inventory. The procedural arrangements ensure that the development, reporting and archiving of the inventory information are in line with the MPGs.

1.2.1. National Entity and Focal Point

The Pollutant Inventories and Reporting Division (PIRD) of Environment and Climate Change Canada (ECCC) is the national entity responsible for Canada's inventory arrangements. More specifically, the National Inventory Focal Point contact person is:

Lindsay Pratt, Director
Pollutant Inventories and Reporting Division
Science Reporting and Assessment Directorate
Science and Technology Branch
Environment and Climate Change Canada
351 Saint-Joseph Boulevard
Gatineau, QC K1A 0H3
E-mail: ges-ghg@ec.gc.ca
Telephone: 1-877-877-8375

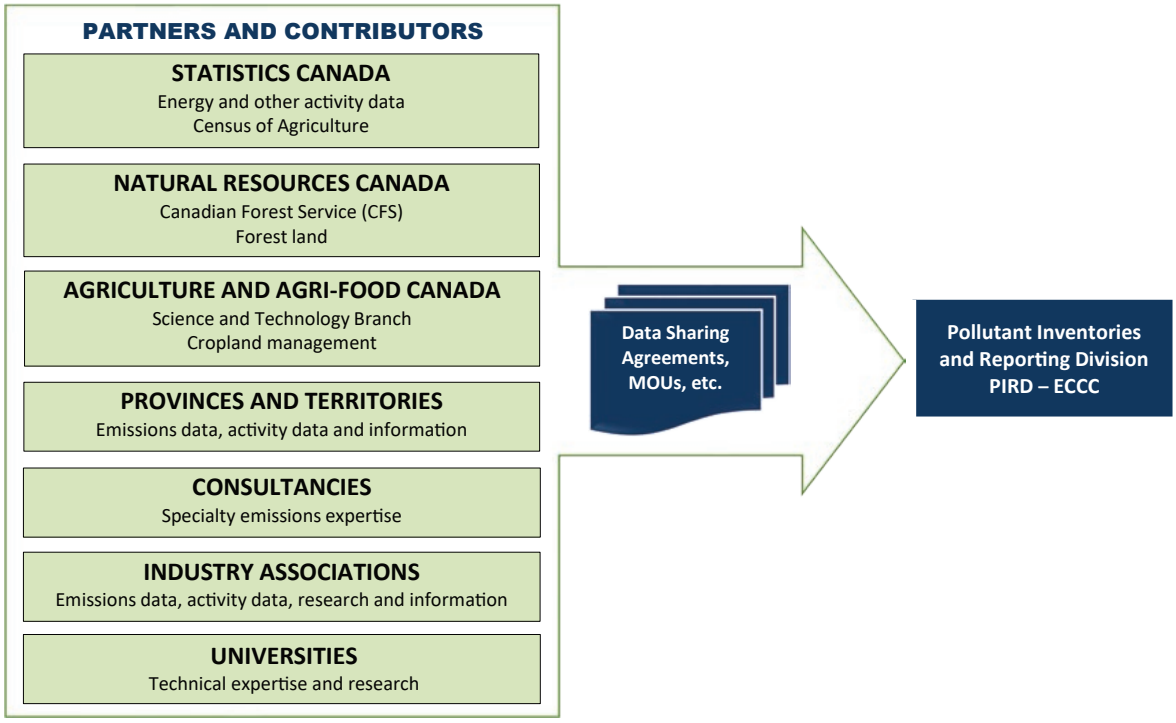
An overview of the institutional arrangements and inventory preparation process is provided in the following sections.

1.2.2. Institutional Arrangements

ECCC, as the federal agency responsible for preparing the national inventory and submitting it to the UNFCCC, establishes and manages all aspects of the arrangements to support the GHG inventory.

GHG sources and sinks originate from a wide range of economic sectors and activities. Leveraging the best available technical and scientific expertise and information, ECCC has defined the various roles and responsibilities for the preparation of the inventory, both internally and externally, and is involved in many agreements, formal and informal, with data providers and expert contributors. These include partnerships with other federal government departments, namely Statistics Canada, Natural Resources Canada (NRCan) and Agriculture and Agri-Food Canada (AAFC); arrangements with industry associations, consultants and universities; and collaborative bilateral agreements with provincial and territorial governments (Figure 1–2).

Figure 1–2 **Partners in and Contributors to National Inventory Arrangements**



Note: A MOU (memorandum of understanding) is an agreement between two or more parties outlined in a formal document.

1.2.2.1. Statistics Canada

As Canada's national statistical agency, Statistics Canada provides ECCC with a large portion of the underlying activity data for estimating the GHG emissions in the Energy and the Industrial Processes and Product Use (IPPU) sectors. Statistics Canada is responsible for the collection, compilation, and dissemination of Canada's energy balance in its annual *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada, n.d.). The energy balance uses a number of Statistics Canada surveys, including the annual Industrial Consumption of Energy (ICE) survey, which collects energy consumption data from various industries. Energy balance figures are transmitted annually to ECCC according to the terms of a Letter of Agreement between the two departments.

Statistics Canada's quality management system for energy balance data includes an internal and external review process. Owing to the complexity of these data, experts from Statistics Canada, ECCC, NRCan and the Canadian Energy and Emissions Data Centre (CEEDC) of Simon Fraser University review quality and technical issues related to the data from the RESD and from the ICE survey, and provide advice, direction and recommendations on improvements to the energy balance. See Annex 3 and Annex 4 of this report for additional information on the use of the energy balance in the development of Energy sector emission estimates.

Statistics Canada also collects other energy data from the mining and electricity industries as well as production data from other non-energy-related industries, including petrochemical industries and mineral resources. In addition, it compiles activity data on agriculture (crops, crop production and management practices through the *Census of Agriculture*), and livestock populations.

1.2.2.2. Natural Resources Canada and Agriculture and Agri-Food Canada (AAFC): Canada's Monitoring System for the Land Use, Land-Use Change and Forestry Sector (LULUCF)

ECCC has officially assigned responsibilities to AAFC and the Canadian Forest Service of Natural Resources Canada (NRCan/CFS) for the development of key components of the LULUCF sector, which has been formalized through memoranda of understanding (MOUs).

Every year, NRCan/CFS develops and submits to ECCC estimates of GHG emissions/removals from forest land, harvested wood products, land conversion to forest land (afforestation) and forest land converted to other land (deforestation). The Deforestation Monitoring Group provides estimates of forest conversion activity.

AAFC provides estimates of GHG emissions/removals from cropland for the LULUCF sector that include the effects of management practices on agricultural soils and the residual impact of land conversion to cropland. In addition, AAFC provides scientific support for the Agriculture sector of the inventory.

ECCC manages and coordinates the annual inventory development process, develops all other LULUCF estimates, undertakes cross-cutting quality assurance/quality control (QA/QC) procedures, and ensures the consistency of land-based estimates through an integrated land representation system. Improvement processes are managed through three-year rolling improvement plans and oversight is provided through interdepartmental director committees, defined through mutually agreed upon Terms of Reference. For more information on the LULUCF improvement plan, refer to Chapter 8.

1.2.2.3. Other Agreements and Data Sources

In addition to supporting Canada's LULUCF estimates (see previous section), NRCan provides energy expertise and analyses, and serves as an expert reviewer for the Energy sector and for the ethanol consumption and wood residues sources. Road vehicle data, such as fuel efficiency and driving rates, are supplied by both Transport Canada and NRCan.

In 2013, an amended bilateral agreement was signed with the Aluminium Association of Canada (AAC), the initial intent of which was to provide ECCC with annual process-related emission estimates for CO_2, PFCs and SF_6. Since the GHGRP has supplied some of these data since 2017, the purpose of the agreement with AAC has evolved, now consisting of the provision, upon request, of supporting data and information on the emission factors (EFs) and parameters used to derive emission estimates. ECCC has also signed an agreement with the Canadian Electricity Association (CEA) to obtain data on SF_6 emissions and other areas related to power transmission systems.

The primary responsibility for the management of natural resources falls to provincial governments and as such, ECCC receives various oil and gas data through both formal and informal agreements with provincial regulators. Data and expertise are provided by the Alberta Energy Regulator, British Columbia Energy Regulator, Saskatchewan Ministry of Energy and Resources, and the Canada-Newfoundland and Labrador Offshore Energy Regulator (C-NLOER).

The Energy and Emissions Research Laboratory (EERL) at Carleton University conducts periodic aerial measurement surveys of CH_4 emissions from oil and gas operations in Canada. Through an informal arrangement, EERL provides measurement-based, source-resolved CH_4 inventories for Saskatchewan, Alberta, and British Columbia to ECCC.

Under its Greenhouse Gas Reporting Program (GHGRP),[7] ECCC collects emissions and other supporting data (e.g., activity data) annually from facilities across Canada that emit large quantities of GHGs. These facility-level data are used directly in

7 https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/facility-reporting.html

the national inventory estimates for specific sectors, and in addition, play a key role in the overall inventory development process, where they are used to compare and verify certain inventory estimates in the NIR. For more information on the facility-level data reported under the GHGRP and specific uses in the NIR, see section 1.4.4.

When required, and resources permitting, contracts are concluded with consulting firms and universities to conduct in-depth studies—for example, on developing or updating country-specific EFs.

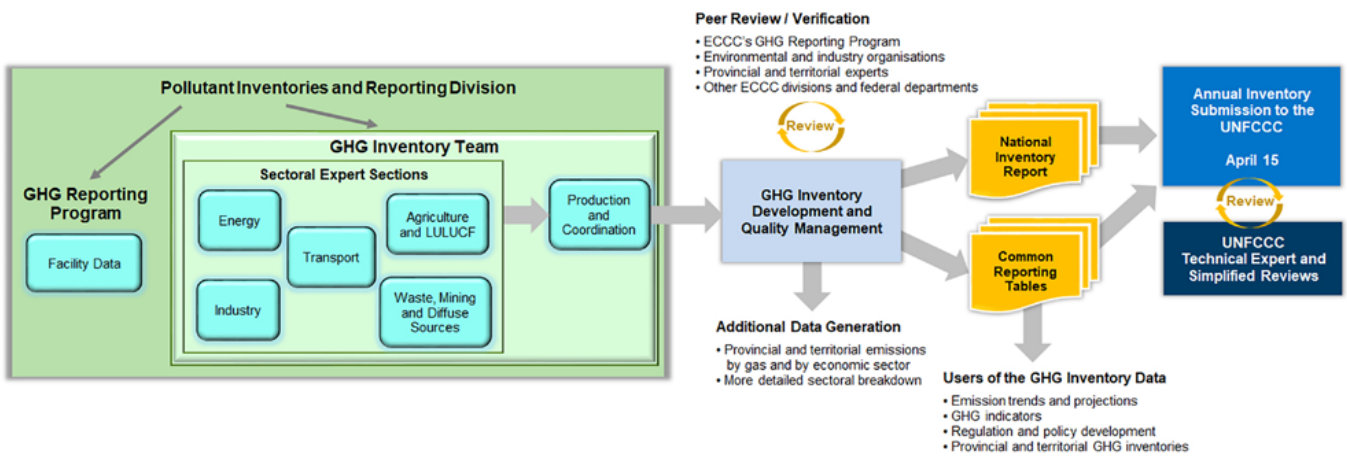
1.2.3. Inventory Preparation Process

Canada's inventory is developed, compiled and published annually by ECCC's Science and Technology Branch, with input from numerous experts across Canada. Figure 1–3 provides an overview of the various stages of the inventory preparation process as well as the different stakeholders involved. Two GHG-related programs are maintained; the GHGRP and the official national GHG inventory. Within the GHG inventory team, there are five sectoral expert sections and one section responsible for compiling estimates, coordinating the activities and producing the final products that are published.

The inventory is built on a continuous process of methodological improvements, refinements and reviews, in accordance with quality management principles and improvement planning. Inventory planning is based on the review of the lessons learned that resulted from the previous inventory cycle, QA/QC follow-up, UNFCCC reviews, data collection context, and collaboration with provincial and territorial governments or other partners. These varying factors will influence the inventory timeline which is adjusted each cycle. This process involves ongoing collaboration and consultation within ECCC, but also with external partners and contributors.

The overall inventory cycle to develop one NIR edition, from the planning phase to the submission, has a duration of over a year (see Figure 1–4).

Figure 1–3 **Overview of the Inventory Production Process**



Phase 1: Inventory Planning

Inventory planning generally starts in January, when sectoral inventory experts begin to plan their work on the anticipated improvements. This includes data sources, methodologies and EFs that will be collected, reviewed, developed and/or refined during the next cycle. The work is prioritized based on the above-mentioned factors, monitored throughout the whole inventory cycle, and involves key partners if needed. Source agencies, the GHGRP and other collaborators collect data for the year that just ended (see section 1.2.2 for details). While the sectoral experts participate in this planning phase, work continues to complete the previous NIR edition for submission at the same time.

Phase 2: Inventory Preparation

In May, after the release of the previous NIR edition, inventory preparation begins. The collection of the required data begins, and roles and responsibilities are formalized. Data collected from the source agencies are assessed for quality during this phase and this continues whenever activity data are received. The integrated timeline for the current cycle is developed, identifying all steps of the production process and due dates for the year. Experts update and refine their models and tools for the estimation and compilation of the GHG data as required. Continuous improvement activities, including the methodological changes, also start, following established guidelines.

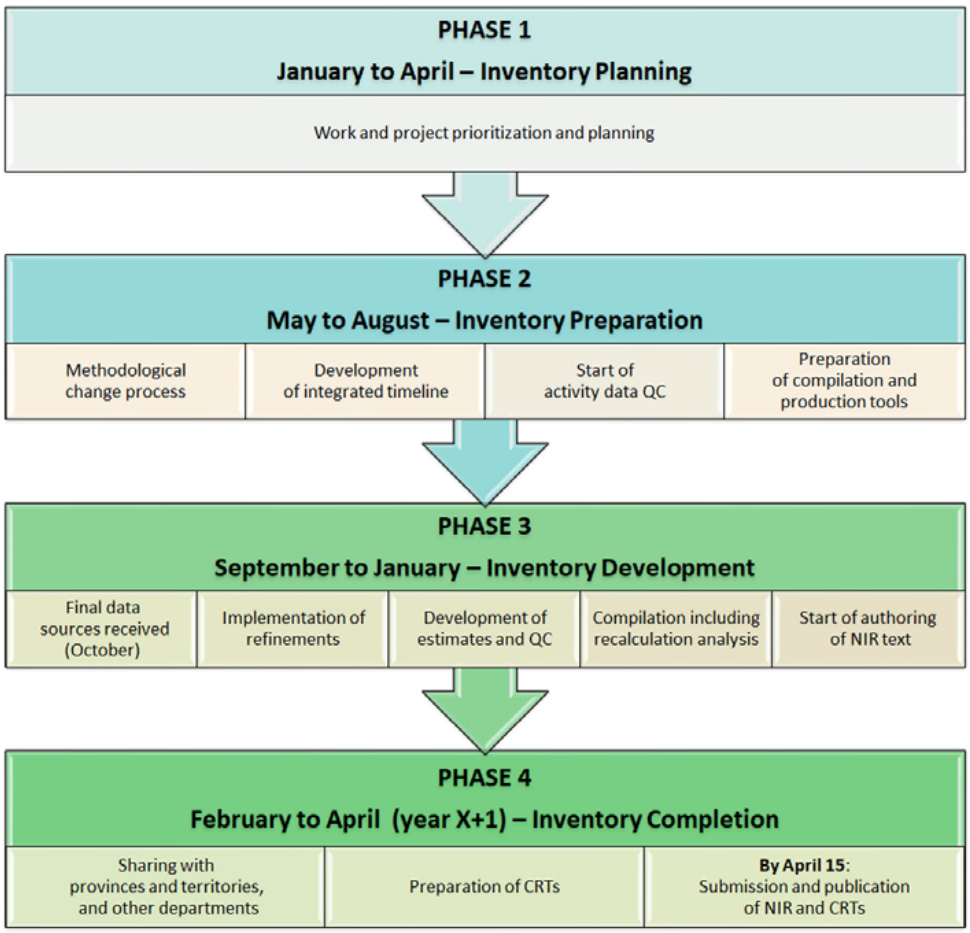
Phase 3: Inventory Development

Methodologies, including those updated from continuous improvement activities, are finalized, reviewed and approved by the end of September. Most of the activity data collection, compilation and review process is completed by October. After that, refinements are fully implemented and the data are entered in emission quantification tools (for example, spreadsheets, scripts and queries). In November and December, draft estimates are developed by designated inventory experts, compiled and internally reviewed. QC checks and recalculation analysis are performed on the compiled emission estimates. In December, the first version of the compiled draft preliminary estimates is ready. During the inventory development phase, the authoring of the report also begins.

Phase 4: Inventory Completion

In the following few months, between January and March, the compiled inventory is reviewed internally. After that, different inventory components are reviewed externally by experts in other federal departments, and provincial and territorial governments. Comments received are documented, analyzed, and if necessary, the inventory content is reviewed. During that same period, the NIR text and CRTs are also prepared and finalized by inventory experts. Uncertainty calculations, key category analysis and completeness assessments are completed by mid-March, along with the accompanying documentation. The NIR and the CRTs are then submitted to the UNFCCC electronically by mid-April. Simultaneously, during the inventory completion phase, the NIR is also translated into French and made available at the same time. After publication, and in line with the continuous improvement principle, lesson learned sessions are conducted and the electronic archiving system is updated.

Figure 1–4 **GHG Inventory Cycle Process by Phases, Main Steps**



1.2.4. Inventory Submission Structure

As per the MPGs, the annual submission of Canada's official GHG inventory comprises the NIR and CRTs. The NIR contains the qualitative information to support the CRTs' quantitative information, including a comprehensive description of the methodologies used in compiling the inventory, data sources, institutional arrangements, and quality assurance and quality control procedures. ECCC is working on improving the efficiency and relevance of the NIR content, including a transition away from heavy amounts of data in the PDF format of the report, to greater data availability and accessibility in various formats on the Government of Canada's Open Data website. For any questions or comments on this, please contact us at ges-ghg@ec.gc.ca.

For more details on the material included in Canada's GHG inventory submission and where to access it, refer to Table 1–2.

The complete NIR in PDF format can be accessed on the UNFCCC website.

Table 1–2 **Canada's GHG Inventory Material and Associated Location**

Category	Content	Location	Format
GHG data	GHG data by IPCC sector and by gas at the national, province and territory levels, 1990-2024	open.canada.ca: folder A	• Excel • CSV
	GHG data by economic sector and by gas at the national, province and territory levels, 1990-2024	open.canada.ca: folder B	• Excel • CSV
	LULUCF data: data by sub-categories, 1990-2024	open.canada.ca: folder E	Excel
	Agriculture data: data by sub-categories, by gas and activity data at the province level	open.canada.ca: folder F	Excel
Emission trends analysis	Chapter 2: cross-cutting text	*National Inventory Report 1990–2024: Greenhouse Gas Sources and Sinks in Canada*	PDF
Sectoral-specific information	Chapter 3: Energy sector Chapter 4: IPPU sector Chapter 5: Agriculture Sector Chapter 6: LULUCF Sector Chapter 7: Waste Sector	*National Inventory Report 1990–2024: Greenhouse Gas Sources and Sinks in Canada*	PDF
Key Categories	Annex 1: Summary and explanations	*National Inventory Report 1990–2024: Greenhouse Gas Sources and Sinks in Canada*	PDF
	Detailed data tables	open.canada.ca: folder G	Excel
Uncertainties	Annex 2: Summary and explanations	*National Inventory Report 1990–2024: Greenhouse Gas Sources and Sinks in Canada*	PDF
	Detailed data tables	open.canada.ca: folder G	Excel
Methodologies	Annex 3.1: Fossil Fuel Combustion Annex 3.2: Fugitive Emissions Annex 3.3: IPPU Sector Annex 3.4: Agriculture Sector Annex 3.5: LULUCF Sector Annex 3.6: Waste Sector	*National Inventory Report 1990–2024: Greenhouse Gas Sources and Sinks in Canada* open.canada.ca: folder G	PDF
Comparison of sectoral and reference approaches, and the national energy balance	Annex 4: Explanations and data tables	*National Inventory Report 1990–2024: Greenhouse Gas Sources and Sinks in Canada* open.canada.ca: folder G	PDF
Ozone and aerosol precursors	Annex 5: Explanation text	*National Inventory Report 1990–2024: Greenhouse Gas Sources and Sinks in Canada* open.canada.ca: folder G	PDF
Emission Factors	Annex 6: Text and data tables	*National Inventory Report 1990–2024: Greenhouse Gas Sources and Sinks in Canada*	PDF
	Data tables	open.canada.ca: folder D	Excel
Electricity Summary and Emission Factors	Annex 7: Summary, explanation text and intensity tables at national level (rounded)	*National Inventory Report 1990–2024: Greenhouse Gas Sources and Sinks in Canada*	PDF
	Annex 7: Intensity tables at national, province and territory levels (unrounded)	open.canada.ca: folder C	Excel

1.2.5. Archiving System

Canada developed an archiving system to ensure the transparency, traceability and reproducibility of Canada's official GHG inventory by defining information management standards and practices in accordance with the MPGs (paragraph 19) and ECCC guidance. In summary, the material to be archived includes all information for the reported time series, including all disaggregated emission factors and activity data, all documentation about generating and aggregating data, including QA/QC, review results and planned inventory improvements.

The archiving plan is an internal document that defines the parameters for the material to be archived, for example, how long to keep a document archived, the archiving location or what is archived internally versus publicly. Most of the internal archived information is managed and kept in internal servers, while some information is available publicly on the Government of Canada's Open Data website. The archiving of documents is completed, updated and monitored annually, including all references cited in Canada's NIR that are compiled and archived in the integrated electronic reference library. The archiving system was developed in accordance with the ECCC File Plan that provides an information structure and organization for efficient management and grouping of information resources of business value.

1.2.6. Processes for the Official Consideration and Approval of the Inventory

The consideration and approval process involves briefing senior officials. Briefings generally start with the planned improvements process and continue with preliminary estimates as soon as they are available. Information and updates are shared continuously with senior management during Phases 2 to 4 of the inventory cycle. A few weeks before the final submission in April, a Memorandum to Minister of Environment and Climate Change is circulated within the department for information. Once the content has been reviewed, the National Inventory Focal Point prepares a letter of submission to accompany the NIR and CRTs, which are then submitted electronically to the UNFCCC.

1.2.7. Annual Inventory Reviews

The review process plays a key role in ensuring that inventory quality is improved over time, and that the Parties comply with the agreed-upon reporting requirements. The transparency, completeness, comparability, consistency and accuracy of the NIR can also be partly attributed to this well-established process.

As part of the annual inventory cycle and up to 2023, Canada's inventory submission was typically reviewed annually by an Expert Review Team (ERT) following agreed-upon UNFCCC review guidelines[8] as adopted in Decision 13/CP.20 in 2014. Starting in 2025, in accordance with Decision 18/CMA.1 (2018) and under Article 13 of the Paris Agreement, information submitted by each Party will undergo a technical expert review (TER) consistent with the MPGs. Every 2 years, these reviews will examine the information presented in the NIR and BTR.[9] On the years that a BTR is not due to the UNFCCC, Canada's GHG inventory will undergo a simplified review, consisting of an initial assessment of completeness and consistency with the MPGs conducted by the UNFCCC Secretariat. The information reviewed for this type of review is mostly quantitative, taken from the CRTs. Once finalized, findings from all reviews are made public by the UNFCCC.[10]

For more information on the review process and improvements implemented following recommendations, refer to Chapter 8. A list of all TERT recommendations and their status is kept up to date on the Government of Canada's Open Data webpage.

1.3. Methodologies and Data Sources

As required by the MPGs, the GHG emission and removal estimates contained in Canada's GHG inventory are developed using methodologies consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). In some cases, the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2019) is also used to further improve methodologies and increase accuracy. The inventory is divided into the following five IPCC main sectors—Energy, IPPU, Agriculture, LULUCF, and Waste—each of which is further subdivided into subsectors or categories. The category descriptions by IPCC sector can be found in Table 1–3. Additionally, for the purposes of analyzing economic trends and policies, and in addition to what is required by inventory reporting requirements, emissions have been allocated to the Canadian economic sector from which they originate. In general, a comprehensive emission profile for a specific economic sector has been developed by reallocating the relevant portion of emissions from various IPCC subcategories. This reallocation simply recategorizes emissions under different headings and does not change the overall magnitude of Canadian emission estimates. The category descriptions by Canadian economic sector can be found in Table 1–4.

8 The *Guidelines for the technical review of information reported under the Convention related to GHG inventories, biennial reports and national communications by Parties included in Annex I to the Convention* can be found here: http://unfccc.int/resource/docs/2014/cop20/eng/10a03.pdf#page=3.

9 Further details about the scope of technical expert reviews, including on exclusions from its scope, are available in the MPGs.

10 Canada's last Annual Inventory Review Report is available online at: https://unfccc.int/first-biennial-transparency-reports.

The emissions and removals of seven direct GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3) are estimated. While not mandatory, the MPGs encourage Parties to provide information on the following indirect GHGs: SO_x, NO_x, CO and NMVOCs (see Annex 5). These gases are inventoried in Canada's Air Pollutant Emissions Inventory (APEI)[11] and reported separately to the United Nations Economic Commission for Europe (UNECE).

Table 1–3 **GHG Source and Sink Category Descriptions by IPCC sectors**

GHG Source and Sink Categories		Descriptions
ENERGY		
a.	**Stationary Combustion Sources**	
	Public Electricity and Heat Production	Emissions from fuel consumed by utility electricity generation and steam production (for sale)
	Petroleum Refining Industries	Emissions from fuel consumed by petroleum refining industries
	Oil and Gas Extraction	Emissions from fuel consumed by oil and gas extraction industries
	Coal Production	Emissions from fuel consumed by coal mines
	Biofuel Manufacturing	Emissions from fuel consumed by biofuel manufacturing industries including the production of ethanol, biodiesel, renewable diesel, renewable natural gas, alternative aviation fuel, biocrude and wood pellets
	Mining and Quarrying	Emissions from fuel consumed by:
		– metal and non-metal mines, stone quarries, and gravel pits
		– mineral exploration and contract drilling operations
	Manufacturing Industries	Emissions from fuel consumed by the following industries:
		– iron and steel (steel foundries, casting and rolling mills)
		– non-ferrous metals (aluminium, magnesium and other production)
		– chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing)
		– pulp and paper (primarily pulp, paper, and paper product manufacturers)
		– cement and other non-metallic mineral production
		– other manufacturing industries not listed (such as automobile manufacturing, textiles, food and beverage industries)
	Construction	Emissions from fuels consumed by the construction industry (buildings, highways etc.)
	Commercial and Institutional	Emissions from fuel consumed by:
		– service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.)
		– federal, provincial and municipal establishments
		– national Defence and Canadian Coast Guard
		– train stations, airports and warehouses
	Residential	Emissions from fuel consumed for personal residences (homes, apartment hotels, condominiums and farm houses).
	Agriculture and Forestry	Emissions from fuel consumed by:
		– forestry and logging service industry
		– agricultural, hunting and trapping industry (excluding food processing, farm machinery manufacturing and repair)
b.	**Transport**	Emissions resulting from the:
	Aviation	– consumption of fossil fuels by civilian aircraft flying domestically and all military aircraft operations with Canadian purchased fuel
	Domestic Aviation (Civil)	– consumption of fossil fuels by civilian aircraft flying domestically with Canadian purchased fuel
	Military	– consumption of fossil fuels by military aircraft operations with Canadian purchased fuel
	Road Transportation	– consumption of fuels (excluding the biogenic CO_2 emissions from ethanol and biodiesel) by vehicles licensed to operate on roads
	Light-Duty Gasoline Vehicles	– consumption of motor gasoline (excluding the biogenic CO_2 emissions from ethanol) by passenger cars
	Light-Duty Gasoline Trucks	– consumption of motor gasoline (excluding the biogenic CO_2 emissions from ethanol) by trucks, vans and SUVs with a Gross Vehicle Weight Rating (GVWR) less than 3856 kg
	Heavy-Duty Gasoline Vehicles	– consumption of motor gasoline (excluding the biogenic CO_2 emissions from ethanol) by trucks, vans and SUVs with a GVWR greater than or equal to 3856 kg
	Motorcycles	– consumption of motor gasoline (excluding the biogenic CO_2 emissions from ethanol) by motorcycles that are licensed to operate on roads
	Light-Duty Diesel Vehicles	– consumption of diesel fuel oil (excluding the biogenic CO_2 emissions from biodiesel) by passenger cars licensed to operate on roads
	Light-Duty Diesel Trucks	– consumption of diesel fuel oil (excluding the biogenic CO_2 emissions from biodiesel) by trucks, vans and SUVs with a GVWR less than 3856 kg
	Heavy-Duty Diesel Vehicles	– consumption of diesel fuel oil (excluding the biogenic CO_2 emissions from biodiesel) by trucks, vans and SUVs with a GVWR greater than or equal to 3856 kg
	Propane and Natural Gas Vehicles	– consumption of propane and natural gas by vehicles that are licensed to operate on roads
	Railways	– consumption of fuels (excluding the biogenic CO_2 emissions from ethanol and biodiesel) by Canadian railways
	Marine	– consumption of fuels (excluding the biogenic CO_2 emissions from ethanol and biodiesel) by marine vessels navigating between Canadian ports (inclusive of all fishing and military operations)
	Domestic Navigation	– consumption of fuels (excluding the biogenic CO_2 emissions from ethanol and biodiesel) by marine vessels navigating between Canadian ports
	Fishing	– consumption of fuels (excluding the biogenic CO_2 emissions from ethanol and biodiesel) by fishing vessels operating in Canadian waters
	Military Water-Borne Navigation	– consumption of fuels (excluding the biogenic CO_2 emissions from ethanol and biodiesel) by military vessels operating in Canadian waters
	Others – Off-road	– consumption of fuels (excluding the biogenic CO_2 emissions from ethanol and biodiesel) by mobile combustion devices not licensed to operate on roads
	Others – Pipeline Transport	– transportation and distribution of crude oil, natural gas, refined petroleum and other products

11 Information on Canada's ozone and aerosol precursors, including CO, NO_x, NMVOC and SO_x, can be found in Canada's Air Pollutant Emissions Inventory, which is available online at www.canada.ca/APEI.

Table 1–3 **GHG Source and Sink Category Descriptions by IPCC sectors** (cont'd)

GHG Source and Sink Categories		Descriptions
ENERGY (cont'd)		
c.	**Fugitive Sources**	Intentional and unintentional releases of greenhouse gases from the following activities:
	Coal Mining	– underground and surface mining, abandoned underground coal mines
	Oil and Natural Gas	– conventional and unconventional oil and gas exploration, production, transportation and distribution
	Oil	– unintentional releases of greenhouse gases from the production, processing, transmission, storage and delivery of crude oil
	Natural Gas	– unintentional releases of greenhouse gases from the production, processing, transmission, storage and delivery of natural gas (includes post-meter fugitive emissions from residential and commercial natural gas appliances, natural gas vehicles and industrial facilities)
	Venting	– intentional releases of greenhouse gases at oil and natural gas facilities
	Flaring	– routine or emergency disposal of waste gas through combustion in an open flame or incinerator at oil and natural gas facilities
d.	**CO_2 Transport and Storage**	Intentional and unintentional releases of greenhouse gases from the transport and storage of carbon dioxide
INDUSTRIAL PROCESSES AND PRODUCT USE		Emissions resulting from the following process activities:
a.	**Mineral Products**	– cement production, lime production, and mineral product use (which includes glass production, other uses of soda ash, non-metallurgical magnesia production and other limestone and dolomite use)
b.	**Chemical Industry**	– production of ammonia, nitric acid, adipic acid, carbide and petrochemicals (petrochemical production includes production of carbon black, ethylene, ethylene dichloride, ethylene oxide, methanol, styrene and other uses of urea)
c.	**Metal Production**	– aluminum production, iron and steel production, magnesium production and casting, and rare earths production
d.	**Production and Consumption of Halocarbons, SF_6 and NF_3**	– by-product production of HFC-23; use of HFCs and/or PFCs in air conditioning units, refrigeration units, fire extinguishers, aerosol cans, solvents, foam blowing, semiconductor manufacturing and electronics industry, and use of SF_6 and NF_3 in semiconductor manufacturing
e.	**Non-Energy Products from Fuels and Solvent Use**	– non-energy use of fossil fuels (including solvents and lubricants) that are not accounted for elsewhere under the Industrial Processes and Product Use Sector and the use of urea in selective catalytic reduction (SCR) equipped vehicles
f.	**Other Product Manufacture and Use**	– use of N_2O as an anaesthetic and propellant; use of SF_6 in electrical equipment; and PFCs in other contained product uses as a dielectric coolant or as an electric insulator
AGRICULTURE		Emissions resulting from:
a.	**Enteric Fermentation**	– eructation of CH_4 during the digestion of plant material by (mainly) ruminants
b.	**Manure Management**	– release of CH_4 and N_2O due to microbial activity during the storage of feces, urine and bedding materials from the cleaning of barns and pens
		– indirect N_2O emissions from volatilization and leaching of nitrogen from animal manure during storage
c.	**Agricultural Soils**	
	Direct sources	– direct N_2O emissions from inorganic nitrogen fertilizers, manure and biosolids applied on cropland, pasture range and paddock, crop residue, loss of soil organic carbon, tillage, irrigation and cultivation of organic soils
	Indirect Sources	– indirect N_2O emissions from volatilization and leaching of animal manure and biosolid nitrogen, inorganic nitrogen fertilizer and crop residue nitrogen
d.	**Field Burning of Agricultural Residues**	– CH_4 and N_2O emissions from crop residue burning
e.	**Liming, Urea Application and Other Carbon-Containing Fertilizers**	– direct emissions of CO_2 from the application of lime, urea and other fertilizers containing carbon
WASTE		Emissions resulting from:
a.	**Landfills**	– disposal of waste in landfills
	Municipal Solid Waste Landfills	– disposal of municipal solid waste and sewage sludge in landfills
	Industrial Wood Waste Landfills	– dedicated wood waste landfills
b.	**Biological Treatment of Solid Waste**	– composting and anaerobic digestion of municipal and industrial facilities including municipal solid waste, biosolids, manures and/or yard wastes that are brought on-site, including emissions from residential composting
c.	**Incineration and Open Burning of Waste**	– municipal solid, hazardous and clinical waste, and sewage sludge incineration and residential waste burning
d.	**Wastewater Treatment and Discharge**	– municipal and industrial wastewater treatment
	Municipal wastewater treatment and discharge	– emissions from treatment of wasteawter at municipal treatment plants and from discharge of effluents
	Industrial wastewater treatment and discharge	– emissions from treatment of wastewater at industrial sites with on-site wastewater treatment and from discharge of effluents
LAND USE, LAND-USE CHANGE AND FORESTRY		Emissions and removals resulting from:
a.	**Forest Land**	– managed forests and lands converted to forests; reports emissions and removals from forest growth and anthropogenic disturbances and transfers to harvested wood products (HWP) related to forest management but tracks separately emissions and removals from fire and most insect disturbances
b.	**Cropland**	– management practices on lands in annual and perennial crops (forage, specialty crops, orchards); soil organic carbon (SOC) impacted by crop productivity changes and manure application; immediate and residual emissions from lands converted to cropland
c.	**Grassland**	– managed agricultural grassland
d.	**Wetlands**	– peatlands disturbed for resource extraction, or lands converted to flooded land from hydro reservoir development
e.	**Settlements**	– forest and grassland converted to built-up land (settlements, transport infrastructure, oil & gas infrastructure, mining, etc); urban tree growth
f.	**Harvested Wood Products**	– the change in storage of carbon during the use and disposal of harvested wood products manufactured from wood coming from forest harvest, fouse and disposal of harvested wood products manufactured from wood coming from forest harvest, forest conversion and firewood collection activities in Canada

Table 1–4 **Canadian Economic Sector Descriptions**

Economic Sector	Descriptions
OIL AND GAS	
Upstream Oil and Gas	Stationary combustion, onsite transportation, electricity and steam production, fugitive and process emissions from:
Natural Gas Production and Processing	– natural gas production and processing
Conventional Oil Production	Emissions resulting from:
Conventional Light Oil Production	– conventional light crude oil production
Conventional Heavy Oil Production	– conventional heavy crude oil production, including primary extraction in designated oil sands areas
Frontier Oil Production	– offshore and arctic production of crude oil
Oil Sands and Thermal Heavy Oil Production	Stationary combustion, onsite transportation, electricity and steam production, fugitive and process emissions from:
Mining and Extraction	– crude bitumen mining and extraction
In Situ Thermal Extraction	– in situ thermal extraction of crude bitumen and heavy oil including cyclic steam stimulation (CSS), steam-assisted gravity drainage (SAGD) and other experimental techniques
Upgrading	– crude bitumen and heavy oil upgrading to synthetic crude oil
Oil, Natural Gas and CO_2 Transmission	Combustion and fugitive emissions from the transport and storage of crude oil and natural gas.
Downstream Oil and Gas	Emissions resulting from:
Petroleum Refining	– stationary combustion, onsite transportation, electricity and steam production, fugitive and process emissions from petroleum refining industries
Natural Gas Distribution	– combustion and fugitive emissions from local distribution of natural gas up to and including the natural gas meter
ELECTRICITY	Combustion and process emissions from utility electricity generation, steam production (for sale) and transmission. Excludes utility owned cogeneration at industrial sites. Includes post-meter, unintentional leaks from natural gas consumption.
TRANSPORT	Mobile related emissions including all fossil fuels and non-CO_2 emission from biofuels. Includes post-meter, unintentional leaks from natural gas powered vehicles.
Passenger Transport	Mobile related combustion, process and refrigerant emissions from the vehicles that primarily transport people.
Cars, Light Trucks and Motorcycles	– light duty cars and trucks and motorcycles with a Gross Vehicle Weight Rating (GVWR) less than 3856 kg
Bus, Rail, Marine and Aviation	– all buses and the passenger component of rail, marine and aviation
Freight Transport	Mobile related combustion, process and refrigerant emissions from the vehicles that primarily move cargo or freight.
Heavy Duty Trucks, Rail	– vehicles with a Gross Vehicle Weight Rating (GVWR) greater than or equal to 3856 kg. Also includes the freight component of rail
Aviation and Marine	– cargo component of aviation and all domestic navigation (inclusive of all fishing and military operations)
Other: Recreational, Commercial and Residential	Combustion emissions from the non-industrial use of off-road engines (e.g., ATVs, snowmobiles, personal watercraft), including portable engines (e.g., generators, lawn mowers, chain saws).
HEAVY INDUSTRY	Stationary combustion, onsite transportation, electricity and steam production, and process emissions. Includes post-meter, unintentional leaks from natural gas consumption.
Mining	– metal and non-metal mines, stone quarries, and gravel pits
Smelting and Refining (Non-Ferrous Metals)	– non-ferrous metals (aluminium, magnesium, rare earths and other production)
Pulp and Paper	– pulp and paper (primarily pulp, paper, and paper product manufacturers)
Iron and Steel	– iron and steel (iron ore pelletizing, primary iron production from blast furnace and direct reduced iron [DRI], and primary steel production from electric arc and basic oxygen furnaces)
Cement	– cement and other non-metallic mineral production
Lime and Gypsum	– lime and gypsum product manufacturing
Chemicals, Fertilizers and Biofuel Manufacturing	– chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing) and biofuel manufacturing
BUILDINGS	Stationary combustion and process (i.e. air conditioning) emissions, including post-meter, unintentional leaks from natural gas appliances from:
Service Industry	– service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.; offices, health, arts, accommodation, food, information & cultural; Federal, provincial and municipal establishments; National Defence and Canadian Coast Guard; Train stations, airports and warehouses
Residential	– personal residences (homes, apartment hotels, condominiums and farm houses)
AGRICULTURE	Emissions resulting from:
On Farm Fuel Use	– stationary combustion, onsite transportation and process emissions from the agricultural, hunting and trapping industry (excluding food processing, farm machinery manufacturing, and repair); includes post-meter, unintentional leaks from natural gas consumption
Crop Production	– Application of biosolids and inorganic nitrogen fertilizers, decomposition of crop residues, loss of soil organic carbon, cultivation of organic soils, indirect emissions from leaching and volatilization, field burning of agricultural residues, liming, and urea application
Animal Production	– Animal housing, manure storage, manure deposited by grazing animals, and application of manure to managed soils
WASTE	Non-CO_2 Emissions from biomass resulting from:
Solid Waste	– municipal landfills, dedicated wood waste landfills, and other treatment of municipal solid waste
Wastewater	– municipal and industrial wastewater treatment
Waste Incineration	– municipal solid, hazardous and clinical waste, and sewage sludge incineration
COAL PRODUCTION	Stationary combustion, onsite transportation and fugitive emissions from underground and surface coal mines. Includes post-meter, unintentional leaks from natural gas consumption.
LIGHT MANUFACTURING, CONSTRUCTION AND FOREST RESOURCES	Stationary combustion, onsite transportation, electricity and steam production, and process emissions, including post-meter, unintentional leaks from natural gas consumption from (excluding LULUCF):
Light Manufacturing	– all other manufacturing industries not included in the Heavy Industry category above
Construction	– construction of buildings, highways etc.
Forest Resources	– forestry and logging service industry

In general, an emissions and removals inventory can be defined as a comprehensive account of anthropogenic emissions by sources, and removals by sinks, where and when they occur, in the specified year and country area. It can be prepared using a top-down or bottom-up approach, or a combination thereof. In most cases, a top-down approach is used in Canada's national inventory to provide estimates at a sectoral and provincial/territorial level, without attribution to individual emitters.

Table 1–5 **Summary of Methodology Tiers used in the NIR by Category**

GHG Categories		Methodology Tier
ENERGY		
a.	**Stationary Combustion Sources**	
	Public Electricity and Heat Production	2,3
	Petroleum Refining Industries	2
	Oil and Gas Extraction	2
	Coal Production	2
	Biofuel Manufacturing	2
	Mining and Quarrying	2
	Manufacturing Industries	2,3
	Construction	2
	Commercial and Institutional	2
	Residential	2
	Agriculture and Forestry	2
b.	**Transport**	
	Aviation	2,3
	Road Transportation	2,3
	Railways	1,2
	Marine	1,2
	Other Transportation	2,3
c.	**Fugitive Sources**	
	Coal Mining	2,3
	Oil and Natural Gas	2,3
d.	**CO_2 Transport and Storage**	**1,3**
INDUSTRIAL PROCESSES AND PRODUCT USE		
a.	**Mineral Products**	
	Cement Production	2,3
	Lime Production	2,3
	Mineral Product Use	1,2,3
b.	**Chemical Industry**	
	Ammonia Production	2,3
	Nitric Acid Production	1,2,3
	Adipic Acid Production	1,2,3
	Petrochemical and Carbon Black Production	1,2,3
c.	**Metal Production**	
	Iron and Steel Production	1,2,3
	Aluminium Production	2,3
	Magnesium and Other Metal Production	1,2
d.	**Production and Consumption of Halocarbons, SF_6 and NF_3**	**1,2**
e.	**Non-Energy Products from Fuels and Solvent Use**	**1**
f.	**Other Product Manufacture and Use**	**1,3**
AGRICULTURE		
a.	**Enteric Fermentation**	**1,2**
b.	**Manure Management**	**1,2**
c.	**Agricultural Soils**	**1,2**
d.	**Field Burning of Agricultural Residues**	**1**
e.	**Liming, Urea Application and Other Carbon-Containing Fertilizers**	**1**
WASTE		
a.	**Landfills**	**2**
b.	**Biological Treatment of Solid Waste**	**3**
c.	**Incineration and Open Burning of Waste**	**1,2,3**
d.	**Wastewater Treatment and Discharge**	**2,3**
LAND USE, LAND-USE CHANGE AND FORESTRY		
a.	**Forest Land**	**1,3**
b.	**Cropland**	**1,2**
c.	**Grassland**	**1**
d.	**Wetlands**	**2**
e.	**Settlements**	**2,3**
f.	**Harvested Wood Products**	**3**

The 2006 IPCC Guidelines and 2019 Refinement to the guidelines (IPCC, 2006, 2019) specify tiers that represent the level of methodological complexity and data requirements applied in the emission estimates. Tier 1 is defined as the simplest, Tier 2 is defined as intermediate, and Tier 3 is defined as the most complex. The choice of methodology tier can be based on multiple factors, but it is suggested that higher tier methods are selected for key categories. Category-specific decision trees are available in the 2006 IPCC Guidelines to support these choices. Key categories are summarized in the Executive Summary and available in Annex 1. A summary of the methodology tiers used in the estimation of each GHG category is provided in Table 1–5. For detail on methodologies, refer to Annex 3.

Emissions and removals are usually calculated or estimated using mass balance, stoichiometry or emission factor relationships under average conditions. In many cases, activity data are combined with average EFs to produce a top-down national inventory. Large-scale regional estimates, based on average conditions, are compiled for diffuse sources such as transportation.

Emissions and removals for LULUCF are mainly based on empirical relationships that estimate biological processes, such as decomposition and photosynthesis as influenced by ecological and climatic factors. Managed lands monitored in LULUCF, such as agricultural lands, forests, and land converted to other uses, are sources or sinks that occur over large areas. Processes that cause emissions and removals display considerable spatial and interannual variability, and can also span years or decades. These systems require a combination of repeated measurements and modelling to estimate emissions and removals. Continual vigilance assures that methodologies in the land sector represent the most recent data and scientific understanding of these processes. The need to separate anthropogenic impacts from large natural fluxes, which is unique to these systems, creates an additional challenge.

The current methodologies (Annex 3) and emission factors (Annex 6) are the best available to date, given the existing activity data. Limitations often arise on the use of more accurate methods or EFs due to a lack of activity data. Over time, numerous methods have undergone revision and improvement, and some new sources have been added to the inventory.

Improvements to methodology and data, which consider the results of QA/QC procedures, reviews and verification, are planned and implemented on a continuous basis. Planned improvements are often rolled out over the course of several years. They are carried out with a view to further refine and increase the transparency, completeness, accuracy, consistency and comparability of the national inventory. The resulting changes in data or methods often lead to recalculations of GHG estimates for the entire time series, from 1990 to the most recent year available. For a further discussion of recalculations and improvements, whether planned or implemented, see Chapter 8.

1.3.1. Treatment of Confidentiality Issues

The data used to compile the national inventory are generally taken from publicly available and published sources, but some require confidentiality to be protected. During the preparation of the inventory, procedures are in place to ensure the confidentiality of source data, as required. For instance, some emissions are aggregated to a level that eliminates confidentiality issues: e.g., in certain cases, emissions in the Cropland category are aggregated with neighbouring reporting zones to protect confidential data. These procedures are documented, and confidential source data are protected and archived accordingly.

For data received from Statistics Canada and used to estimate GHG emissions in the Energy and IPPU sectors, confidentiality protocols are applied to the GHG estimates prior to submission to the UNFCCC. This ensures that the statistical aggregates that are released or published do not directly or indirectly identify a person, business or organization, in accordance with the data-sharing agreement between Statistics Canada and ECCC. In addition, for facility-reported data collected directly by ECCC through the GHGRP and used to develop certain inventory estimates, aggregation is applied where necessary to ensure that facility-specific information considered confidential by individual facilities (and appropriately justified) is not disclosed.

1.4. Quality Assurance, Quality Control and Verification

QA/QC and verification procedures are an integral part of the inventory development and submission process. These procedures ensure that Canada will meet the MPGs of transparency, consistency, comparability, completeness and accuracy and, at the same time, continuously improve data and methods to ensure that a credible and defensible inventory is developed.

1.4.1. Overview of Canada's Quality Management System

The development of Canada's GHG inventory is based on a continuous process of data collection, methodological refinement, and review. QA/QC procedures take place at all stages of the inventory development cycle. To ensure that a high-quality inventory is produced every year, a national inventory quality management system has been developed and implemented for the annual compilation and publication of the national GHG inventory. The quality management system

includes a QA/QC plan; planning and governance modules; documentation and archiving processes; a standardized process for implementing methodological changes; and a timeline for completing the various NIR-related tasks and activities. Further details on QA/QC and verification activities are available in Chapter 3 to Chapter 7.

1.4.2. Canada's Quality Assurance/Quality Control Plan

Canada's QA/QC plan uses an integrated approach to inventory quality management and focuses on the continuous improvement of emission and removal estimates. It is designed so that QA/QC and verification procedures are implemented throughout the inventory development process, from initial data collection to the determination of emission and removal estimates, to the publication of the NIR in English and French. QC checks are completed during each stage and archived along with other procedural and methodological documentation, by inventory categories and submission years.

1.4.2.1. Quality Control Procedures

Quality control procedures consist of routine technical checks to 1) measure and control the quality of the inventory; 2) ensure data consistency, integrity, correctness and completeness; and 3) identify and address errors and omissions. The QC procedures used during the inventory development cycle target a wide range of inventory processes, including data acquisition and handling, application of approved procedures and methods, and calculation of estimates and documentation.

A series of systematic Tier 1 QC checks in line with Volume 1, section 6.6, of the 2006 IPCC Guidelines (IPCC, 2006) are performed annually by inventory experts in the key categories and across sectors. Prior to submission, cross-cutting QC checks are conducted on the final NIR documents (English and French), quality checks are performed on the data entered into the CRT online tool by the national inventory compiler and reviewer, and the tables are reviewed by the sector experts, for the entire time series of CRT. The category-specific Tier 1 QC procedures complement the general inventory QC procedures and are directed at specific types of data. These procedures require knowledge of the specific category, including methodologies, types of data available and the parameters associated with emissions or removals. To facilitate these Tier 1 checks, inventory experts develop annual QC plans specific to each sector and require attestations of completion from section managers when reaching the compilation stage of inventory development. A Tier 2 QC assessment is an opportunity to critically review a specific category or categories. A comprehensive assessment is required to ensure that the category will remain current and relevant for several years beyond the analysis year. This investigation is typically broad and uses a variety of sector-specific approaches, including assessments of the continued applicability of methods, EFs, activity data, uncertainty and others, and lays the foundation for future activities by developing and prioritizing recommendations for improvement. The Tier 2 QC checks may be documented with a standard checklist or an in-depth study to provide a comprehensive assessment as part of continuous improvement activities.

1.4.2.2. Quality Assurance Procedures

In accordance with the 2006 IPCC Guidelines (IPCC, 2006), QA activities consist of a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process, to be performed in parallel with QC procedures. The QA process helps to ensure that the inventory represents the best possible estimates of emissions and removal based on the current state of scientific knowledge and data availability and enhances the effectiveness of the QC program. Selected underlying data and methods are independently assessed each year by various expert groups and individuals from industry, provincial governments, academia and other federal government departments.

1.4.2.3. Verification

In accordance with the 2006 IPCC Guidelines (Volume 1, Chapter 6.10 of IPCC, 2006), inventory verification activities typically consist of comparing inventory estimates with independent estimates to either confirm the reasonableness of the inventory estimates or identify major discrepancies. Appropriate comparisons depend on the availability of data (which may include data sets, EFs or activity data) that can be meaningfully compared with inventory estimates. For this reason, verification activities are often conducted on subsets of inventory categories. Consistency between the national inventory and independent estimates increases the confidence level and reliability of the inventory estimates.

1.4.3. Planning and Prioritization of Improvements

Inventory improvements can come from a variety of external and internal sources. For example, at the end of the annual in-depth review of Canada's GHG inventory, technical expert review teams (TERTs) provide feedback and recommendations on any methodological or procedural issues encountered. These recommendations usually refer to instances where the adherence of the inventory to the guiding principles of transparency, consistency, comparability, completeness and accuracy could be improved. In addition to the improvements identified by the TERTs, members of the GHG inventory team are also encouraged to use their knowledge and experience in developing inventory estimates to identify areas for improvement in the future, based on evolving science, new and innovative modelling approaches and new sources of activity data.

Canada identifies, tracks, plans and prioritizes improvements to both the emission estimates (including the underlying activity data, EFs and methodologies) and to the components of the national inventory arrangements (including the QA/QC plan, data infrastructure and management, archiving processes, uncertainty analysis and key category assessment). Improvements are prioritized by respective teams based on the outcomes of QA/QC and verification activities, key category and uncertainty analyses, resource availability and assessment of potential impacts. Additional information on inventory improvements can be found in Chapter 8.

1.4.4. The Greenhouse Gas Reporting Program

In March 2004, the Government of Canada established the GHGRP to collect GHG emissions information annually from facilities across the country. Under this mandatory reporting program, requirements are described in the legal notice issued under section 46(1) of the *Canadian Environmental Protection Act, 1999* (Canada, 1999) and published biennially in the *Canada Gazette*.[12] The GHGRP, developed and administered by ECCC, allows the Government of Canada to continuously track GHG emissions from individual facilities to inform the public, improve the national GHG inventory and guide regulatory initiatives.

Specific requirements under the GHGRP were changed or expanded progressively over two years (2017 and 2018) in order to enable the direct use of the reported data in the national GHG inventory, increase the consistency and comparability of GHG data across jurisdictions, and obtain a more comprehensive picture of Canadian facility-level emissions. Starting in 2017, the reporting threshold was lowered to require all facilities with annual GHG emissions exceeding 10 kt CO_2 eq. to report their emissions, and new requirements were added for any facility involved in CO_2 capture, transport, injection and/or geological storage activities to report specified information about these activities. Facilities in 13 industry sectors (complete list available on the GHGRP website) were also required to start using prescribed methods outlined in the Canada's Greenhouse Gas Quantification Requirements manual (ECCC, 2023b) to quantify their emissions and to provide additional information on their calculations. Starting in 2022, additional program changes were introduced; the expanded requirements for the sectors and activities identified above were maintained while some changes designed to improve the integration of facility-reported data (FRD) into the national GHG inventory were implemented. The notice requiring the reporting of 2024 and 2025 emissions was amended in December 2025 to extend reporting to 2026. ECCC continues to assess potential changes under the GHGRP and further expansion in future years.

Facilities not covered by the expansion can choose the quantification methodologies most appropriate for their particular industry or application. However, these emission estimation methods must be consistent with the guidelines developed by the IPCC and adopted by the UNFCCC for the preparation of national GHG inventories. Voluntary submissions from facilities with GHG emissions below the 10 kt reporting threshold are also accepted.

To date, facility-reported GHG information has been collected and published by the GHGRP for the period 2004 to 2024. In 2024, a total of 1879 facilities (mostly industrial or large manufacturing operations) reported their GHG emissions to the program. The GHGRP website[13] provides public access to this GHG emission information (e.g., emission totals by gas by facility).

It is important to note that the GHGRP applies to specific emission sources at facilities and does not cover all sources of GHG emissions (e.g., road transportation, residential fuel combustion, and agricultural sources), while the NIR is a complete accounting of all GHG sources and sinks in Canada. In 2024, total facility-reported GHG emissions represented 44% of Canada's total GHG emissions, which was 685 Mt, and 65% of Canada's industrial GHG emissions. The proportion of industrial emissions represented by FRD in each province varies significantly, depending on the size and number of facilities in each province that have emissions above the 10 kt reporting threshold (Figure 1–5).

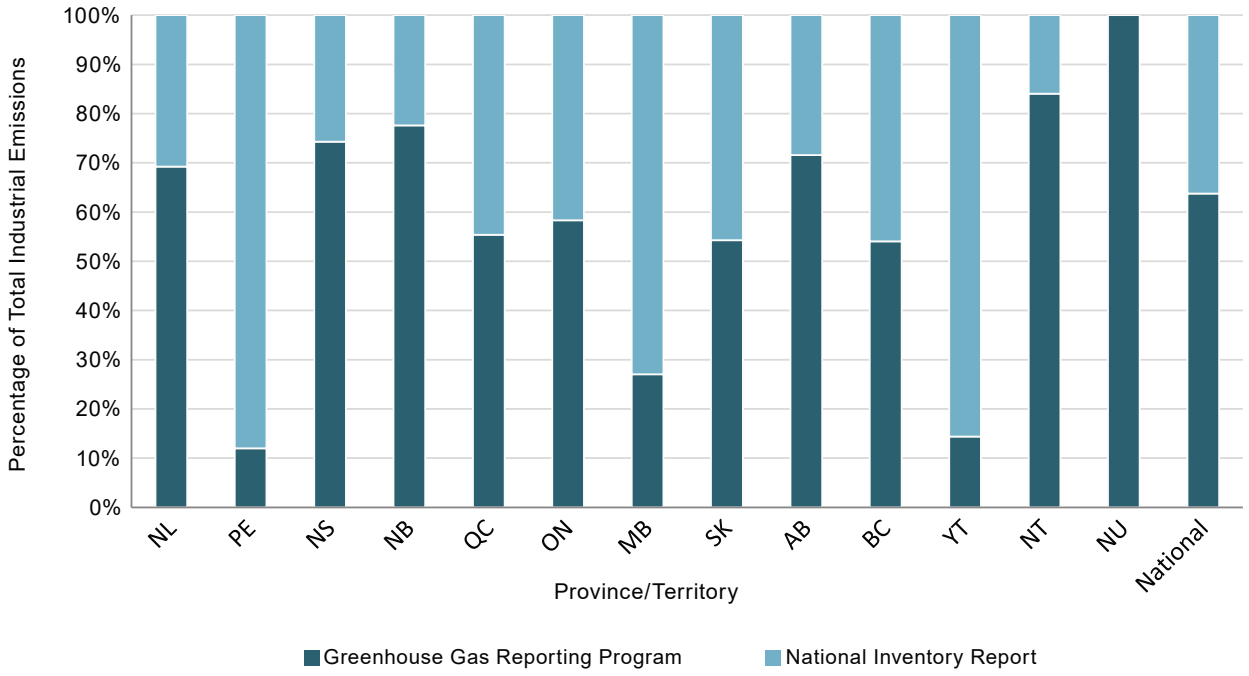
The GHGRP provides Canadians with information about large GHG emitters across Canada and yearly changes in their emission levels, which is also shared with provincial and territorial jurisdictions. In accordance with the 2006 IPCC Guidelines (IPCC, 2006), FRD—which include all required data and supporting information reported by those facilities subject to the expanded reporting requirements (see Schedule 3 of the notice)[14]—are used by inventory experts for improvements when these data are assessed to be of good quality (see Table 1–6). Based on the information provided in Table 1–6, it is estimated that approximately 21% of the FRD collected by the GHGRP is used in some manner to generate specific NIR estimates. While not explicitly included in the table, additional FRD are utilized for various activities such as quality control and analysis.

12 The notice published in the *Canada Gazette* requiring the reporting of 2024 and 2025 emissions information can be found at: https://gazette.gc.ca/rp-pr/p1/2023/2023-12-09/html/sup1-eng.html.

13 The GHGRP website can be found at: https://www.canada.ca/ghg-reporting.

14 The notice that required the reporting of 2024 and 2025 emissions information can be found at : https://gazette.gc.ca/rp-pr/p1/2023/2023-12-09/html/sup1-eng.html.

Figure 1–5 **2024 Facility-Reported Emissions as a Percentage of Industrial Greenhouse Gas Emissions by Province and Territory**



Notes:
In this figure, Canada's industrial GHG emissions include the following GHG categories from the *National Inventory Report 1990–2024: Greenhouse Gas Sources and Sinks in Canada*: Stationary Combustion Sources (except Residential), Other Transportation, Fugitive Sources, Industrial Processes and Product Use, and Waste.

The objective of using FRD (collected under the GHGRP) in the national inventory is to help improve the quality of the inventory estimates by taking into account national circumstances such as industry-specific operations and process changes (e.g., process-specific or fuel-specific emission factors) where possible, in accordance with the 2006 IPCC Guidelines and the 2019 IPCC Refinement to the 2006 IPCC Guidelines (IPCC, 2006, 2019). Continuous improvements are underway, including examining approaches for integrating FRD in the inventory and addressing time-series consistency and completeness issues, considering the coverage of each specific industry, since the collection of additional data under the GHGRP expansion only started with the 2017 data for a subset of industries as noted above.

Prior to the integration of any FRD, several QA/QC assessment and analysis processes are performed to ensure the quality of the reported emission estimates in terms of transparency, accuracy, completeness, consistency and comparability. In response to the UNFCCC review recommendations from the 2021 cycle, explanations were added to the corresponding categories to indicate that the time-series consistency of the reported GHG emission estimates was addressed where FRD were used. In each category, the most suitable method described in the 2006 IPCC Guidelines (Volume 1, Chapter 5 of IPCC, 2006) was applied. More details are provided in the corresponding sections in Chapter 3 (Energy), Chapter 4 (IPPU) and Chapter 7 (Waste). Since FRD cover a significant part of industrial emissions in some provinces and territories (Figure 1–5), the enhanced data of this type that have been collected to date under the GHGRP expansion will continue to be reviewed, with the aim of its further integration into the NIR in the coming years.

For more information on the facility-level data reported under Canada's GHGRP, including changes observed in facility-reported emissions, see *Facility Greenhouse Gas Reporting Program: Overview of 2024 Reported Emissions* (ECCC, 2026).

Table 1–6 **Use of Facility-Reported Data Collected Under the GHGRP in the NIR by Corresponding IPCC Sector and CRT Category**

IPCC Sector and CRT Category	FRD Obtained Under the GHGRP	Uses in NIR	NIR Reference for Additional Details
ENERGY			
1.A.1.a.i Electricity generation, solid fuels	Amount of CO_2 captured	Direct reporting	• section 3.4 • CRT Table 1.A(a)s1
1.A.1.c Manufacture of solid fuels and other energy industries	Combustion emissions reported in Oil Sands category	Used to disaggregate stationary combustion emissions from Oil and Gas Extraction and Mining categories; fuel consumption is modelled and adjusted so that resultant emissions align with reporting by oil sands facilities	• section 3.2 • economic sector emission data (see Open Data website)
1.A.2.f Non-metallic minerals	• Quantities of mixed waste fuel used • CO_2 emissions	• Direct reporting • Input data for emission estimates	• section 3.2 • CRT Table 1.A(a)s2
1.B.2.c.ii.1 Flaring – Oil	Refinery reported flaring emissions	Input data for emission estimates	• section 3.3.2 • CRT Table 1.B.2
1.B.2.c Oil, natural gas and other emissions from energy production – Venting and Flaring	Amount of CO_2 captured during petroleum refining and crude bitumen upgrading activities	Direct reporting	• section 3.4 • CRT Table 1.B.2
1.C.1 Transport of CO_2	Amount of captured CO_2 transported by pipelines	Input data for calculated values	• section 3.4 • CRT Table 1.C
1.C.2 CO_2 injection and storage	Amount of captured CO_2 injected or stored	Input data for calculated values	• section 3.4 • CRT Table 1.C
IPPU			
2.A.1 Cement production	• CO_2 emissions • Clinker production, CaO content of clinker • CKD quantities, CaO content of CKD	• Direct reporting • Input data for emission estimates • Quality control	section 4.2.1
2.A.2 Lime production	• CO_2 emissions • Lime production, CaO and MgO contents of lime • By-product and waste quantities, CaO and MgO contents of by-product and waste	• Direct reporting • Input data for emission estimates • Quality control	section 4.2.2
2.A.4.d Other Limestone and Dolomite Use	• Quantities of limestone used in pulp and paper production • Quantities, carbon contents of limestone and dolomite used as flux in iron and steel production	• Input data for emission estimates • Quality control	section 4.2.3
2.B.1 Ammonia production	• Natural gas feedstock, carbon contents of natural gas • Urea production, CO_2 recovered for urea production • Amount of CO_2 captured	• Input data for emission estimates • Quality control	section 4.3.1
2.B.2 Nitric acid production	• Nitric acid production • N_2O emission factors • N_2O emissions	• Input data for emission estimates • Quality control	section 4.3.2
2.C.1 Iron and steel production	• Iron, steel and pellet production • Carbon contents of pig iron, crude steel produced in basic oxygen furnace (BOF) and electric arc furnace (EAF), and scrap steel • Emission factors for coke use, and electrode consumption in BOF and EAF	• Input data for emission estimates • Quality control	section 4.4.1
2.C.3 Aluminium production	• Aluminium production • CO_2, CF_4, C_2F_6 and SF_6 emissions	Direct reporting	section 4.4.3
2.C.4 Magnesium Production	Industrial process emissions of SF_6 (confirmed to be used as a cover gas for magnesium casting)	Direct reporting	section 4.4.4
WASTE			
5.C.1 Waste incineration	GHG emissions	Direct reporting	• section 7.5 • section A3.6.3
5.D Wastewater treatment	GHG emissions	Direct reporting of industrial wastewater emissions	• section 7.6 • section A3.6.4

1.5. Uncertainty Assessment

While national GHG inventories should be accurate, complete, comparable, transparent and consistent, estimates will always inherently involve some uncertainty. Uncertainties[15] in the inventory estimates may be caused by systematic and/or random uncertainties in the input parameters or estimation models. Quantifying and reducing uncertainty may require in-depth reviews of the estimation models, improvements to the activity data regimes and the evaluation of EFs and other model parameters. In a limited number of cases, uncertainty may be reduced through a validation exercise using an independent data set, such as the total emissions reported by individual facilities in each industry sector. The 2006 IPCC Guidelines (IPCC, 2006) specify that the primary purpose of providing quantitative uncertainty information is to assist in setting priorities for the improvement of future inventories and to guide decisions about which methods to use. Typically, the uncertainties associated with trends and the national totals are much lower than those associated with individual gases and sectors.

Annex 2 presents the uncertainty assessment for Canadian GHG emissions for the base year, the latest year and the trend. While more complex methods (Approach 2) were used in some cases to develop uncertainty estimates at the sector or category level, the simple (Approach 1) error propagation method was employed for the whole inventory to combine these uncertainties, using Table 3.3 in the 2006 IPCC Guidelines (IPCC, 2006). Separate analyses were conducted for the overall inventory with and without LULUCF. For further details on the uncertainty related to specific sectors, see the section on uncertainty in Chapter 3 to Chapter 7.

According to the error propagation method, the uncertainty for the national inventory, not including the LULUCF sector, is ±3% for both the base year and 2024. The five emission source categories that contribute the most to uncertainty at the national level, for 2024, when LULUCF is not included, were:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
2. Agriculture – Enteric Fermentation, CH_4
3. Agriculture – Direct Agriculture Soils, N_2O
4. Agriculture – Indirect Agriculture Soils, N_2O
5. Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries, CH_4

When the LULUCF emissions and removals are included, the uncertainty in the national total was found to be ±7% for 2024 and ±11% for the base year. For 2024, the top five contributors influencing the national uncertainty, when LULUCF is included, were:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
2. Agriculture – Enteric Fermentation, CH_4
3. Agriculture – Direct Agriculture Soils, N_2O
4. Agriculture – Indirect Agriculture Soils, N_2O
5. Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries, CH_4

1.6. Completeness Assessment

The national GHG inventory serves as a comprehensive assessment of anthropogenic GHG emissions and removals in Canada. Overall, this NIR is a complete inventory of emissions and removals of the seven GHGs required under the MPGs. However, a small minority of emissions and removals for some categories have not been estimated or have been included within other categories for the following reasons:

- sources/sinks that are not occurring in Canada
- data unavailability at the required category level
- methodological issues specific to national circumstances
- emission estimates that are considered insignificant[16]

Efforts are continuously being made to identify new or improved data sources or methodologies to provide estimates for those categories that are “not estimated.” Further details on the completeness of the inventory, including the source/sink category, notation key (either “NE” – not estimated or “IE” – included elsewhere) and explanation can be found in Table 9 of the corresponding CRTs[17] associated with this NIR.

15 Uncertainty is the lack of knowledge of the true value of a variable that can be described as a probability density function characterizing the range and likelihood of possible values (IPCC, 2006).

16 Emissions should only be considered insignificant if the likely level of emissions is less than 0.05% of total national GHG emissions, and does not exceed 500 kt CO_2 eq. The total national aggregate of estimated emissions for all gases and categories considered insignificant shall remain below 0.1% of the total national GHG emissions (as stated in the MPGs, paragraph 32).

17 https://unfccc.int/ghg-inventories-annex-i-parties/2026

CHAPTER 2

GREENHOUSE GAS EMISSIONS TRENDS

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2.1. Summary of GHG Emissions Trends

In 2024, the most recent year for which data are available for this report, Canada's greenhouse gas (GHG) emissions were 685 megatonnes of carbon dioxide equivalent (Mt CO_2 eq), excluding the Land Use, Land-Use Change and Forestry (LULUCF) sector.[1,2] Emissions decreased by 78 Mt (10%) from 2005, and by 2.2 Mt (0.3%) from 2023, with emissions remaining 63 Mt (8.5%) below pre-pandemic 2019 levels (Figure 2–1).[3] In terms of the overall trend, Canada's 2024 GHG emissions were 77 Mt (13%) above 1990 levels. Main emission trends and drivers since 1990 and 2005 are discussed in this chapter, while subsector-specific information is presented in each sectoral chapter (3 to 7).

Over the last 10 years (2015–2024), total emissions decreased by 59 Mt or 7.9%. Since 2015, significant decreases occurred from Oil and Natural Gas Fugitive Sources (-33 Mt or -34%) as well as Public Electricity and Heat Production (-25 Mt or -31%). These decreases can be explained mostly by methane emission reductions from conventional oil and gas activities (more specifically from decreased venting) as well as the phase-out of coal-fired electricity generation and increased electricity generation from renewable sources. In contrast, from 2015 to 2024, Oil and Gas Extraction combustion emissions increased by 12 Mt (12%). Emissions from some transport sources also increased, notably Light-Duty Gasoline Trucks by 6.2 Mt (13%) and Other Transportation[4] by 3.4 Mt (6.8%). These increases can be attributed mainly to continued production growth in Canada's oil sands operations and an increase in the off- and on-road vehicle fleet, leading to more kilometres driven overall.

When observing long-term emission trends, large-scale events can have a significant impact on a portion of the time series analysis and should be considered. The years 2020 and 2021 were marked by the COVID-19 pandemic. This coincides with an abrupt decrease of 67 Mt (9.0%) in total GHG emissions between 2019 and 2020, with almost half of the decrease from Transport (-32 Mt or -15%). The year after, between 2020 and 2021, emissions increased slightly by 10 Mt (1.5%) and between 2021 and 2022 they continued to increase by 4.5 Mt (0.7%), while remaining below their 2019 pre-pandemic levels. Finally, between 2022 and 2024, emissions decreased by 11 Mt (1.6%). Impacts of the pandemic, more pronounced in 2020, are now harder to distinguish in the latest years. Notwithstanding the abrupt decrease between 2019 and 2020, and recent year changes, the general breakdown of emissions by sector (IPCC or economic) has not substantially changed over time.

In general, year-to-year fluctuations are superimposed over trends observed over a longer period. During the period covered in this report, Canada's economy grew more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (GHGs per gross domestic product [GDP]) has continued to decline in 2024, by 48% since 1990 and by 37% since 2005 (Figure 2–2 and Table 2–1). The decline in emissions intensity can be attributed to factors such as fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.

1 Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO_2 eq.

2 National totals presented in Canada's official GHG inventory do not include Land Use, Land-Use Change and Forestry (LULUCF) sector emissions or removals.

3 Throughout this report, data are presented in the form of rounded figures. However, all calculations (including those done to obtain percentages) were performed using unrounded data.

4 Other Transportation includes consumption of fuels (excluding the biogenic CO_2 emissions from ethanol and biodiesel) by mobile combustion devices not licensed to operate on roads, as well as pipeline transportation and distribution of crude oil, natural gas, refined petroleum and other products.

Canada accounts for approximately 1.4% of global GHG emissions (Climate Watch, 2026 for the year 2022), making Canada the 11th largest emitter of GHGs. While Canada's per capita emissions have declined since 2005 from 24 t CO_2 eq/capita to 17 t CO_2 eq/capita in 2024 (StatCan, n.d.[b]), it is also one of the world's highest per capita emitters. The complete datasets of Canadian GHG emissions from 1990 to 2024 can be found on open.canada.ca.[5]

Figure 2–1 **Canadian GHG Emission Trend (excluding the Land Use, Land-Use Change and Forestry Sector) (1990–2024)**

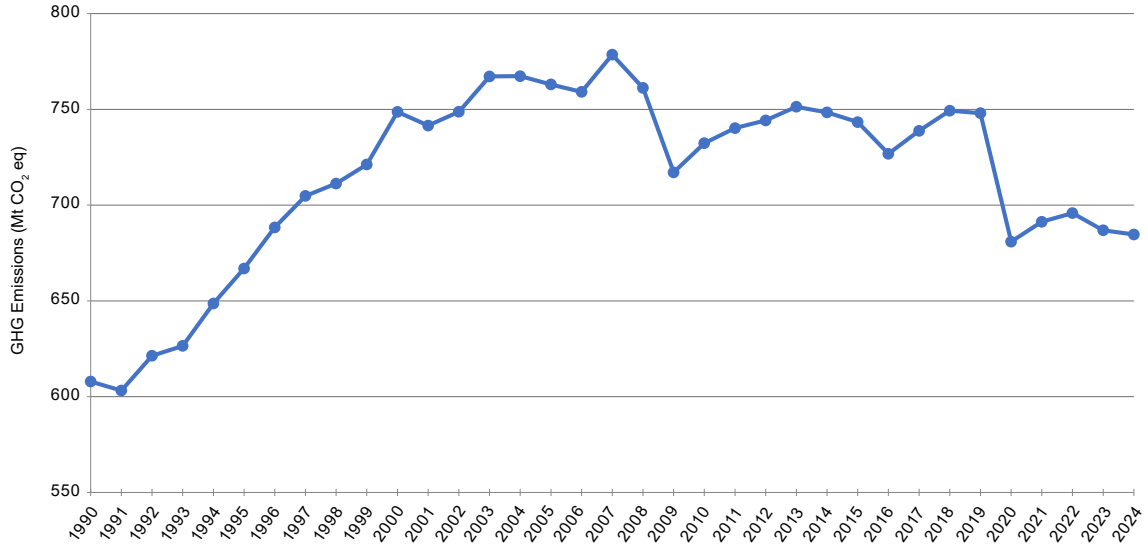
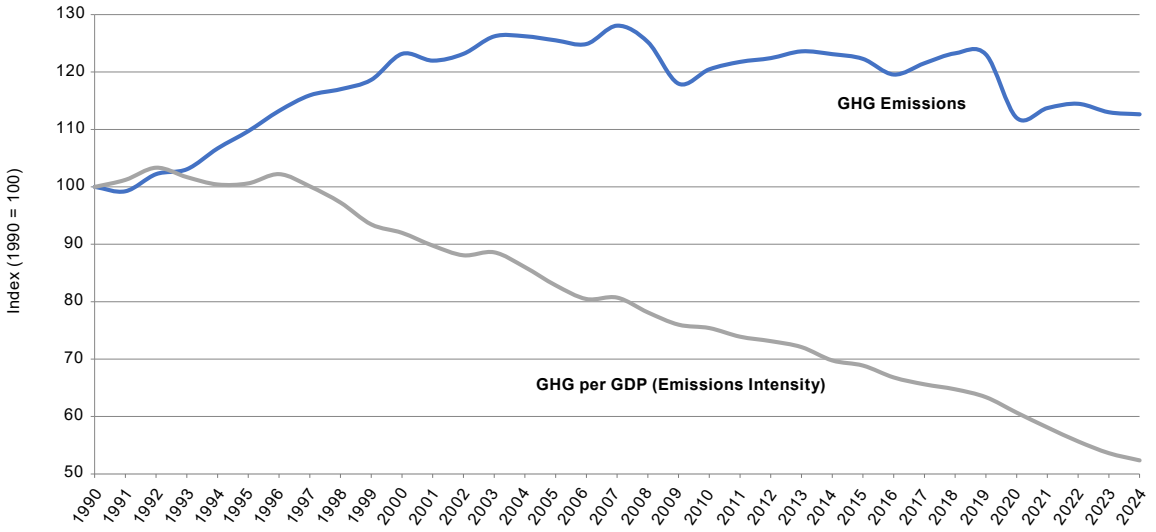


Figure 2–2 **Indexed Trend in GHG Emissions and GHG Emissions Intensity (excluding the Land Use, Land-Use Change and Forestry Sector) (1990–2024)**



Note:
GDP data source: StatCan (n.d.[a])

5 http://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

Table 2–1 **Trends in GHG Emissions and Economic Indicators, Selected Years**

Year	1990	2005	2019	2020	2021	2022	2023	2024
Total GHG Emissions (Mt)	**608**	**763**	**748**	**681**	**691**	**696**	**687**	**685**
Change since 2005 (%)	NA	NA	-2.0%	-11%	-9.4%	-8.8%	-10%	-10%
Change since 1990 (%)	NA	26%	23%	12%	14%	14%	13%	13%
GDP[a] (Billion 2017$)	**1 156**	**1 751**	**2 244**	**2 133**	**2 262**	**2 376**	**2 435**	**2 486**
Change since 2005 (%)	NA	NA	28%	22%	29%	36%	39%	42%
Change since 1990 (%)	NA	51%	94%	85%	96%	106%	111%	115%
GHG Intensity (Mt/$B GDP)	**0.53**	**0.44**	**0.33**	**0.32**	**0.31**	**0.29**	**0.28**	**0.28**
Change since 2005 (%)	NA	NA	-24%	-27%	-30%	-33%	-35%	-37%
Change since 1990 (%)	NA	-17%	-37%	-39%	-42%	-44%	-46%	-48%

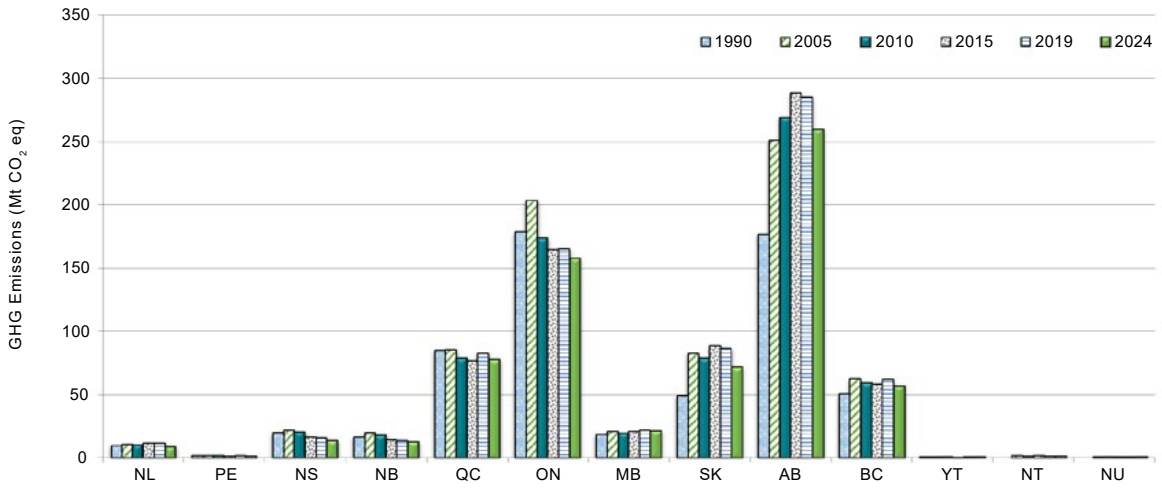
Notes:
NA = Not applicable
a. Data source: StatCan (n.d.[a])

2.1.1. Provincial and Territorial GHG Emissions Trends

Emissions vary significantly by province and territory because of such factors as population, energy sources and economic structure (Figure 2–3). All else being equal, economies based on resource extraction will tend to have higher emission levels than service-based economies. Likewise, provinces that rely on fossil fuels for electricity generation emit relatively higher amounts of GHGs than those that rely more on low-emitting energy sources, such as hydroelectricity.

Historically, Alberta and Ontario have been the highest-emitting provinces, accounting for 38% and 23% of Canada's total emissions in 2024, respectively. Since 2005, emission patterns in these two provinces have diverged. Those in Alberta have increased by 9.0 Mt (3.6%) since 2005, primarily because of the expansion of oil and gas operations offset by the closure of coal-fired power plants (Table 2–2). Specifically, Oil and Gas emissions in Alberta have increased by 34 Mt but have been offset by decreases in Electricity (-30 Mt). In contrast, Ontario's emissions have decreased by 46 Mt (22%) since 2005, including a decrease of 24 Mt in the Electricity sector, owing primarily to the closure of coal-fired electricity generation plants. Overall, emissions have decreased in eight provinces and one territory between 2005 and 2024, while emissions of two provinces and two territories have increased. For most provinces and territories, the 1990-2024 trends are similar to the 2005-2024 trends, except for Saskatchewan and British Columbia (Table 2–2).

Figure 2–3 **GHG Emissions by Province and Territory, Selected Years**



Note: The year 2019 has been included and 2020 excluded, as significant emission drops happened during the first pandemic year and do not represent emission trends of the time series.

Table 2–2 **GHG Emissions by Province and Territory, Selected Years**

Province and Territory	GHG Emissions (Mt CO_2 eq)										Change (%)	
	1990	2005	2010	2015	2019	2020	2021	2022	2023	2024	1990–2024	2005–2024
CANADA	**608**	**763**	**732**	**743**	**748**	**681**	**691**	**696**	**687**	**685**	**13%**	**-10%**
NL	9.7	11	10	11	11	9.1	8.2	8.3	8.1	8.6	-12%	-19%
PE	1.8	1.9	1.8	1.5	1.6	1.6	1.6	1.6	1.5	1.5	-17%	-21%
NS	20	22	20	16	16	14	14	14	13	14	-30%	-38%
NB	16	20	18	14	13	11	12	13	11	13	-21%	-36%
QC	85	85	79	77	82	75	78	79	78	78	-8.6%	-9.1%
ON	179	203	174	164	165	149	152	158	160	158	-12%	-22%
MB	18	21	19	21	22	21	21	22	21	21	17%	2.7%
SK	49	83	79	89	87	75	77	75	73	72	46%	-13%
AB	177	251	269	289	285	265	267	262	260	260	47%	3.6%
BC	51	62	59	58	62	58	59	60	58	57	12%	-9.1%
YT	0.55	0.56	0.65	0.53	0.69	0.59	0.65	0.66	0.67	0.72	32%	28%
NT	NA	1.7	1.5	1.6	1.4	1.2	1.3	1.4	1.4	1.3	NA	-22%
NU	NA	0.64	0.65	0.69	0.90	0.78	0.83	0.84	0.88	0.93	NA	44%

Notes:
Totals may not add up due to rounding.
NA = Not applicable

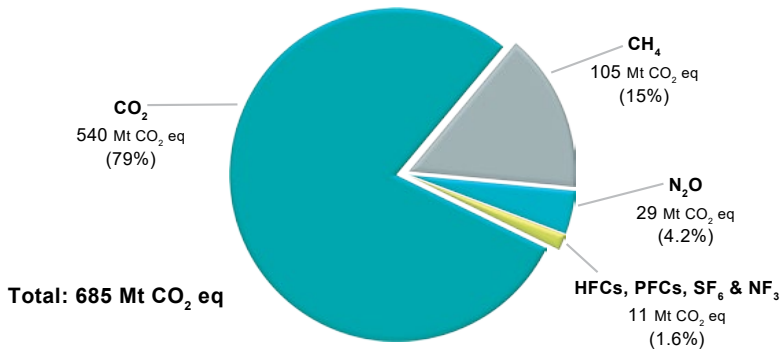
2.2. GHG Emissions Trends by Gas

Canada's GHG emissions profile is similar to most industrialized countries, in that carbon dioxide (CO_2) is the largest contributor to total emissions, accounting for 540 Mt or 79% of total emissions in 2024 (Figure 2–4). As a result, trends in CO_2 emissions follow the same pattern as total GHG emissions, as described in the previous section (Figure 2–1). Most of the CO_2 emissions in Canada result from the combustion of fossil fuels. Canada's emissions of methane, nitrous oxide and fluorinated gases are described below (Table 2–3).

Methane (CH_4)

Methane (CH_4) emissions in 2024 amounted to 105 Mt of CO_2 eq or 15% of Canada's total. These CH_4 emissions consist largely of fugitive emissions from oil and natural gas systems (46 Mt or 44%), agriculture (31 Mt or 30%), and landfills (municipal solid waste and industrial wood waste landfills) (19 Mt or 18%). Total CH_4 emissions increased steadily from 1990, peaking in 2006 at 154 Mt (44% increase), fluctuated until 2014, which was followed by periods of significant declines in emissions to reach the lowest level reported in 2024 (Figure 2–5).

Figure 2–4 **Breakdown of Canada's Emissions by GHG (2024)**



Note: Totals may not add up due to rounding.

Table 2–3 2024 GHG Emissions for Canada by Gas and by IPCC Sector

GHG Source Category		Greenhouse Gases							
		CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3	TOTAL
Global Warming Potential		1	28	265	varies[a]	varies[a]	23 500	16 100	NA
Unit		kt	kt CO_2 eq						
TOTAL[b]		**540 000**	**105 397**	**28 628**	**9 679**	**568**	**432**	**0.58**	**684 704**
ENERGY		**494 703**	**53 587**	**4 194**	**-**	**-**	**-**	**-**	**552 485**
a.	**Stationary Combustion Sources**	**291 252**	**4 465**	**1 819**	**-**	**-**	**-**	**-**	**297 536**
	Public Electricity and Heat Production	56 798	327	356	-	-	-	-	57 481
	Petroleum Refining Industries	14 597	9	26	-	-	-	-	14 632
	Oil and Gas Extraction	104 851	3 160	560	-	-	-	-	108 571
	Coal Production	526	0.28	2	-	-	-	-	529
	Biofuel Manufacturing	802	0.73	6	-	-	-	-	808
	Mining and Quarrying	5 264	3	27	-	-	-	-	5 294
	Manufacturing Industries	37 550	66	377	-	-	-	-	37 993
	Construction	1 545	0.78	12	-	-	-	-	1 558
	Commercial and Institutional	32 242	22	184	-	-	-	-	32 448
	Residential	33 667	874	246	-	-	-	-	34 787
	Agriculture and Forestry	3 411	2	23	-	-	-	-	3 436
b.	**Transport[c]**	**185 359**	**1 301**	**2 283**	**-**	**-**	**-**	**-**	**188 943**
	Aviation	8 002	6	62	-	-	-	-	8 070
	Road Transportation	117 222	199	954	-	-	-	-	118 375
	Railways	5 258	9	580	-	-	-	-	5 847
	Marine	3 389	9	26	-	-	-	-	3 424
	Other Transportation	51 487	1 079	661	-	-	-	-	53 227
c.	**Fugitive Sources**	**18 092**	**47 821**	**93**	**-**	**-**	**-**	**-**	**66 006**
	Coal Mining	-	1 367	-	-	-	-	-	1 367
	Oil and Natural Gas	18 092	46 454	93	-	-	-	-	64 639
d.	**CO_2 Transport and Storage**	**0.65**	**-**	**-**	**-**	**-**	**-**	**-**	**0.65**
INDUSTRIAL PROCESSES AND PRODUCT USE		**41 798**	**110**	**697**	**9 679**	**568**	**432**	**0.58**	**53 284**
a.	**Mineral Products**	**8 472**	**-**	**-**	**-**	**-**	**-**	**-**	**8 472**
	Cement Production	6 895	-	-	-	-	-	-	6 895
	Lime Production	1 282	-	-	-	-	-	-	1 282
	Mineral Product Use	295	-	-	-	-	-	-	295
b.	**Chemical Industry**	**5 342**	**108**	**141**	**-**	**-**	**-**	**-**	**5 590**
	Ammonia Production	2 291	-	-	-	-	-	-	2 291
	Nitric Acid Production	-	-	129	-	-	-	-	129
	Adipic Acid Production	-	-	-	-	-	-	-	-
	Petrochemical and Carbon Black Production	3 051	108	12	-	-	-	-	3 170
c.	**Metal Production**	**15 669**	**3**	**-**	**-**	**529**	**297**	**-**	**16 499**
	Iron and Steel Production	10 238	3	-	-	-	-	-	10 241
	Aluminium Production	5 430	-	-	-	529	0.28	-	5 960
	Magnesium and Other Metal Production	0.07	-	-	-	0.04	297	-	297
d.	**Production and Consumption of Halocarbons, SF_6 and NF_3[d]**	**-**	**-**	**-**	**9 679**	**17**	**29**	**0.58**	**9 725**
e.	**Non-Energy Products from Fuels and Solvent Use**	**12 315**	**-**	**-**	**-**	**-**	**-**	**-**	**12 315**
f.	**Other Product Manufacture and Use**	**-**	**-**	**556**	**-**	**22**	**106**	**-**	**684**
AGRICULTURE		**3 415**	**31 174**	**21 814**	**-**	**-**	**-**	**-**	**56 403**
a.	**Enteric Fermentation**	**-**	**26 390**	**-**	**-**	**-**	**-**	**-**	**26 390**
b.	**Manure Management**	**-**	**4 746**	**3 439**	**-**	**-**	**-**	**-**	**8 186**
c.	**Agricultural Soils**	**-**	**-**	**18 366**	**-**	**-**	**-**	**-**	**18 366**
	Direct Sources	-	-	14 520	-	-	-	-	14 520
	Indirect Sources	-	-	3 845	-	-	-	-	3 845
d.	**Field Burning of Agricultural Residues**	**-**	**38**	**9**	**-**	**-**	**-**	**-**	**47**
e.	**Liming, Urea Application and Other Carbon-Containing Fertilizers**	**3 415**	**-**	**-**	**-**	**-**	**-**	**-**	**3 415**
WASTE		**84**	**20 525**	**1 922**	**-**	**-**	**-**	**-**	**22 531**
a.	**Landfills**	**-**	**19 149**	**-**	**-**	**-**	**-**	**-**	**19 149**
	Municipal Solid Waste Landfills	-	18 446	-	-	-	-	-	18 446
	Industrial Wood Waste Landfills	-	703	-	-	-	-	-	703
b.	**Biological Treatment of Solid Waste**	**-**	**309**	**300**	**-**	**-**	**-**	**-**	**609**
c.	**Incineration and Open Burning of Waste**	**71**	**3**	**74**	**-**	**-**	**-**	**-**	**147**
d.	**Wastewater Treatment and Discharge**	**14**	**1 063**	**1 548**	**-**	**-**	**-**	**-**	**2 626**
	Municipal Wastewater Treatment and Discharge	-	881	1 514	-	-	-	-	2 395
	Industrial Wastewater Treatment and Discharge	14	182	35	-	-	-	-	231
LAND USE, LAND-USE CHANGE AND FORESTRY		**2 350**	**1 784**	**215**	**-**	**-**	**-**	**-**	**4 350**
a.	**Forest Land**	**-1 452**	**146**	**94**	**-**	**-**	**-**	**-**	**-1 212**
b.	**Cropland**	**-3 812**	**182**	**79**	**-**	**-**	**-**	**-**	**-3 551**
c.	**Grassland**	**-**	**1**	**0.26**	**-**	**-**	**-**	**-**	**1**
d.	**Wetlands**	**4 079**	**1 347**	**5**	**-**	**-**	**-**	**-**	**5 431**
e.	**Settlements**	**4 167**	**109**	**37**	**-**	**-**	**-**	**-**	**4 313**
f.	**Harvested Wood Products**	**-633**	**-**	**-**	**-**	**-**	**-**	**-**	**-633**

Notes:
Totals may not add up due to rounding.
Estimates are based on the best information available at the time of publication and are subject to revision in subsequent editions of the inventory.
For information on the uncertainty of emissions estimates, refer to Annex 2.
a. Chapter 1, Table 1–1 provides a list of global warming potentials (GWPs) used.
b. Totals exclude all GHGs from the Land Use, Land-Use Change and Forestry sector.
c. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
d. HFCs and PFCs consumption began in 1995; HFC emissions occurring as a by-product of HCFC production HCFC-22 exclusively), only occurred from 1990 to 1992, and prior to 1995, PFC emissions were a by-product of CF_4 emissions associated with the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
- Indicates no emissions.
NA = Not applicable

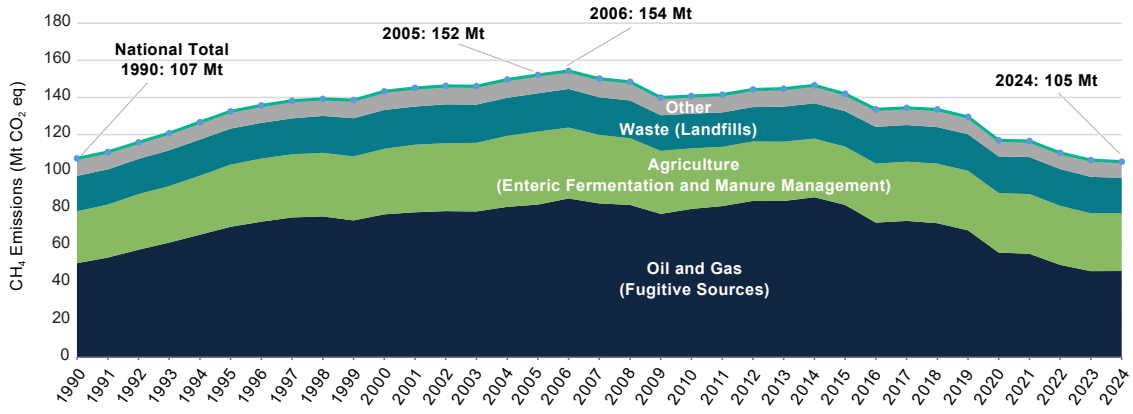
The oil and gas industry is a strong driver of the trends in CH_4 emissions, accounting for almost 80% of the 2005-2024 methane emissions decline. Between 1990 and 2006, CH_4 emissions from fugitive oil and gas increased by 35 Mt, consistent with a 60% increase in natural gas production and a 14% increase in conventional oil production.[6] From 2006 to 2019, fugitive oil and gas CH_4 emissions decreased by 17 Mt, largely from reductions in venting (12 Mt). Over the same period, the combination of improved leak detection and repair (LDAR) programs and a 9% decrease in natural gas production contributed an additional 5.1 Mt reduction. Emissions decreased 22 Mt between 2020 and 2024, coinciding with federal regulations to reduce CH_4 emissions from the upstream oil and gas industry and equivalent provincial regulations in Saskatchewan, Alberta and British Columbia. See section 2.3.1.3 for more detailed discussion of the trends in emissions from fugitive sources.

From 1990 to 2006, CH_4 emissions from agriculture increased by 10 Mt driven by increasing beef cattle population. From 2006 to 2024, agricultural emissions decreased by 7.1 Mt, mainly due to a 27% decline in beef cattle populations that led to a reduction in enteric fermentation emissions, but populations and emissions have stabilized in recent years.

Landfill CH_4 emissions (from municipal and industrial wood waste landfills, combined) increased by 1.8 Mt from 1990 to 2006 (21 Mt in 2006), after which they generally decreased. Landfill emissions are down by 1.7 Mt from their peak in 2006 to 2024, driven by an increase in methane recovered from municipal landfills (+3.0 Mt recovered) and a decrease in methane generated from industrial wood waste landfills (-0.3 Mt), which offset an increase in methane generated from municipal landfills over the same period (+1.5 Mt).

While the NIR provides valuable information on GHG emissions within Canada, it does not distinguish localized sources of emissions within the provincial and territorial level aggregations. In this respect, work is ongoing to attribute emissions closer to where they originate geographically. Models have been developed and used to spatially distribute the methane emissions. Methane was chosen among other GHGs as Canada has specific commitments to reduce methane and it is an opportunity to visualize decreasing trends in the data. Figure 2–6 and Figure 2–7 represent static maps of methane emissions on a 1 km grid, for 2006 and 2024, respectively. Since both maps were created using the same symbology scale (classification of emissions into 6 equal classes), the reduction in methane emissions between 2006 and 2024 can be seen visually, in particular, in Western Canada where oil and gas industries are predominantly located. As the project moves forward, the models will be refined, and the distribution of emissions will become more precise. The maps produced represent the total emissions over the year as opposed to a concentration at a certain point in time. Please contact ec.dirp.donnees-data.pird.ec@ec.gc.ca if additional details regarding the maps are needed.

Figure 2–5 **Methane Emission Trends in Canada (1990–2024)**



Note: Other includes various methane sources from the Energy, IPPU, Agriculture and Waste sectors.

6 From 1990 to 2024, thermal production of heavy oil/crude bitumen and synthetic crude oil increased by over 950% with CO_2 eq emissions increasing by 530%. However, CH_4 emissions from the Oil Sands and Thermal Heavy Oil sector increased by only 150% and the contribution to total Oil and Gas CH_4 emissions increased from 2.7 % in 1990 to 6.7% in 2024, demonstrating that the Oil Sands and Thermal Heavy Oil sector is not a significant source of CH_4 as compared to conventional oil and gas production.

Figure 2–6 **Methane Emissions in Canada (2006)**

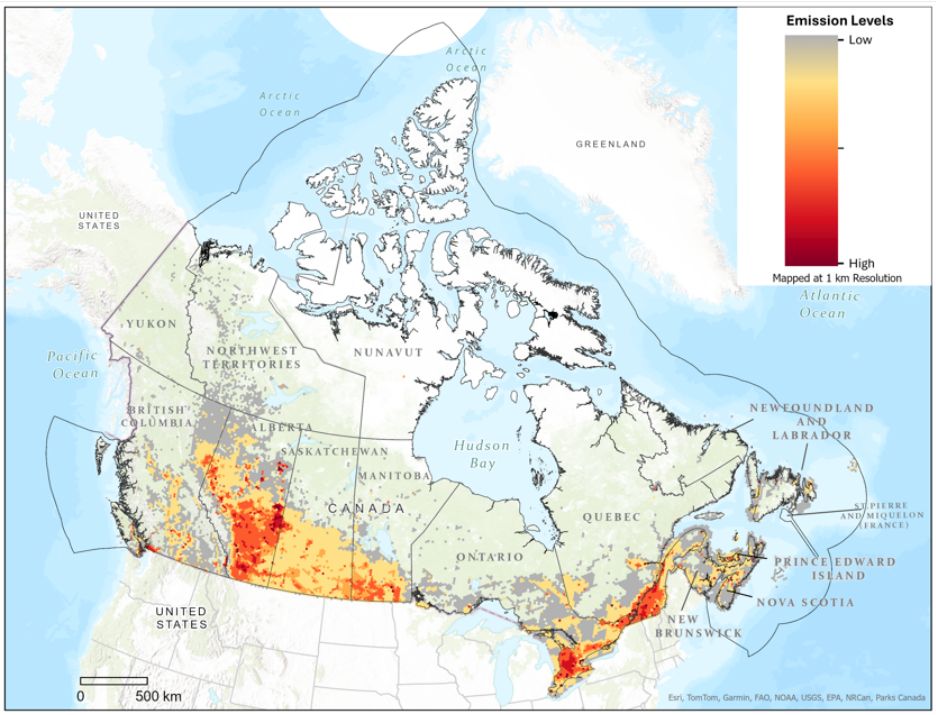
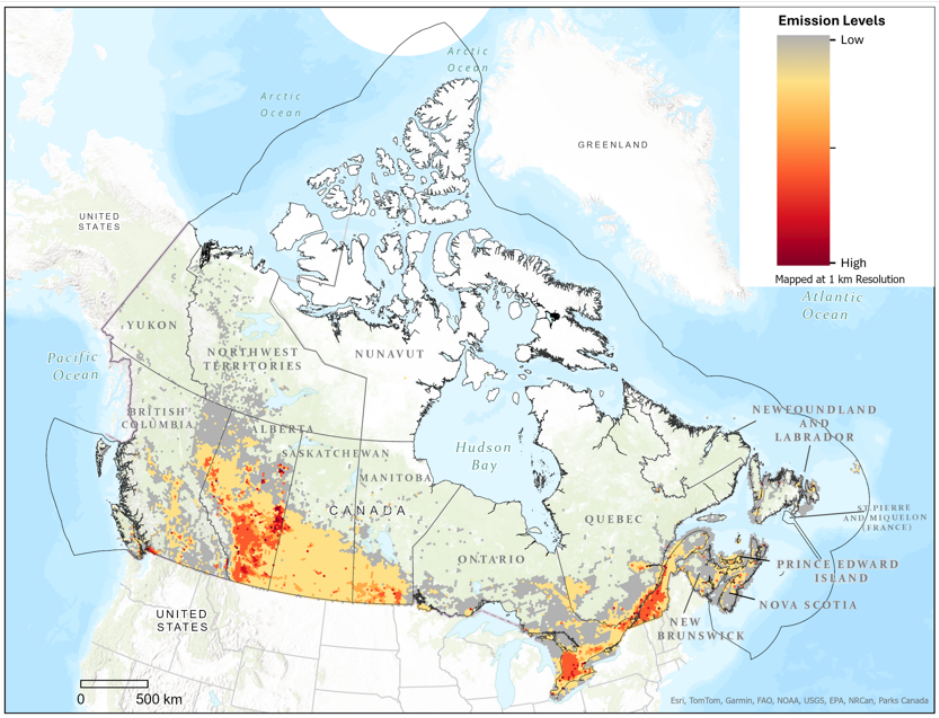


Figure 2–7 **Methane Emissions in Canada (2024)**



Nitrous Oxide (N_2O)

Nitrous oxide (N_2O) emissions accounted for 29 Mt of CO_2 eq (4.2%) of Canada's national emissions in 2024. The primary source of N_2O emissions is the application of nitrogen fertilizers to agricultural soils. In 2024, the Agriculture sector accounted for 22 Mt (76%) of national N_2O emissions, up from 63% in 1990 and 36% in 2005. Since 2005, a 108% increase in nitrogen fertilizer use has resulted in a 107% increase in agricultural N_2O emissions.

The continual proportional increase in the importance of agricultural N_2O emissions in relation to total N_2O emissions is due not only to an absolute increase in emissions from that sector, but also from offsetting emission decreases from other sectors. These include N_2O emission a decrease of 9.2 Mt from Adipic Acid Production since 1990 due to the cessation of production in Canada as of 2009. Additional decreases since 2005 include a 60% decrease (3.4 Mt) from Transport and an 88% decrease (0.9 Mt) from Nitric Acid Production due to emission abatement installations. As a result of these offsetting trends, national emissions of N_2O are down overall by 2.0 Mt (6.5%) from 1990 levels and 0.14 Mt (0.5%) from 2005 levels.

Fluorinated Gases (HFCs, PFCs, SF_6 and NF_3)

Emissions of fluorinated gases, consisting of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3), accounted for 11 Mt of CO_2 eq, or 1.6%, of Canada's emissions in 2024. From 1990 to 2024, emissions of HFCs rose by 8.9 Mt (1090%), while emissions of PFCs and SF_6 decreased by 6.2 Mt (92%) and 2.9 Mt (87%), respectively. Similar trends are observed since 2005, with a 4.9 Mt (101%) increase in HFC emissions, and 2.9 Mt (84%) and 1.0 Mt (70%) decreases in emissions of PFCs and SF_6, respectively. Increases in HFC emissions can be explained by the replacement of ozone-depleting substances (ODS) with HFCs in refrigeration, air conditioning and foam blowing applications. Since 2018, HFC emissions have declined by 2.0 Mt (17%), coinciding with the 2019 implementation of federal regulations limiting net imports of HFCs as mandated under the Kigali Amendment to the Montreal Protocol. The decreases in emissions of PFCs are largely due to modernization in the aluminium industry. The decreases in SF_6 are mainly due to a decline in the number of magnesium smelters and casters.

2.3. GHG Emissions Trends by IPCC Sector

The Intergovernmental Panel on Climate Change (IPCC) defines inventory sectors as the Energy sector (consisting of Stationary Combustion, Transport, and Fugitive Sources), the Agriculture sector, the Industrial Processes and Product Use (IPPU) sector, the Waste sector, and the LULUCF sector.

In 2024, the Energy sector accounted for 552 Mt, or 81%, of Canada's total GHG emissions with the remainder being shared between Agriculture (56 Mt or 8.2%), IPPU (53 Mt or 7.8%) and Waste (23 Mt or 3.3%). When included with emissions from other sectors, LULUCF sector emissions corresponded to 0.6% of the 2024 national total. The general emission breakdown by IPCC sector has not substantially changed over time (Figure 2–8).

The Energy sector dominated the long-term trend over the 1990–2024 period, with increases of 44 Mt (30%) in Transport, 20 Mt (7.3%) in Stationary Combustion, and 0.24 Mt (0.4%) in Fugitive Sources. Over the same period, emissions in the Agriculture sector increased by 14 Mt (32%), while the IPPU sector saw a decrease of 2.5 Mt (4.4%). Emissions in the Waste sector have increased by 1.2 Mt (5.8%) since 1990. Net emissions from the LULUCF sector were 61 Mt in 1990, and emissions increased on average through the 1990s and early 2000s, before generally trending downward to 4.3 Mt in 2024 (Figure 2–8 and Table 2–4).

Over the 2005–2024 period, total emissions decreased by 78 Mt (10%) with decreases in emissions from all IPCC sectors. The Energy sector dominated this trend, with emission decreases of 38 Mt (11%) in Stationary Combustion, 34 Mt (34%) in Fugitive Sources and 1.3 Mt (0.7%) in Transport. Over the same period, emissions decreased by 3.5 Mt (6.2%) in the IPPU sector and 0.96 Mt (4.1%) in the Waste sector. The Agriculture sector emissions have remained relatively stable with a 0.39 Mt (0.7%) decrease since 2005 (Figure 2–9). The net fluxes in the LULUCF sector demonstrate interannual variability throughout the time series, but reached 81 Mt in 2005 and have trended downward since, reaching a low of 4.3 Mt in 2024 (Figure 2–8).

Several emission sources, while not major contributors to Canada's overall GHG emissions, have changed significantly since 1990. These include emission increases of 8.9 Mt (1089%) from the Production and Consumption of Halocarbons, SF_6 and NF_3, 6.4 Mt (109%) from Non-Energy Products from Fuels and Solvent Use, 2.2 Mt (192%) from Liming, Urea Application and Other Carbon-Containing Fertilizers, and 0.67 Mt (499%) from Biofuel Manufacturing. Also included are decreases of 9.2 Mt (100%) from Adipic Acid Production, 2.9 Mt (91%) from Magnesium and Other Metal Production, and 0.74 Mt (85%) from Nitric Acid Production.

Between 2005 and 2024, noteworthy changes that are minor contributors to the national total include emission increases of 4.9 Mt (102%) from the Production and Consumption of Halocarbons, SF_6 and NF_3, 2.0 Mt (142%) from Liming, Urea Application and Other Carbon-Containing Fertilizers, and 0.66 Mt (429%) from Biofuel Manufacturing. In contrast, emissions decreased by 2.3 Mt (100%) from Adipic Acid Production, 1.1 Mt (79%) from Magnesium and Other Metal Production, and 0.94 Mt (88%) from Nitric Acid Production.

Figure 2–8 **Trends in Canadian GHG Emissions by IPCC Sector (1990–2024)**

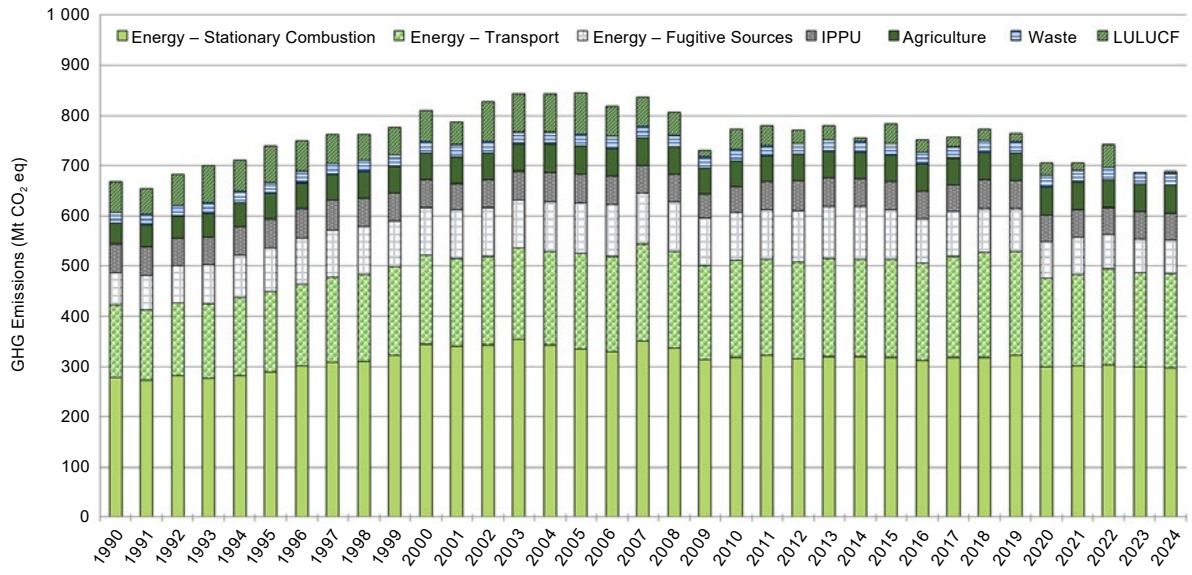


Figure 2–9 **Changes in GHG Emissions by IPCC Sector (2005–2024)**

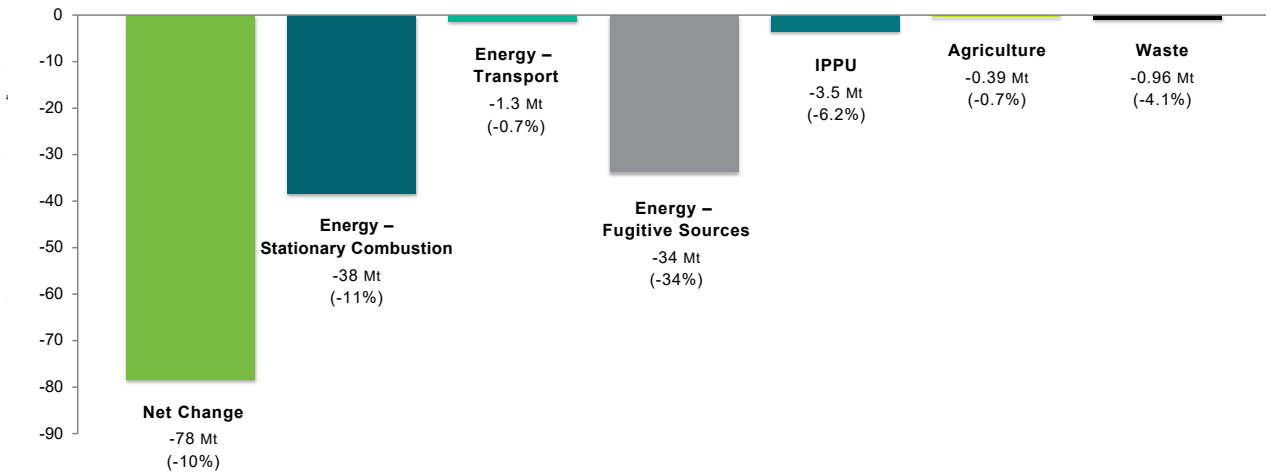


Table 2–4 Canada's GHG Emissions by IPCC Sector (1990–2024)

GHG Source Category	GHG Emissions (Mt CO_2 eq)																																					
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
TOTAL[a, b]	**608**	**603**	**621**	**627**	**649**	**667**	**688**	**705**	**711**	**721**	**749**	**742**	**749**	**767**	**767**	**763**	**759**	**779**	**761**	**717**	**732**	**740**	**744**	**751**	**748**	**743**	**727**	**739**	**749**	**748**	**681**	**691**	**696**	**687**	**685**
ENERGY	**488**	**482**	**500**	**503**	**521**	**537**	**555**	**572**	**580**	**591**	**617**	**612**	**617**	**632**	**628**	**626**	**622**	**645**	**628**	**595**	**608**	**613**	**610**	**619**	**619**	**613**	**594**	**609**	**616**	**616**	**549**	**558**	**563**	**554**	**552**
a. Stationary Combustion Sources	**277**	**273**	**282**	**277**	**282**	**290**	**300**	**308**	**311**	**322**	**344**	**341**	**343**	**355**	**343**	**336**	**329**	**351**	**338**	**315**	**318**	**322**	**316**	**320**	**321**	**318**	**312**	**318**	**319**	**322**	**299**	**300**	**303**	**298**	**298**
Public Electricity and Heat Production	94	95	102	93	95	99	98	110	123	120	132	133	128	132	125	123	119	124	116	100	102	93	91	88	85	83	82	79	71	70	62	62	58	59	57
Petroleum Refining Industries	18	17	18	18	17	17	20	20	20	19	18	19	20	22	22	20	21	21	20	19	20	19	18	17	16	16	16	14	13	15	14	14	15	14	15
Oil and Gas Extraction	30	29	31	34	35	36	36	35	37	49	53	55	58	63	60	63	66	74	74	75	76	83	86	90	94	97	92	99	105	105	101	104	105	106	109
Coal Production	0.48	0.50	0.36	0.54	0.46	0.57	0.69	0.65	0.49	0.55	0.56	0.80	0.61	0.66	0.64	0.36	0.56	0.63	0.67	0.60	0.67	0.65	0.70	0.65	0.59	0.48	0.54	0.49	0.52	0.55	0.45	0.52	0.52	0.56	0.53
Biofuel Manufacturing	0.13	0.12	0.11	0.11	0.16	0.18	0.14	0.14	0.13	0.14	0.14	0.12	0.13	0.07	0.17	0.15	0.26	0.40	0.63	0.64	0.75	0.79	0.94	0.96	0.90	0.93	0.89	0.86	0.86	0.96	0.84	0.80	0.77	0.79	0.81
Mining and Quarrying	4.1	3.8	3.3	3.4	4.1	4.4	4.3	4.6	4.2	3.9	4.3	4.1	3.9	4.2	4.1	3.9	4.5	4.7	4.9	4.6	4.6	4.6	5.0	4.3	4.0	3.7	3.3	4.0	5.4	5.4	4.9	5.3	5.8	5.2	5.3
Manufacturing Industries	56	54	53	50	53	56	57	57	54	55	55	51	51	49	50	47	45	46	43	38	40	43	42	43	44	42	41	41	41	42	39	39	40	39	38
Construction	1.9	1.6	1.8	1.4	1.4	1.2	1.3	1.3	1.1	1.2	1.1	1.0	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.2	1.5	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.6	1.5	1.6
Commercial and Institutional	26	27	27	28	28	29	30	30	28	29	33	33	34	35	34	32	29	31	30	30	29	31	29	30	31	30	34	36	37	38	35	33	35	33	32
Residential	43	42	43	45	46	44	49	46	40	42	44	41	43	45	44	43	41	46	45	43	41	43	40	42	41	41	38	39	40	41	38	37	39	35	35
Agriculture and Forestry	2.4	2.7	3.2	3.0	2.5	2.8	2.9	2.9	2.6	2.7	2.6	2.2	2.2	2.3	2.2	2.2	2.1	2.5	2.5	2.5	2.7	3.2	3.3	3.2	3.0	3.0	3.2	3.1	3.2	3.3	3.1	3.2	3.3	3.2	3.4
b. Transport	**145**	**140**	**144**	**148**	**155**	**159**	**163**	**169**	**172**	**177**	**178**	**176**	**177**	**182**	**186**	**190**	**190**	**193**	**191**	**186**	**193**	**193**	**193**	**196**	**194**	**196**	**195**	**201**	**208**	**208**	**176**	**184**	**192**	**190**	**189**
Aviation	7.5	6.5	6.4	6.0	6.4	6.7	7.1	7.2	7.5	7.9	7.8	7.1	7.0	7.1	7.6	7.7	7.7	7.8	7.5	6.6	6.7	6.6	7.6	7.9	7.6	7.6	7.5	7.9	8.7	8.6	4.7	5.6	7.7	8.4	8.1
Domestic Aviation (Civil)	7.3	6.3	6.2	5.8	6.2	6.5	6.8	7.0	7.3	7.7	7.5	6.9	6.8	6.8	7.3	7.5	7.5	7.5	7.2	6.4	6.4	6.4	7.3	7.7	7.4	7.3	7.3	7.7	8.4	8.3	4.6	5.4	7.5	8.2	7.9
Military	0.23	0.22	0.23	0.21	0.21	0.23	0.25	0.25	0.24	0.21	0.26	0.20	0.26	0.31	0.30	0.26	0.24	0.30	0.30	0.27	0.26	0.23	0.24	0.21	0.21	0.24	0.26	0.23	0.25	0.24	0.18	0.20	0.20	0.20	0.22
Road Transportation	92	89	91	94	99	100	102	105	107	109	110	110	111	117	121	122	124	129	130	131	134	132	131	132	130	129	128	129	132	132	111	116	120	119	118
Light-Duty Gasoline Vehicles	44	43	44	45	45	44	44	43	43	42	42	42	42	42	42	41	40	40	39	39	38	36	35	35	34	34	34	32	32	31	24	25	25	25	24
Light-Duty Gasoline Trucks	25	24	25	26	28	28	30	31	33	35	35	36	37	39	40	41	42	43	43	44	45	43	44	46	46	47	50	52	54	56	47	49	51	52	53
Heavy-Duty Gasoline Vehicles	4.8	4.5	4.5	4.4	4.4	4.2	4.1	4.1	4.1	4.4	4.3	4.4	4.3	4.5	4.6	4.6	4.6	4.7	4.6	4.6	4.6	4.4	4.5	4.4	4.3	4.3	4.3	4.5	4.5	4.6	4.2	4.2	3.9	4.0	4.1
Motorcycles	0.20	0.20	0.21	0.22	0.23	0.23	0.23	0.24	0.26	0.28	0.32	0.33	0.36	0.39	0.43	0.46	0.49	0.53	0.55	0.58	0.60	0.73	0.78	0.78	0.78	0.83	0.87	0.90	0.92	0.96	0.75	0.80	0.75	0.76	0.78
Light-Duty Diesel Vehicles	0.37	0.36	0.37	0.38	0.41	0.43	0.44	0.46	0.45	0.43	0.46	0.46	0.48	0.58	0.63	0.66	0.74	0.81	0.81	0.81	0.74	0.77	0.74	0.76	0.76	0.71	0.65	0.60	0.47	0.43	0.31	0.33	0.36	0.31	0.29
Light-Duty Diesel Trucks	0.99	0.95	1.1	1.1	1.1	1.2	1.3	1.4	1.3	1.3	1.2	0.94	0.82	0.87	0.81	0.75	0.70	0.68	0.69	0.65	0.53	0.53	0.53	0.55	0.63	0.62	0.60	0.70	0.78	0.80	0.64	0.77	0.98	0.91	0.87
Heavy-Duty Diesel Vehicles	16	15	16	17	19	21	22	24	25	26	27	26	27	30	32	34	35	39	42	42	44	46	45	45	45	41	38	38	40	39	33	36	38	36	35
Propane and Natural Gas Vehicles	0.76	0.62	0.53	0.30	0.29	0.22	0.17	0.12	0.09	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.05	0.07	0.08	0.10	0.11	0.14	0.15	0.16	0.17	0.16	0.16
Railways	6.1	6.2	6.0	6.0	6.3	6.2	6.1	6.1	5.9	5.8	5.9	6.0	5.9	5.9	6.1	6.5	6.5	6.6	6.4	5.5	6.0	6.1	6.2	6.1	6.4	6.2	5.8	6.2	6.5	6.5	6.0	5.8	5.8	5.8	5.8
Marine	3.1	3.2	3.2	3.2	3.3	3.3	3.4	3.4	3.5	3.5	3.6	3.7	3.7	3.8	3.9	4.0	3.9	3.9	3.8	3.8	3.7	3.7	3.6	3.6	3.6	3.6	3.5	3.7	4.1	4.0	3.8	2.9	3.3	3.3	3.4
Domestic Navigation	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.0	3.0	2.9	2.9	2.9	2.9	3.0	3.1	3.3	3.4	3.3	3.5	3.9	3.8	3.5	2.8	3.2	3.2	3.3
Fishing	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.86	0.85	0.84	0.84	0.83	0.69	0.57	0.44	0.32	0.19	0.19	0.20	0.22	0.20	0.20	0.13	0.12	0.11	0.10
Military Water-Borne Navigation	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01
Other Transportation	36	35	37	38	40	43	45	48	49	50	51	49	49	48	48	50	48	45	43	39	43	45	44	46	46	50	50	54	56	57	50	53	55	53	53
Off-Road Agriculture and Forestry	8.7	7.8	7.3	7.4	7.7	7.8	8.1	8.8	8.6	8.7	9.2	8.6	8.4	8.9	9.4	9.9	9.5	9.4	9.2	8.0	9.2	9.8	9.8	10	11	12	12	13	14	14	12	13	13	12	12
Off-Road Commercial and Institutional	4.3	3.9	3.8	3.6	3.5	4.0	3.9	4.2	4.4	4.7	4.6	4.6	4.7	4.5	4.5	4.5	4.4	3.8	3.6	3.7	4.7	5.3	5.1	5.1	4.6	4.8	5.1	5.5	5.8	5.9	5.3	5.8	5.9	5.9	6.0
Off-Road Manufacturing, Mining and Construction	12	12	12	13	13	14	15	16	16	17	17	17	16	16	16	16	16	15	15	13	15	16	16	16	15	17	17	19	20	20	17	18	18	17	18
Off-Road Residential	0.37	0.41	0.47	0.54	0.64	0.69	0.75	0.81	0.86	0.95	1.0	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.0	1.1	1.1	1.0	1.0	1.0	0.96	0.91	0.84	0.83	0.76
Off-Road Other Transportation	3.5	3.3	3.3	3.6	4.0	4.9	5.3	5.8	6.3	7.0	7.3	7.6	8.0	8.0	7.9	7.7	7.4	7.1	6.8	6.4	6.5	6.4	6.5	6.8	6.6	7.0	7.6	7.6	7.6	7.5	6.9	7.1	7.0	6.9	6.8
Pipeline Transport	6.9	7.7	9.9	10	11	12	13	13	13	13	11	10	11	9.1	8.5	10	9.6	8.4	7.5	6.4	5.7	5.7	5.8	6.8	8.0	8.3	7.7	7.6	8.4	8.5	7.8	8.7	10	9.7	10
c. Fugitive Sources	**66**	**69**	**74**	**78**	**83**	**88**	**91**	**94**	**96**	**92**	**95**	**96**	**96**	**96**	**99**	**100**	**103**	**101**	**99**	**93**	**96**	**98**	**102**	**103**	**105**	**99**	**88**	**89**	**89**	**85**	**74**	**74**	**68**	**66**	**66**
Coal Mining	3.2	3.2	2.6	2.8	2.8	2.6	2.4	2.5	2.2	1.9	1.9	1.9	1.7	1.6	1.7	1.5	1.4	1.5	1.5	1.3	1.5	1.5	1.6	1.7	1.5	1.3	1.4	1.4	1.6	1.6	1.4	1.4	1.4	1.6	1.4
Oil and Natural Gas	63	66	71	75	81	85	89	91	94	90	93	94	95	94	97	98	102	99	98	92	95	97	100	101	103	98	86	88	88	84	72	73	67	64	65
d. CO_2 Transport and Storage	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
INDUSTRIAL PROCESSES AND PRODUCT USE	**56**	**57**	**55**	**56**	**57**	**58**	**60**	**60**	**57**	**55**	**55**	**52**	**55**	**57**	**60**	**57**	**57**	**56**	**55**	**48**	**52**	**55**	**60**	**57**	**54**	**54**	**55**	**54**	**56**	**54**	**52**	**54**	**53**	**55**	**53**
a. Mineral Products	**8.5**	**7.6**	**7.3**	**7.4**	**8.5**	**9.2**	**8.9**	**9.5**	**9.6**	**9.9**	**10**	**9.4**	**9.7**	**9.7**	**10**	**10**	**10**	**10**	**9.4**	**7.2**	**7.9**	**8.0**	**8.5**	**7.8**	**7.9**	**8.1**	**7.9**	**8.6**	**9.0**	**8.9**	**8.3**	**9.0**	**8.4**	**8.9**	**8.5**
Cement Production	5.8	4.8	4.8	4.9	5.8	6.5	6.2	6.7	6.8	7.1	7.2	7.0	7.1	7.2	7.5	7.6	7.7	7.7	7.0	5.4	6.0	6.0	6.5	6.0	5.9	6.2	6.1	6.9	7.3	7.2	6.8	7.4	6.8	7.3	6.9
Lime Production	1.9	1.9	1.9	1.9	2.0	2.0	1.9	2.0	2.0	2.0	2.0	1.8	1.8	1.8	1.9	1.8	1.8	1.7	1.6	1.3	1.5	1.5	1.6	1.5	1.6	1.5	1.4	1.4	1.4	1.3	1.2	1.3	1.3	1.2	1.3
Mineral Product Use	0.80	0.91	0.64	0.62	0.78	0.69	0.81	0.91	0.85	0.71	0.83	0.68	0.75	0.70	0.79	0.83	0.80	0.79	0.75	0.61	0.41	0.45	0.44	0.38	0.38	0.41	0.39	0.33	0.33	0.32	0.32	0.32	0.32	0.31	0.29
b. Chemical Industry	**16**	**16**	**15**	**16**	**18**	**17**	**18**	**16**	**13**	**10**	**8.5**	**8.4**	**8.7**	**9.0**	**11**	**10**	**8.7**	**7.9**	**8.7**	**5.8**	**5.7**	**6.3**	**6.6**	**6.6**	**6.3**	**6.7**	**6.8**	**6.3**	**6.4**	**6.2**	**5.9**	**5.7**	**5.7**	**5.6**	**5.6**
Ammonia Production	2.7	2.7	2.5	2.9	3.0	2.9	2.8	2.8	3.1	3.0	2.9	2.6	2.6	2.6	2.9	2.7	2.8	2.6	2.8	2.4	2.5	2.9	3.0	3.0	2.6	2.9	2.8	2.6	2.4	2.5	2.3	2.5	2.6	2.4	2.3
Nitric Acid Production	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	0.7	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
Adipic Acid Production	9.2	8.5	8.5	7.8	9.4	9.2	9.8	8.5	4.3	1.5	0.8	0.7	1.1	0.9	2.6	2.3	1.0	1.3	2.1	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Petrochemical and Carbon Black Production	3.5	3.6	3.6	4.2	4.5	4.3	4.6	4.2	4.4	4.1	3.7	4.1	3.9	4.3	4.4	3.9	3.8	3.1	3.1	2.4	2.8	3.1	3.3	3.3	3.6	3.6	3.7	3.5	3.7	3.5	3.5	3.0	3.0	3.1	3.2
c. Metal Production	**24**	**27**	**26**	**26**	**25**	**24**	**24**	**24**	**25**	**24**	**24**	**22**	**22**	**22**	**22**	**21**	**22**	**20**	**20**	**17**	**17**	**18**	**18**	**16**	**16**	**16**	**17**	**16**	**17**	**16**	**15**	**16**	**16**	**17**	**16**
Iron and Steel Production	11	13	13	13	12	12	12	12	13	13	13	12	12	12	12	12	12	12	12	9	10	11	11	9	10	10	11	10	11	10	9	10	10	10	10
Aluminium Production	10	10	10	11	10	9.4	10	10	10	8.8	8.4	7.9	7.6	7.8	7.4	8.3	7.8	7.4	7.5	7.3	6.7	6.6	6.3	6.4	5.7	5.6	5.9	5.9	5.4	5.2	5.8	5.8	5.7	6.1	6.0
Magnesium and Other Metal Production	3.2	3.7	2.4	2.2	2.3	2.2	1.8	1.8	2.3	2.4	2.9	2.5	3.0	2.6	2.3	1.4	1.5	0.5	0.5	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.2	0.3	0.5	0.3
d. Production and Consumption of Halocarbons, SF_6 and NF_3[c]	**0.82**	**0.89**	**0.70**	**0.00**	**0.00**	**0.46**	**0.78**	**1.1**	**1.5**	**2.1**	**2.6**	**3.0**	**3.4**	**3.8**	**4.3**	**4.8**	**5.1**	**5.7**	**5.8**	**6.5**	**7.5**	**8.3**	**8.7**	**9.3**	**9.9**	**10**	**11**	**11**	**12**	**12**	**11**	**11**	**11**	**10**	**9.7**
e. Non-Energy Products from Fuels and Solvent Use	**5.9**	**5.7**	**5.4**	**6.0**	**6.1**	**6.4**	**7.9**	**8.6**	**7.9**	**8.8**	**8.7**	**8.7**	**10**	**12**	**13**	**10**	**11**	**11**	**11**	**11**	**13**	**14**	**17**	**16**	**14**	**13**	**12**	**11**	**11**	**11**	**11**	**12**	**12**	**13**	**12**
f. Other Product Manufacture and Use	**0.36**	**0.36**	**0.34**	**0.34**	**0.35**	**0.37**	**0.33**	**0.37**	**0.47**	**0.55**	**0.57**	**0.64**	**0.48**	**0.57**	**0.59**	**0.51**	**0.48**	**0.52**	**0.50**	**0.44**	**0.41**	**0.36**	**0.46**	**0.51**	**0.42**	**0.51**	**0.56**	**0.58**	**0.65**	**0.62**	**0.66**	**0.66**	**0.61**	**0.65**	**0.68**

Table 2–4 **Canada's GHG Emissions by IPCC Sector (1990–2024)** (cont'd)

GHG Source Category	GHG Emissions (Mt CO_2 eq)																																				
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
AGRICULTURE	**43**	**43**	**45**	**46**	**48**	**50**	**51**	**51**	**52**	**52**	**53**	**54**	**54**	**55**	**56**	**57**	**56**	**55**	**55**	**52**	**51**	**51**	**53**	**54**	**53**	**54**	**54**	**53**	**55**	**55**	**57**	**56**	**56**	**55**	**56**
a. Enteric Fermentation	**25**	**26**	**27**	**27**	**29**	**30**	**30**	**30**	**30**	**31**	**31**	**32**	**32**	**32**	**34**	**35**	**33**	**32**	**31**	**30**	**28**	**28**	**28**	**28**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**26**	**26**
b. Manure Management	**6.2**	**6.3**	**6.6**	**6.7**	**6.9**	**7.3**	**7.4**	**7.5**	**7.7**	**7.9**	**8.1**	**8.5**	**8.6**	**8.7**	**8.9**	**9.0**	**8.9**	**8.6**	**8.5**	**8.1**	**8.0**	**7.9**	**8.0**	**8.0**	**8.0**	**8.1**	**8.2**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.2**	**8.1**	**8.2**
c. Agricultural Soils	**10**	**10**	**10**	**11**	**11**	**11**	**12**	**12**	**12**	**12**	**12**	**12**	**11**	**12**	**12**	**12**	**12**	**12**	**13**	**13**	**13**	**13**	**15**	**16**	**15**	**16**	**16**	**16**	**16**	**17**	**18**	**17**	**18**	**18**	**18**
Direct Sources	7.9	7.6	7.9	8.7	8.6	8.6	9.1	9.2	9.4	9.2	9.2	9.1	8.9	9.7	9.2	9.0	9.3	9.6	10	10	10	10	12	12	12	13	13	12	13	13	14	13	14	14	15
Indirect Sources	2.3	2.2	2.3	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.7	2.6	2.5	2.7	2.8	2.7	2.7	2.8	3.0	2.9	2.9	2.9	3.1	3.4	3.3	3.3	3.5	3.3	3.5	3.5	3.7	3.5	3.6	3.7	3.8
d. Field Burning of Agricultural Residues	**0.24**	**0.19**	**0.17**	**0.19**	**0.20**	**0.20**	**0.19**	**0.20**	**0.21**	**0.16**	**0.14**	**0.12**	**0.12**	**0.14**	**0.04**	**0.05**	**0.05**	**0.04**	**0.05**	**0.06**	**0.04**	**0.03**	**0.04**	**0.06**	**0.05**	**0.06**	**0.05**	**0.05**	**0.05**	**0.05**	**0.06**	**0.04**	**0.05**	**0.05**	**0.05**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**1.2**	**1.1**	**1.2**	**1.2**	**1.4**	**1.5**	**1.5**	**1.6**	**1.6**	**1.5**	**1.6**	**1.4**	**1.5**	**1.6**	**1.5**	**1.4**	**1.5**	**1.7**	**1.7**	**1.8**	**1.8**	**2.0**	**2.3**	**2.7**	**2.5**	**2.6**	**2.5**	**2.4**	**2.6**	**2.7**	**3.0**	**3.1**	**2.8**	**3.1**	**3.4**
WASTE	**21**	**21**	**21**	**22**	**22**	**22**	**22**	**22**	**23**	**23**	**24**	**23**	**24**	**23**	**23**	**23**	**24**	**23**	**23**	**22**	**22**	**22**	**22**	**22**	**22**	**22**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**
a. Landfills	**19**	**19**	**19**	**19**	**20**	**19**	**19**	**19**	**20**	**21**	**21**	**21**	**21**	**21**	**20**	**21**	**21**	**20**	**20**	**19**	**19**	**19**	**19**	**19**	**19**	**19**	**19**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**19**
Municipal Solid Waste Landfills	18	18	18	18	19	18	18	18	19	19	20	19	20	20	19	20	20	19	19	18	18	18	18	18	18	18	19	19	19	19	19	19	19	19	18
Industrial Wood Waste Landfills	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7
b. Biological Treatment of Solid Waste	**0.15**	**0.17**	**0.20**	**0.22**	**0.24**	**0.26**	**0.28**	**0.28**	**0.31**	**0.28**	**0.29**	**0.29**	**0.30**	**0.30**	**0.32**	**0.33**	**0.32**	**0.35**	**0.37**	**0.38**	**0.38**	**0.43**	**0.42**	**0.43**	**0.44**	**0.44**	**0.45**	**0.46**	**0.50**	**0.50**	**0.51**	**0.60**	**0.61**	**0.61**	**0.61**
c. Incineration and Open Burning of Waste	**0.29**	**0.30**	**0.32**	**0.33**	**0.36**	**0.40**	**0.37**	**0.32**	**0.35**	**0.32**	**0.36**	**0.38**	**0.39**	**0.34**	**0.35**	**0.35**	**0.33**	**0.31**	**0.33**	**0.29**	**0.31**	**0.30**	**0.18**	**0.19**	**0.18**	**0.20**	**0.20**	**0.19**	**0.18**	**0.17**	**0.16**	**0.15**	**0.17**	**0.16**	**0.15**
d. Wastewater Treatment and Discharge	**1.8**	**1.9**	**1.9**	**1.9**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.1**	**2.1**	**2.1**	**2.1**	**2.1**	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**	**2.3**	**2.4**	**2.4**	**2.4**	**2.4**	**2.5**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.5**	**2.5**	**2.6**	**2.6**
Municipal Wastewater Treatment and Discharge	1.4	1.4	1.5	1.5	1.5	1.5	1.6	1.6	1.6	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.9	2.0	2.0	2.0	2.0	2.0	2.1	2.1	2.2	2.2	2.2	2.2	2.3	2.3	2.4
Industrial Wastewater Treatment and Discharge	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.42	0.41	0.41	0.42	0.42	0.42	0.42	0.42	0.41	0.40	0.40	0.41	0.51	0.52	0.45	0.46	0.41	0.37	0.35	0.28	0.24	0.23
LAND USE, LAND-USE CHANGE AND FORESTRY	**61**	**51**	**62**	**74**	**64**	**73**	**62**	**59**	**51**	**55**	**62**	**47**	**79**	**76**	**75**	**81**	**60**	**58**	**46**	**14**	**41**	**40**	**26**	**28**	**6**	**42**	**26**	**19**	**24**	**16**	**26**	**14**	**46**	**-8.7**	**4.3**
a. Forest Land	**79**	**72**	**81**	**87**	**94**	**105**	**92**	**99**	**88**	**113**	**119**	**99**	**118**	**111**	**145**	**145**	**123**	**102**	**70**	**36**	**62**	**58**	**56**	**58**	**54**	**63**	**55**	**52**	**56**	**36**	**36**	**29**	**15**	**1.3**	**-1.2**
b. Cropland	**5.6**	**-1.9**	**0.8**	**8.2**	**-4.8**	**-6.4**	**-5.2**	**-8.6**	**-4.6**	**-14**	**-16**	**-9.5**	**6.8**	**9.7**	**-22**	**-20**	**-24**	**-17**	**-19**	**-34**	**-20**	**-13**	**-21**	**-22**	**-40**	**-7.8**	**-13**	**-19**	**-19**	**-12**	**-10**	**-14**	**24**	**-21**	**-3.6**
c. Grassland	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
d. Wetlands	**10**	**9.7**	**9.5**	**9.0**	**8.6**	**8.8**	**8.4**	**8.2**	**8.2**	**8.3**	**7.5**	**7.3**	**7.3**	**7.3**	**7.2**	**7.0**	**6.8**	**6.9**	**6.8**	**6.8**	**6.6**	**6.2**	**6.2**	**6.4**	**6.3**	**6.0**	**6.1**	**5.8**	**5.6**	**5.6**	**5.6**	**6.0**	**5.7**	**5.5**	**5.4**
e. Settlements	**4.9**	**5.0**	**4.7**	**4.3**	**4.1**	**3.7**	**4.4**	**4.1**	**4.4**	**4.3**	**4.3**	**4.5**	**4.9**	**4.8**	**5.2**	**5.1**	**5.6**	**5.5**	**5.8**	**4.7**	**4.8**	**5.1**	**5.6**	**6.2**	**6.3**	**6.3**	**6.3**	**5.4**	**4.9**	**5.0**	**4.7**	**4.6**	**4.5**	**4.6**	**4.3**
f. Harvested Wood Products	**-39**	**-34**	**-34**	**-35**	**-39**	**-39**	**-38**	**-43**	**-44**	**-57**	**-52**	**-55**	**-58**	**-57**	**-61**	**-57**	**-51**	**-39**	**-17**	**1.0**	**-12**	**-16**	**-21**	**-21**	**-20**	**-26**	**-28**	**-25**	**-24**	**-18**	**-10**	**-11**	**-3.0**	**0.7**	**-0.6**

Notes:
Totals may not add up due to rounding.
Estimates are based on the best information available at the time of publication and are subject to revision in subsequent editions of the inventory.
For information on the uncertainty of emissions estimates, refer to Annex 2.
a. Totals exclude all GHGs from the Land Use, Land-Use Change and Forestry sector.
b. Emissions from ethanol and biodiesel are included in the Transport categories using gasoline and diesel respectively.
c. HFC and PFC consumption began in 1995; HFC emissions occurring as a by-product of HCFC production (HCFC-22 exclusively) only occurred in Canada from 1990−1992 and PFC emissions prior to 1995 are the result of by-product CF_4 emissions from the use of NF_3.
0.00 Indicates emissions were truncated due to rounding.
- Indicates no emissions.

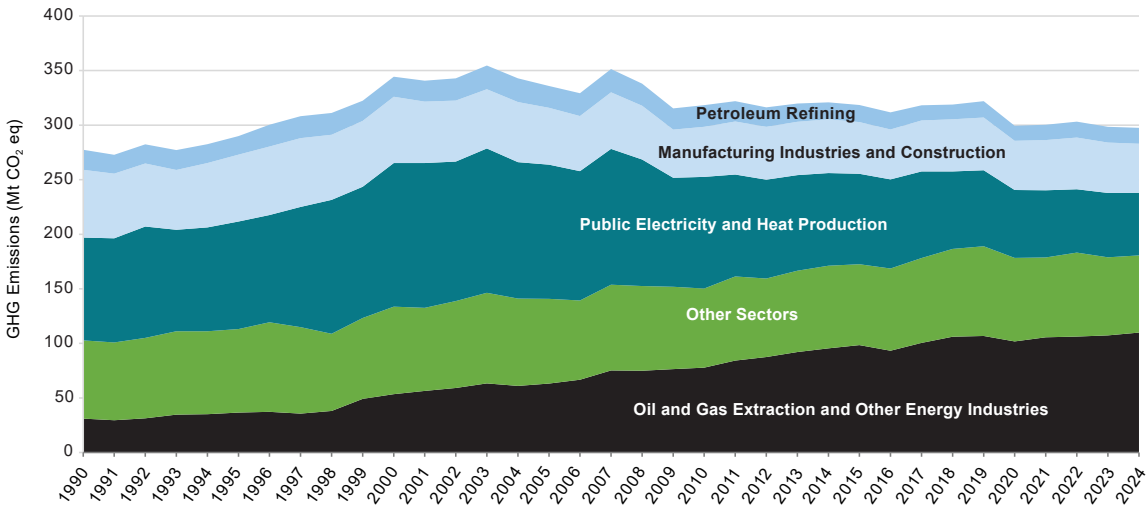
2.3.1. Energy Sector (2024 GHG emissions, 552 Mt)

In 2024, the Energy sector contributed 81% of Canada's total GHG emissions. Sources in the Energy sector are grouped under Stationary Combustion Sources, Transport, Fugitive Sources, and CO_2 Transport and Storage. Chapter 3 provides a detailed description of each.

2.3.1.1. Stationary Combustion Sources (2024 GHG Emissions, 298 Mt)

Stationary Combustion Sources account for 54% of emissions from the Energy sector. In 2024, emissions totalled 298 Mt, an increase of 7.3% from the 1990 emissions level of 277 Mt and a decrease of 11% from the 2005 emissions level of 336 Mt (Figure 2–10, Table 2–5). Dominant categories in Stationary Combustion Sources are Oil and Gas Extraction as well as Public Electricity and Heat Production, which in 2024 contributed 36% and 19%, respectively, to total Stationary Combustion emissions. Manufacturing Industries, Residential Buildings, and Commercial and Institutional Buildings contributed 13%, 12% and 11%, respectively, of total Stationary Combustion emissions in 2024.

Figure 2–10 **Trends in Canadian GHG Emissions from Stationary Combustion Sources (1990–2024)**



Notes:
"Oil and Gas Extraction and Other Energy Industries" includes Oil and Gas Extraction, Coal Production, and Biofuel Manufacturing.
"Manufacturing Industries and Construction" includes Manufacturing Industries, Mining and Quarrying, and Construction.
"Other Sectors" includes Residential, Commercial and Institutional, and Agriculture and Forestry.

Table 2–5 **GHG Emissions from Stationary Combustion Sources, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2019	2020	2021	2022	2023	2024	1990–2024	2005–2024
STATIONARY COMBUSTION SOURCES	**277**	**336**	**322**	**299**	**300**	**303**	**298**	**298**	**7.3%**	**-11%**
Public Electricity and Heat Production	**94**	**123**	**70**	**62**	**62**	**58**	**59**	**57**	**-39%**	**-53%**
Petroleum Refining	**18**	**20**	**15**	**14**	**14**	**15**	**14**	**15**	**-20%**	**-27%**
Oil and Gas Extraction and Other Energy Industries	**31**	**63**	**107**	**102**	**106**	**106**	**107**	**110**	**254%**	**74%**
Oil and Gas Extraction	30	63	105	101	104	105	106	109	257%	73%
Coal Production	0.48	0.36	0.55	0.45	0.52	0.52	0.56	0.53	10%	46%
Biofuel Manufacturing	0.13	0.15	0.96	0.84	0.80	0.77	0.79	0.81	499%	429%
Manufacturing Industries and Construction	**62**	**52**	**48**	**45**	**46**	**47**	**46**	**45**	**-28%**	**-14%**
Iron and Steel	4.9	5.0	5.0	4.3	4.8	4.5	4.5	4.6	-6.7%	-8.4%
Non-Ferrous Metals	3.5	3.8	3.4	3.2	3.0	3.2	3.1	2.9	-17%	-23%
Chemicals	8.1	8.2	9.4	9.4	9.2	9.1	9.3	9.4	15%	15%
Pulp, Paper and Print	14	8.6	7.1	6.4	6.7	6.8	6.5	5.8	-60%	-33%
Cement	3.9	5.0	4.2	3.7	3.5	3.6	3.5	3.3	-16%	-34%
Other Manufacturing	21	16	13	12	12	13	12	12	-43%	-25%
Mining and Quarrying	4.1	3.9	5.4	4.9	5.3	5.8	5.2	5.3	28%	35%
Construction	1.9	1.4	1.4	1.4	1.4	1.6	1.5	1.6	-17%	7.9%
Commercial and Institutional	**26**	**32**	**38**	**35**	**33**	**35**	**33**	**32**	**24%**	**0.2%**
Residential	**43**	**43**	**41**	**38**	**37**	**39**	**35**	**35**	**-19%**	**-19%**
Agriculture/Forestry/Fishing	**2.4**	**2.2**	**3.3**	**3.1**	**3.2**	**3.3**	**3.2**	**3.4**	**43%**	**57%**

Note: Totals may not add up due to rounding.

Public Electricity and Heat Production (2024 GHG emissions, 57 Mt)

Emissions from this category vary with the characteristics of an instantaneous demand and with fluctuations between low GHG-emitting and high GHG-emitting supply sources. Between 1990 and 2024, Statistics Canada (StatCan) data shows electricity generation (driven by demand) increased by 30% (StatCan, n.d. [c]), from 433 TWh[7] to 562 TWh. Despite the increase in demand over this period, GHG emissions dropped by 39% (37 Mt) between 1990 and 2024. This is a 53% decrease in GHG emissions per kilowatt-hour (see Annex 7 for further details). Likewise, between 2005 and 2024, electricity generation rose by 1.0%, while corresponding emissions fell by 53% (65 Mt). Over both periods, the principal cause of the decrease in emissions is a considerably less GHG-intensive mix of sources used to generate electricity (Figure 2–11).

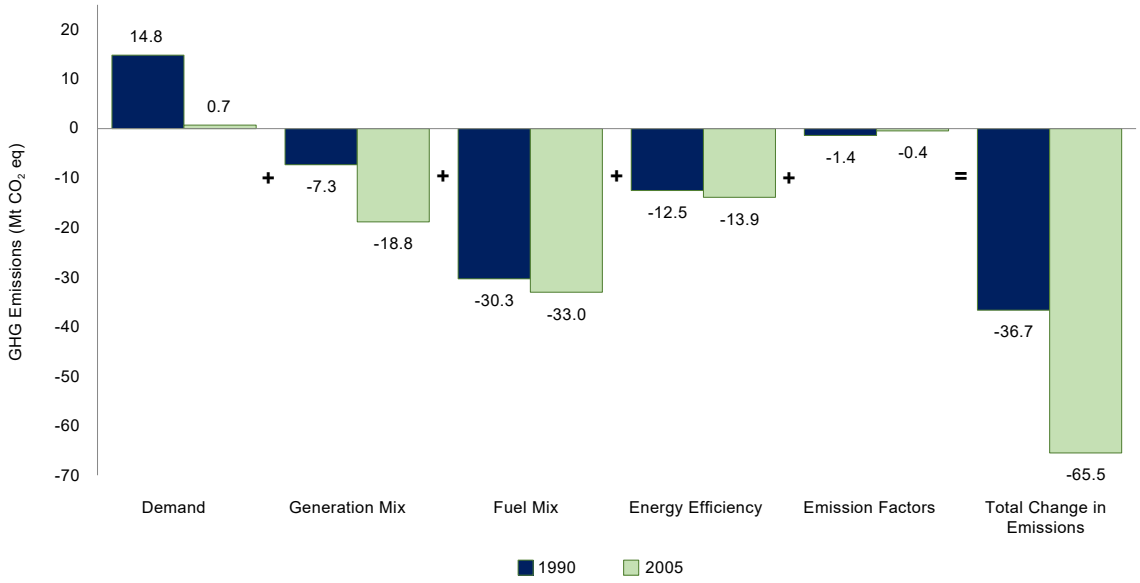
Low-emitting non-combustion sources—hydroelectric generation, nuclear power and non-hydro renewables (wind turbines, solar photovoltaic cells and tidal power)—accounted for 94% of the increased generation between 1990 and 2024 and for 81% of the total electricity generated in Canada in 2024. Hydroelectric generation alone accounted for 57% of the total electricity generated in 2024, followed by nuclear power generation at 14% and non-hydro-based renewables at 9%. The increased level of non-combustion sources in the generation mix in 2024 was the second-largest contributor to emission reductions since 2005 (19 Mt).

The largest contributor to emission reductions since 2005 is a steady move to a less GHG-intensive mix of fuels for combustion generation. Between 2005 and 2024, the quantity of electricity generated by natural gas-fired units increased by 194% (58 TWh), while the amount generated by coal and refined petroleum products decreased by 84% (79 TWh) and 77% (8.3 TWh), respectively. Natural gas combustion is about half as carbon-intensive as coal and approximately 25% less carbon-intensive than most refined petroleum products. The overall impact of the displacement of coal and refined petroleum products by natural gas is a decrease of about 30 Mt between 1990 and 2024, and about 33 Mt between 2005 and 2024.

The efficiency of combustion equipment has also played a role in the GHG emission reductions. Energy efficiency improvements resulted in an approximately 13 Mt reduction in GHG emissions between 1990 and 2024 and a 14 Mt reduction between 2005 and 2024.

7 1 TWh is 1 billion kWh. It is the amount of electricity consumed by about 90,000 households in Canada in approximately one year.

Figure 2–11 **Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 1990–2024 and 2005–2024**



Notes:
Demand – Demand refers to the level of electricity generation activity in the utility sector and consists of generation from combustion and non-combustion sources.
Generation mix – The generation mix refers to the relative share of combustion and non-combustion sources in generation activity.
Fuel mix (combustion generation) – Fuel mix refers to the relative share of each fuel used to generate electricity.
Energy efficiency – Energy efficiency refers to the efficiency of the equipment used in combustion-related generation of electricity.
Emission factors – The emission factor effect reflects changes to where fuels are sourced and their energy content over time.

Petroleum Refining (2024 GHG emissions, 15 Mt)

From 1990 to 2024, GHG emissions from the Petroleum Refining category decreased by 3.7 Mt (20%). This reflects a consolidation of the industry during that period. In 1990, 27 refineries were in operation in Canada with an average crude oil capacity of approximately 11,000 m^3 per day (CER, 2018) whereas in 2024, there were 16 operating refineries with an average capacity of approximately 18,500 m^3 per day (CAPP, 2025). Since 2005, five refineries have permanently closed or converted to terminal facilities with one converting to a biofuel facility: North Atlantic Come-By-Chance (2020), Imperial Oil Dartmouth (2013), Parkland Bowden (2012), Shell Montreal (2010), and Petro-Canada Oakville (2005). These closures contributed to a decrease of 5.4 Mt (27%) in emissions between 2005 and 2024.

Oil and Gas Extraction and Other Energy Industries (2024 GHG emissions, 110 Mt)

Stationary combustion emissions from Oil and Gas Extraction and Other Energy Industries increased by 79 Mt (254%) between 1990 and 2024 and by 47 Mt (74%) between 2005 and 2024. This category includes emissions associated with fuel combustion for Oil and Gas Extraction (Natural Gas Production and Processing, Conventional Oil Production, Thermal In-situ Production, and Oil Sands Mining, Extraction and Upgrading), Coal Production, and Biofuel Manufacturing. The increase between 2005 and 2024 is driven by Oil and Gas Extraction (46 Mt), with significantly smaller increases in Biofuel Manufacturing (0.7 Mt) and Coal Production (0.2 Mt).

Increases in emissions for Oil and Gas Extraction are consistent with a 276% increase in the production of non-upgraded crude bitumen and synthetic crude oil from the oil sands industry since 2005 (AER, n.d.) and the increased use of more energy-intensive extraction techniques, such as horizontal drilling, hydraulic fracturing and enhanced oil recovery.

In the oil sands/heavy oil industry, crude oil extraction occurs through surface mining, in situ thermal extraction techniques such as steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS), or through primary production methods that are similar to conventional oil production techniques. Thermal extraction processes involve the injection of large volumes of steam, typically produced by combusting natural gas, into the producing formation. In general, while emission increases from Oil and Gas Extraction may originate from multiple activities, they tend to be consistent with a 100% increase in natural gas consumption since 2005, coinciding with a 467% increase in in situ thermal crude bitumen / heavy oil production (AER, n.d.; Petrinex, n.d.) in Alberta and Saskatchewan, primarily from SAGD operations. In contrast, since 2005, natural gas production has increased by just 5% (StatCan, n.d.[h]) while conventional oil production, including primary production of crude bitumen in oil sands areas, has increased by only 12% (AER, n.d., StatCan, n.d.[d], n.d.[e]).

Additional information about the Oil and Gas Extraction category is provided in Table 2–14, where emissions are broken down by economic sectors (Natural Gas Production and Processing, Conventional Oil Production, and Oil Sands and Thermal Heavy Oil Production). Section 2.4.1 presents a short discussion of trends in the oil and gas industry by economic sector.

Manufacturing Industries and Construction (2024 GHG emissions, 45 Mt)

Combustion-based GHG emissions from the Manufacturing Industries and Construction category include the combustion of fossil fuels by several industries: Iron and Steel; Non-Ferrous Metals; Chemicals; Cement; Pulp, Paper and Print; Other Manufacturing; Mining; and Construction.

In 2024, GHG emissions from the Manufacturing Industries and Construction category were 45 Mt, which represents a 28% (17 Mt) decrease from 1990 and a 14% (7.2 Mt) decrease from 2005. The decrease between 2005 and 2024 is driven by Other Manufacturing (-4.1 Mt), Pulp, Paper and Print (-2.8 Mt), Cement (-1.7 Mt), Non-Ferrous Metals (-0.9 Mt), and Iron and Steel (-0.4 Mt), offset by an increase in Mining and Quarrying (1.4 Mt), Chemicals (1.2 Mt), and Construction (0.1 Mt).

As with Electricity Generation, emission decreases in Manufacturing Industries and Construction largely resulted from decreases in fuel combustion and fuel switching to lower GHG-intensive fuels. In 1990, natural gas made up 89% of the fuel mix in Other Manufacturing, while in 2024 it only accounted for 67%. Wood consumption primarily replaced the natural gas, which together accounted for 97% of the fuel mix in 2024. In 1990, heavy fuel oil made up 17% of the fuel mix in the Pulp, Paper and Print subcategory while in 2024, 99% of the fuel mix consisted of less GHG-intensive fuels such as natural gas, spent pulping liquor and wood waste. In contrast, combustion emissions from chemical industries showed an increase in emissions of 1.2 Mt (15%). At the same time, production of chemicals grew 44% (CEEDC, n.d.) between 1990 and 2024.

Other Sectors (2024 GHG emissions, 71 Mt)

The Other Sectors category includes emissions from the Residential, Commercial and Institutional, and Agriculture and Forestry subcategories. GHG emissions in the Residential and the Commercial and Institutional subcategories come from the combustion of fuels such as natural gas, home heating oil and biomass fuels (non-CO_2 only), primarily to heat residential, commercial and institutional buildings. Emissions in these categories contributed 67 Mt of GHG emissions in 2024, a 3.0% decrease since 1990. Emissions in the Agriculture and Forestry subcategory largely result from the combustion of fuels for activities such as grain drying and heating barns, buildings, or greenhouses. Emissions in this subcategory showed an increase of 1.0 Mt (43%).

Overall, Residential emissions decreased by 8.4 Mt (19%) between both 1990 and 2024 and 2005 and 2024. In contrast, Commercial and Institutional emissions increased by 6.3 Mt (24%) from 1990 to 2024 and by 0.06 Mt (0.19%) from 2005 to 2024. Energy efficiency improvements, new home construction, increases in population and increases in commercial floor space are the major factors that influenced the changes in energy-related emissions in the Residential and the Commercial and Institutional subcategories (Figure 2–12 and Figure 2–13).

In the Residential subcategory, population and floor space per capita are the most significant upward drivers of emissions, although their effects have been more than offset by improvements in energy efficiency, which are equivalent to a 24.8 Mt decrease in emissions between 1990 and 2024. Decreasing consumption of light fuel oil in all provinces and territories, especially Quebec and Ontario, between 1990 and 2024 is the largest driver of the 1.3 Mt decrease in the fuel mix contributing to residential emissions in that period.

In the long term, floor space was the most significant upward driver of emissions in the Commercial and Institutional subcategory, having increased by 52% since 1990.[8] The resulting 11.8 Mt increase in emissions was partially offset by improvements in the fuel mix and energy efficiency, equivalent to a 1.2 Mt and 0.4 Mt decrease in GHG emissions, respectively (Figure 2–13).

Weather patterns can influence emissions when comparing different years, as suggested by the close relationship between heating degree-days (HDDs) and GHG emissions (Figure 2–14). The impact that weather can have on space heating requirements and fuel demand results in emission patterns that mirror interannual weather variability.

8 Lasota, M. 2026. Personal communication (email from Lasota M. to Kay J., Physical Scientist, PIRD, dated January 13, 2026). Economic Analysis Directorate, Environment and Climate Change Canada.

Figure 2–12 **Factors Contributing to the Change in Stationary GHG Emissions from the Residential Category between 1990 and 2024**

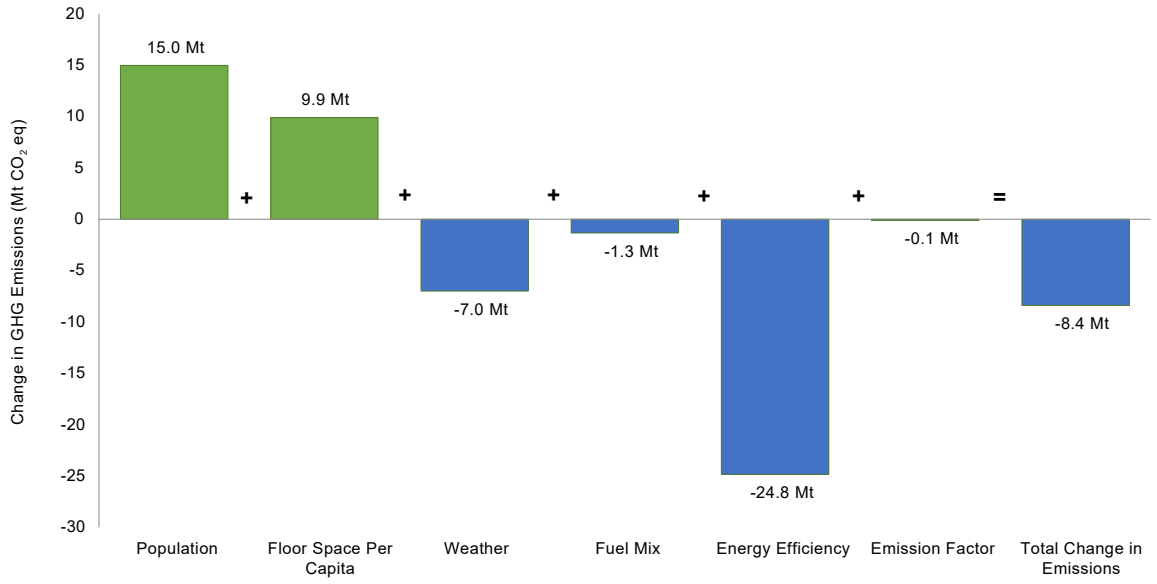
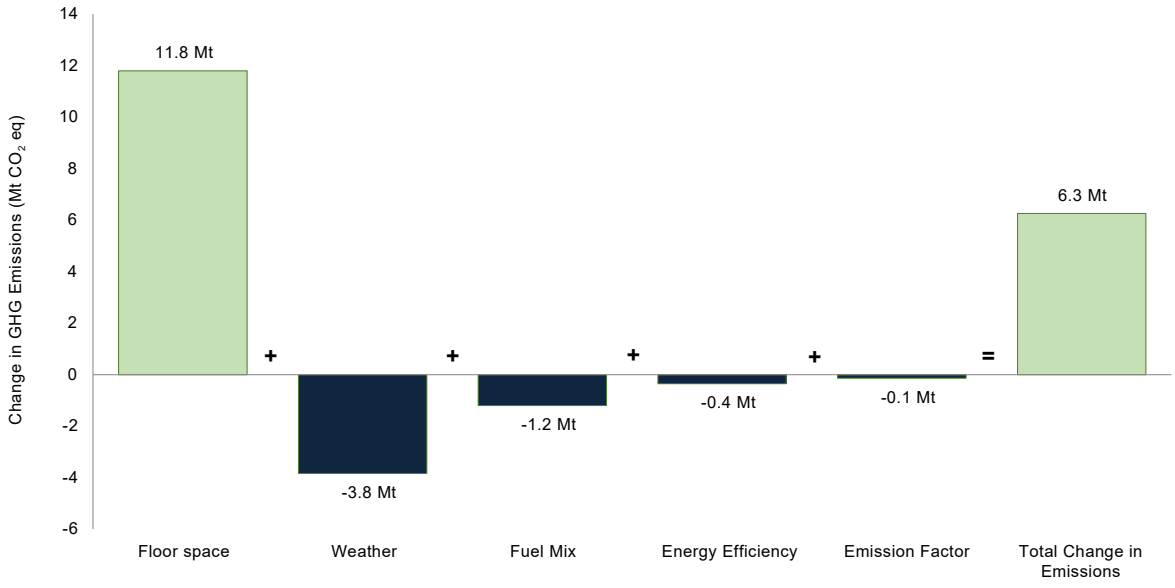


Figure 2–13 **Factors Contributing to the Change in Stationary GHG Emissions from the Commercial and Institutional Category between 1990 and 2024**



Notes:

Floor space and population – Floor space refers to the change in total floor area over time. In the case of the residential sector, floor space is further broken down into the change in population and the change in floor space per capita.

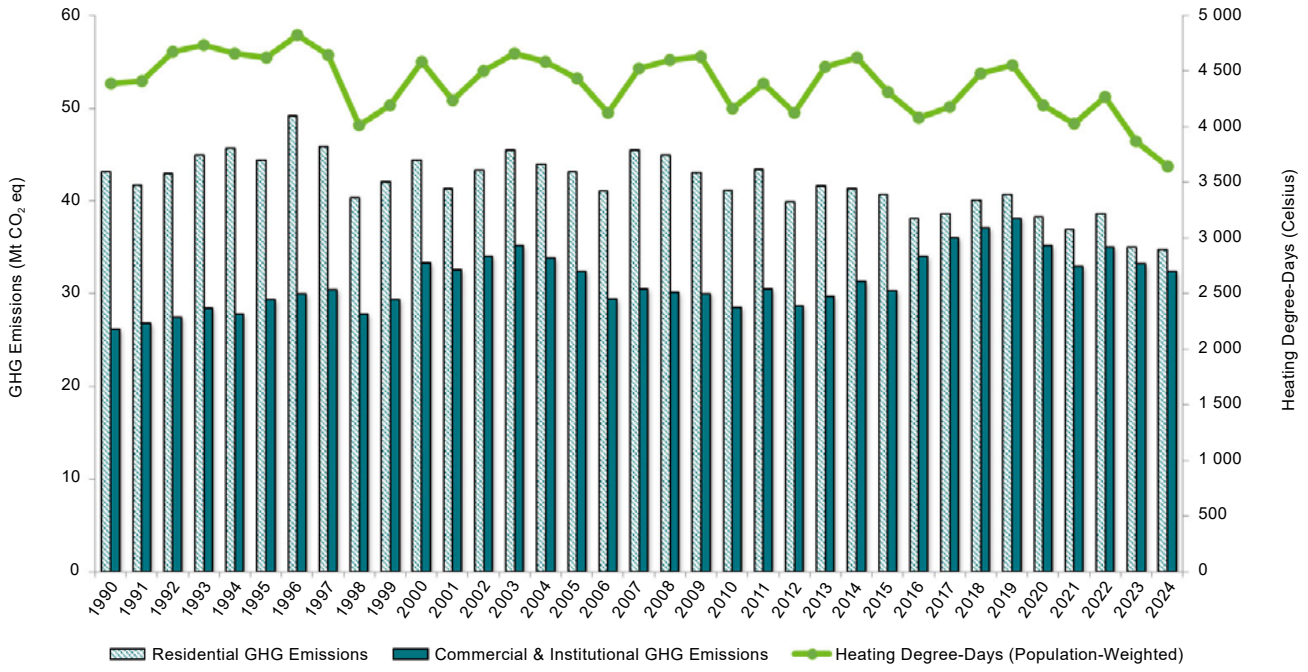
Weather – Weather refers to the fluctuations in weather conditions, particularly outdoor winter temperature.

Fuel mix – Fuel mix refers to the relative share of each fuel used to provide heating.

Energy efficiency – Energy efficiency refers to the efficiency of the buildings and heating equipment.

Emission factors – The emission factor effect reflects changes to where fuels are sourced and their energy content over time.

Figure 2–14 **Heating Degree-Days (HDDs) and GHG Emissions from the Residential and the Commercial and Institutional Categories (1990–2024)**



2.3.1.2. Transport (2024 GHG emissions, 189 Mt)

Transport is a large and diverse sector, accounting for 189 Mt of GHG emissions or 28% of Canada's Energy sector emissions in 2024. Transport includes emissions from fuel combustion in five categories: Road Transportation, Aviation, Marine, Railways, and Other Transportation (Off-Road and Pipelines) (Table 2–6). From 1990 to 2024, Transport emissions rose by 30% (44 Mt), accounting for a significant portion of Canada's emissions growth. Between 2019 and 2020, Transport emissions decreased by 15% (32 Mt), the first notable year-to-year decrease to occur since 2008–2009, which had a year-to-year decrease of 2.6% (5.0 Mt). Between 2020 and 2024, Transport emissions increased by 7.3% (13 Mt).

Emissions from Transport result primarily from Road Transportation, which includes personal transportation (light-duty gasoline vehicles and trucks) and heavy-duty diesel vehicles, accounting for 63% of Transport emissions in 2024 (Figure 2–15). Other Transportation (Off-Road and Pipelines) is the second-largest category, accounting for 28% of Transport emissions in 2024, mainly through the combustion of diesel fuel used in off-road applications. The Aviation category was relatively stable over the reported time series until 2020, when it underwent a 45% (3.8 Mt) decrease of emissions from 2019 levels. Between 2020 and 2024, the Aviation category increased by 70% (3.3 Mt). The Marine and Railways categories combined contributed approximately 4.9% of the Transport emissions in 2024 and, overall, were stable over the 1990–2024 time series.

Figure 2–15 **Trends in Canadian GHG Emissions from Transport (1990–2024)**

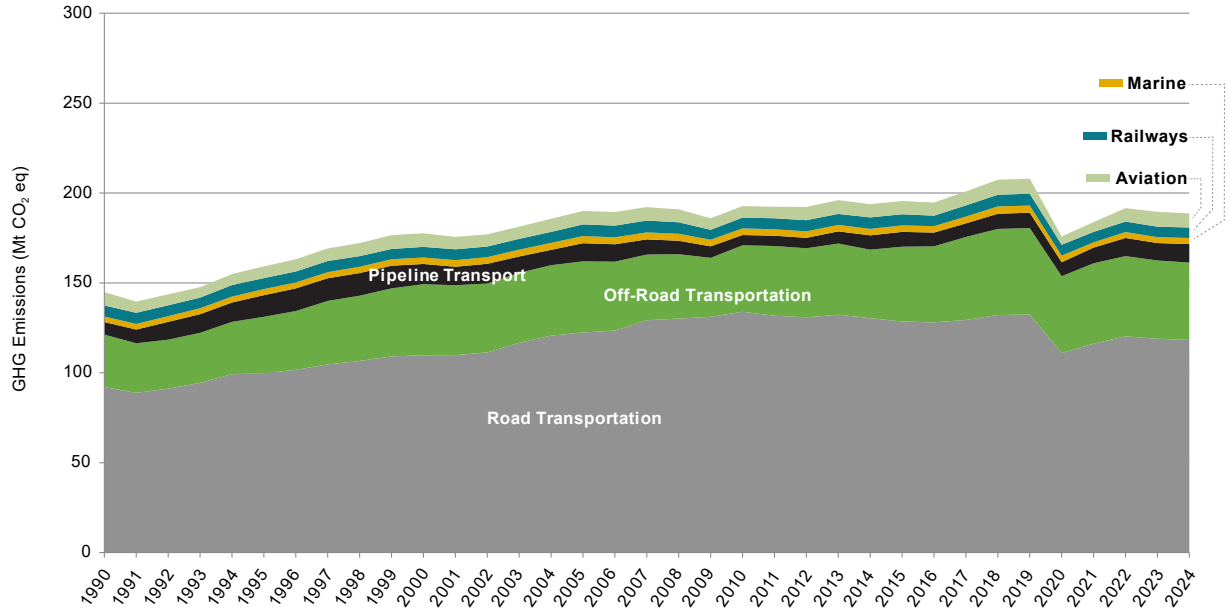


Table 2–6 **GHG Emissions from Transport, Selected Years**

CRT Category		GHG Emissions (Mt CO_2 eq)								Change (%)	
		1990	2005	2019	2020	2021	2022	2023	2024	1990–2024	2005–2024
TRANSPORT		**145**	**190**	**208**	**176**	**184**	**192**	**190**	**189**	**30%**	**-0.7%**
Aviation		**7.5**	**7.7**	**8.6**	**4.7**	**5.6**	**7.7**	**8.4**	**8.1**	**7.5%**	**4.6%**
1.A.3.a	Domestic Aviation (Civil)	7.3	7.5	8.3	4.6	5.4	7.5	8.2	7.9	7.9%	5.3%
1.A.5.b	Military	0.23	0.26	0.24	0.18	0.20	0.20	0.20	0.22	-6.2%	-16%
Road Transportation		**92**	**122**	**132**	**111**	**116**	**120**	**119**	**118**	**29%**	**-3.3%**
1.A.3.b.i	Light-Duty Gasoline Vehicles	44	41	31	24	25	25	25	24	-47%	-42%
1.A.3.b.ii	Light-Duty Gasoline Trucks	25	41	56	47	49	51	52	53	117%	30%
1.A.3.b.iii	Heavy-Duty Gasoline Vehicles	4.8	4.6	4.6	4.2	4.2	3.9	4.0	4.1	-15%	-12%
1.A.3.b.iv	Motorcycles	0.20	0.46	0.96	0.75	0.80	0.75	0.76	0.78	282%	70%
1.A.3.b.i	Light-Duty Diesel Vehicles	0.37	0.66	0.43	0.31	0.33	0.36	0.31	0.29	-20%	-56%
1.A.3.b.ii	Light-Duty Diesel Trucks	1.0	0.75	0.80	0.64	0.77	0.98	0.91	0.87	-12%	17%
1.A.3.b.iii	Heavy-Duty Diesel Vehicles	16	34	39	33	36	38	36	35	118%	2.6%
1.A.3.b.v	Propane and Natural Gas Vehicles	0.76	0.02	0.14	0.15	0.16	0.17	0.16	0.16	-79%	583%
1.A.3.c	Railways	6.1	6.5	6.5	6.0	5.8	5.8	5.8	5.8	-4.2%	-10%
Marine		**3.1**	**4.0**	**4.0**	**3.8**	**2.9**	**3.3**	**3.3**	**3.4**	**10%**	**-14%**
1.A.3.d	Domestic Navigation	2.2	3.1	3.8	3.5	2.8	3.2	3.2	3.3	50%	7.9%
1.A.4.c.iii	Fishing	0.87	0.87	0.20	0.20	0.13	0.12	0.11	0.10	-88%	-88%
1.A.5.b	Military Water-Borne Navigation	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	-48%	-45%
Other Transportation		**36**	**50**	**57**	**50**	**53**	**55**	**53**	**53**	**47%**	**7.2%**
1.A.4.c.ii	Off-Road Agriculture and Forestry	8.7	10	14	12	13	13	12	12	37%	20%
1.A.4.a.ii	Off-Road Commercial and Institutional	4.3	4.5	5.9	5.3	5.8	5.9	5.9	6.0	40%	33%
1.A.2.g.vii	Off-Road Manufacturing, Mining and Construction	12	16	20	17	18	18	17	18	41%	8.1%
1.A.4.b.ii	Off-Road Residential	0.37	1.2	1.0	1.0	0.91	0.84	0.83	0.76	105%	-38%
1.A.3.e.ii	Off-Road Other Transportation	3.5	7.7	7.5	6.9	7.1	7.0	6.9	6.8	95%	-12%
1.A.3.e.i	Pipeline Transport	6.9	10	8.5	7.8	8.7	10	9.7	10	49%	1.8%

Road Transportation (2024 GHG emissions, 118 Mt)

Emissions from Road Transportation are influenced by several factors, including vehicle kilometres travelled (VKT), vehicle type, fuel efficiency, fuel type, emission control technology and biofuel consumption.

The growth trend since 1990 in Road Transportation emissions is largely due to more driving as measured in VKT, which is the net result of changes to annual vehicle kilometre accumulation rates (KAR) and the size of the vehicle fleet. In 2020, total VKT decreased by 17% relative to 2019 levels, driven by reductions to KAR. In 2024, total VKT is 15% higher than 2020 levels but is 4.5% below 2019 levels.

The total vehicle fleet has increased by 61% since 1990 (35% since 2005), most notably for light-duty trucks, which have steadily increased throughout the 1990–2024 time series (Table 2–7). The heavy-duty vehicle fleet steadily increased for most of the time series but has plateaued in recent years. The light-duty car fleet was relatively stable for much of the time series but has noticeably decreased in recent years.

Despite decreases to total VKT from 2019 levels, the steady expansion of the overall fleet resulted in the total VKT for 2024 being 76% and 24% greater than the 1990 and 2005 totals, respectively. While no emissions were reported for electric vehicles in the Transport sector, the fleet has grown exponentially in recent years. In 2024, approximately 491 000 fully electric vehicles were in the vehicle fleet, a 50% growth from 2023 (StatCan, n.d.[f]).

Table 2–7 **Trends in Vehicle Populations for Canada, Selected Years**

Year	Number of Vehicles (000s)			
	Light-Duty Vehicles		Heavy-Duty Vehicles	All Vehicles
	Cars	Trucks		
1990	10 860	4 062	1 085	16 284
2005	10 509	6 925	1 637	19 514
2019	10 031	12 640	1 937	25 357
2020	9 843	13 114	1 943	25 652
2021	9 888	13 412	1 976	26 095
2022	9 387	13 406	1 932	25 535
2023	9 017	13 605	1 948	25 384
2024	8 994	14 439	2 007	26 298
Change since 1990	-17%	255%	85%	61%
Change since 2005	-14%	109%	23%	35%

Notes:
Light-duty trucks include most pickups, minivans and sport utility vehicles.
"All vehicles" also include motorcycles and natural gas and propane vehicles.
Vehicle populations do not include electric vehicles.

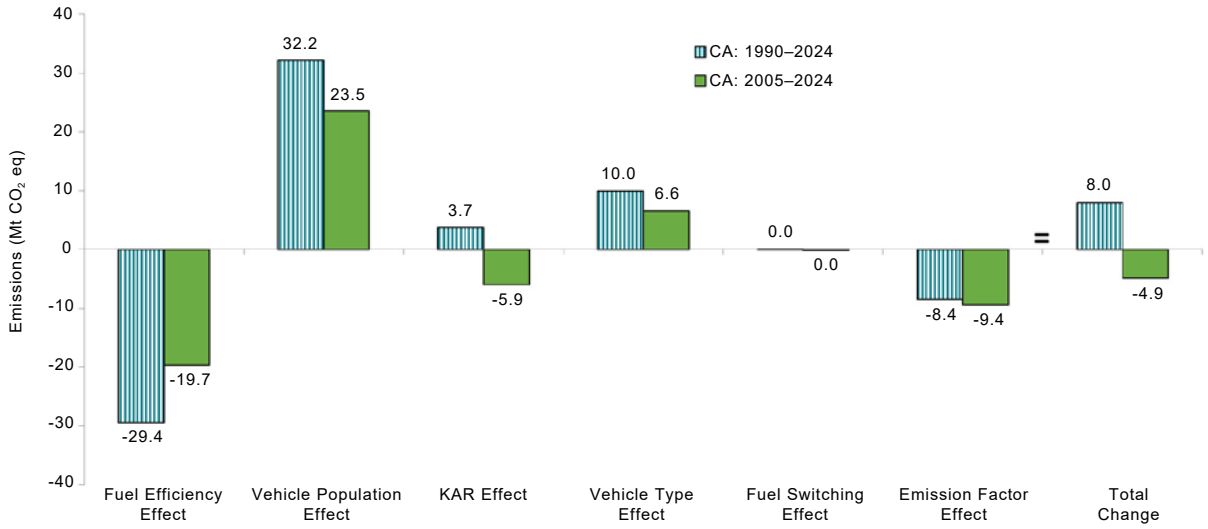
Light-Duty Gasoline Vehicles (2024 GHG emissions, 24 Mt)

Since 1990, emissions from Light-Duty Gasoline Vehicles (i.e., passenger cars) have steadily decreased and in 2024 were 47% (21 Mt) and 42% (17 Mt) lower than those in 1990 and 2005, respectively. These decreases are largely due to increased fleet-average fuel efficiency, decreased average annual driving rates and reduced sales of passenger cars. As new model year vehicles replace older, less efficient ones, the overall fleet fuel efficiency improves. However, the reduced sales of passenger cars are offset by increased sales of light-duty trucks, which emit significantly more GHGs per kilometre. The implementation of emission control technologies and increased use of biofuels have also contributed to decreased emissions (Figure 2–16).

Light-Duty Gasoline Trucks (2024 GHG emissions, 53 Mt)

Since 1990, emissions from Light-Duty Gasoline Trucks, which include sport utility vehicles (SUVs), many pickups and all minivans, have steadily increased, with estimates in 2024 being 117% (29 Mt) and 30% (12 Mt) higher than those in 1990 and 2005, respectively. These increases are largely due to increased sales of light-duty trucks, mitigated somewhat by increased fleet-average fuel efficiency, the implementation of emission control technologies and increased use of biofuels (Figure 2–16). Since 2005, emissions from the light-duty gasoline trucks category have been the top contributor to transportation emissions totals, making up 22% and 28% of that total for 2005 and 2024, respectively.

Figure 2–16 **Factors Contributing to Changes in Light-Duty Vehicle Emissions, 1990–2024 and 2005–2024**



Notes:

Fuel economy, fuel efficiency and fuel consumption ratios are all metrics which describe the efficacy with which a vehicle can obtain energy from fuel, typically presented in either the volume of fuel needed to move a vehicle a prescribed distance (litres/100 km) or the distance a vehicle can travel for a prescribed amount of fuel (miles per gallon - mpg).

Kilometre accumulation rate (KAR) is the average distance travelled by a single vehicle of a given class typically measured over one year, while vehicle kilometres travelled is the total distance travelled by all vehicles of a given class (KAR multiplied by the vehicle population in that class) over that same period.

Total change is the difference in total emissions over the selected time periods, 1990–2024 and 2005–2024.

Fuel efficiency effect refers to the change in emissions due to the change in fuel consumption rates (expressed as litres/100 km).

Vehicle population effect refers to the change in emissions attributable to the change in the total number of fossil fuel powered light-duty vehicles on Canadian roads.

Kilometre accumulation (KAR) effect refers to the change in emissions due to average annual driving rates.

Vehicle type effect refers to the change in emissions due to the shift between different vehicle types (e.g. cars and trucks).

Fuel switching effect refers to the change in emissions due to the shift between fuels (e.g. motor gasoline vs. diesel fuel).

Overall emission factor effect refers to the change in emissions from emission control technologies on CH_4 and N_2O emissions as well as the use of biofuels.

Heavy-Duty Diesel Vehicles (2024 GHG emissions, 35 Mt)

From 1990 to 2011, emissions from Heavy-Duty Diesel Vehicles steadily increased, peaking at 46 Mt in 2011. Since then, emissions from these vehicles have followed a downward trend, largely due to decreased average annual driving rates and reduced growth of the heavy-duty vehicle fleet. In 2024, emissions from these vehicles were estimated to be about 35 Mt, which is 118% (19 Mt) and 2.6% (0.9 Mt) higher than those in 1990 and 2005, respectively. These increases are largely due to the expansion of the heavy-duty vehicle fleet, particularly those with a gross vehicle weight rating below 4,536 kilograms. However, increases to the fleet-average fuel efficiency and decreases to average annual driving rates heavily mitigated emissions growth.

Other Transportation: Off-Road (2024 GHG emissions, 43 Mt)

Off-road emissions primarily result from the combustion of diesel and gasoline in a wide variety of applications, including heavy mobile equipment used in the construction, mining and logging industries; agricultural tractors and combines; recreational vehicles, such as snowmobiles and all-terrain vehicles (ATVs); and residential equipment, such as lawnmowers and trimmers. In 2024, the Off-Road Manufacturing, Mining and Construction subcategory and the Off-Road Agriculture and Forestry subcategory accounted for 41% and 28% of off-road emissions, respectively. The net emissions for all off-road subcategories have increased by 47% (14 Mt) since 1990 and increased by 8.6% (3.4 Mt) since 2005. These increases are largely due to increased fleet-average engine power as well as increased total equipment use.

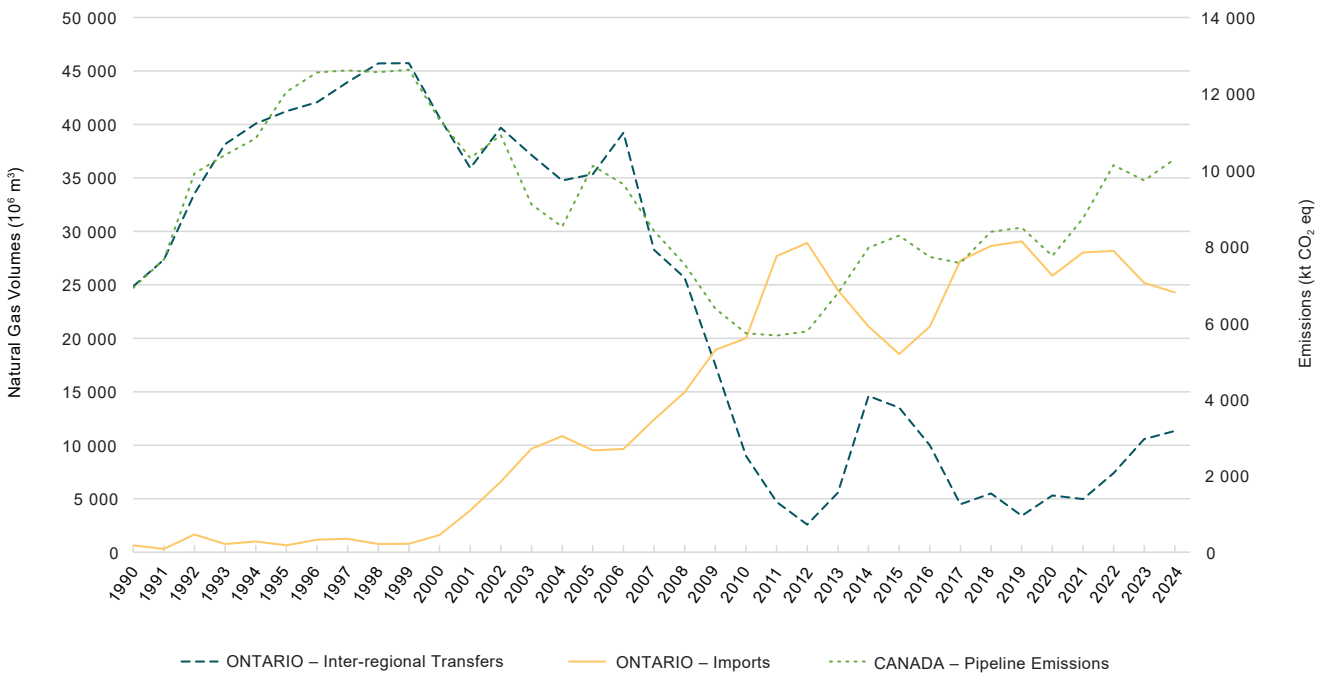
Other Transportation: Pipeline Transport (2024 GHG emissions, 10 Mt)

Pipeline emissions result from the combustion of natural gas at compressor stations used for natural gas transport. In 2024, over 99% of marketable natural gas production occurred in western Canada: Alberta (62%), British Columbia (36%) and Saskatchewan (1.6%). While these provinces account for approximately 63% of marketable natural gas consumption in Canada, Ontario, the most populous province, accounts for approximately 26% of natural gas consumption but produces only 0.03% of natural gas (StatCan, n.d.[c]). The natural gas demand in Ontario, along with the geographical separation from producing regions, necessitates the long-range transport of natural gas through transmission pipelines. For that reason, the source of the natural gas consumed in Ontario has a large impact on pipeline emissions.

Historically, inter-regional transfers of large quantities of western Canadian natural gas to eastern Canada, especially Ontario, has been the main driver of pipeline emissions. The amount of gas transported from west to east has decreased starting in the early 2000s as western Canadian natural gas was displaced by imports from the United States (StatCan, n.d.[c]) and as more natural gas was consumed in Alberta's oil sands industry. In general, as imports into Ontario increase, inter-regional transfers of gas from western Canada decline, resulting in a decrease in combustion emissions from pipelines (Figure 2–17).

The increase in emissions from 2023 to 2024 reflects a 6% increase in natural gas consumption resulting from an 8% increase in volumes of natural gas transported from Alberta to other provinces and a 7% increase in exports to the United States.

Figure 2–17 **Relationship between Canadian Pipeline Emissions, US Imports into Ontario and Inter-Regional Transfers of Western Canadian Natural Gas**



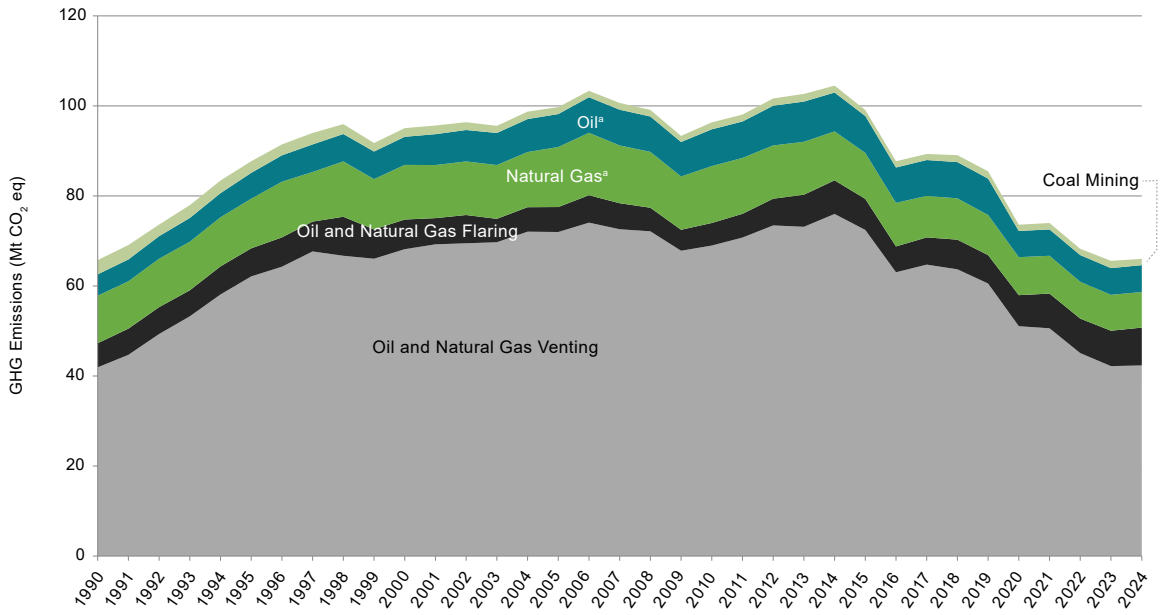
2.3.1.3. Fugitive Sources (2024 GHG Emissions, 66 Mt)

Fugitive emissions are intentional or unintentional releases of GHGs from the production, processing, transmission, storage, delivery and consumption of fossil fuels. Released hydrocarbon gases that are disposed of by combustion (e.g., flaring of natural gases at oil and gas production and processing facilities) and post-production emissions, including those from abandoned coal mines and abandoned oil and gas wells, as well as post-meter fugitive emissions from natural gas appliances, are all considered fugitive emissions. Fugitive Sources are broken down into two main categories: Oil and Natural Gas (98% of fugitive emissions) and Coal Mining (2%).

Fugitive emissions increased by 0.2 Mt (0.4%) between 1990 (66 Mt) and 2024 (66 Mt) (Table 2–8) with considerably more variation over the time series. Fugitive emissions peaked in 2014 at 105 Mt (Figure 2–18), 59% higher than 1990. Fugitive emissions from Oil and Natural Gas alone increased by 40 Mt (65%) over this period, while releases from Coal Mining decreased by 1.6 Mt (52%), mainly due to mine closures in eastern Canada.

Although oil sands production represented approximately 71% of total oil production in 2024, it accounted for only 19% of total oil and gas fugitive emissions. Since most fugitive emissions originate from conventional oil and natural gas production and processing activities, the increase in crude bitumen production from the oil sands has little impact on fugitive emissions. In contrast, oil sands production has a large impact on combustion emissions (refer to section 2.3.1.1).

Figure 2–18 **Trends in Canadian GHG Emissions from Fugitive Sources (1990–2024)**



Note:
a. These categories represent fugitive releases due to leakage from oil and natural gas systems.

Table 2–8 **GHG Emissions from Fugitive Sources, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2019	2020	2021	2022	2023	2024	1990–2024	2005–2024
FUGITIVE SOURCES[a]	**66**	**100**	**85**	**74**	**74**	**68**	**66**	**66**	**0%**	**-34%**
Coal Mining	**3.2**	**1.5**	**1.6**	**1.4**	**1.4**	**1.4**	**1.6**	**1.4**	**-57%**	**-12%**
Oil and Natural Gas	**63**	**98**	**84**	**72**	**73**	**67**	**64**	**65**	**3.3%**	**-34%**
Oil[b]	4.7	7.3	8.1	5.8	5.9	5.9	5.9	6.0	26%	-19%
Natural Gas[b]	11	13	8.9	8.5	8.4	8.2	8.0	7.9	-25%	-41%
Venting	42	72	61	51	51	45	42	42	1.0%	-41%
Flaring	5.4	5.6	6.3	6.9	7.7	7.7	7.8	8.4	56%	51%

Notes:
a. Totals may not add up due to rounding.
b. These categories represent fugitive releases due to leakage from oil and natural gas systems.

The trend in fugitive oil and gas emissions can be broken down into three main periods:

1. 1990–2000: rapid growth in emissions
2. 2000–2014: relative stability
3. 2014–2024: declining emissions

Fugitive oil and gas emissions increased steadily from 63 Mt in 1990 to 93 Mt in 2000 (49%). Additionally, over 120,000 oil and gas wells were drilled between 1990 and 2000 (CAPP, n.d. [a]). As the number of extraction and processing facilities in the oil and gas industry increases, the number of potential sources of fugitive emissions also grows, driving the increase in emissions. From 2000 to 2014, the oil and gas industry continued to grow substantially, but fugitive emissions did not grow at the same rate, because of the combined effect of improved inspection and maintenance programs, better industry practices, technological improvements and initiatives by provincial regulators. For example, in 1999, the province of Alberta introduced *Directive 060: Upstream Petroleum Industry Flaring, Incinerating, and Venting* to reduce flaring and venting emissions from its oil industry by requiring operators to connect to gas gathering systems under specific conditions (AER, 2014). In 2006, leak detection and repair best management practices were added to Directive 060 to reduce emissions from fugitive equipment leaks. In 2010, British Columbia introduced the *Flaring and Venting Reduction Guideline* (BCOGC, 2015), and in 2012, Saskatchewan adopted *Directive S-10: Saskatchewan Upstream Petroleum Industry Associated Gas Conservation Standards*, both of which have similar goals to Alberta's Directive 060.

Despite these efforts, fugitive oil and gas emissions increased by 9.8 Mt (10%) between 2000 and 2014, peaking in 2014 at 103 Mt. This was mainly due to significant expansion of the industry as the number of operating oil and gas wells increased by over 100% and approximately 270,000 new wells were drilled. These trends indicate that while the various measures had a positive impact on emission reductions, they were not enough to counteract the continued expansion of the industry, as operators required more and more wells to maintain production levels. In fact, between 2000 and 2014 the average production per oil well decreased by about 38% (CAPP, n.d. [a]; StatCan, n.d.[d], n.d.[e]) and the average production per natural gas well decreased by 62% in western Canada (CAPP, n.d. [a]; StatCan, n.d.[g], n.d.[h]).

From 2014 to 2024, emissions dropped by 38 Mt (37%), mainly due to reductions in venting as more gas was conserved and further measures were adopted to mitigate unintentional leaks. This trend was partly driven by a gradual shift away from conventional heavy oil production in Saskatchewan and Alberta, including Cold Heavy Oil Production with Sand (CHOPS), towards in situ thermal heavy oil production techniques like SAGD. Gas produced from thermal heavy oil wells is predominantly conserved and consumed onsite to offset the significant energy demands of these operations. Compared to 2014, the number of active conventional heavy oil wells had decreased 36% by 2024, while the number of thermal heavy oil production wells grew by 17%. There was also an overall contraction within the sector as the number of operating wells decreased by 21% and the annual number of wells drilled fell by over 50% (CAPP, n.d. [b]).

Further to existing provincial directives, federal (ECCC, 2018) and equivalent[9] provincial regulations (AB, 2018; BC, 2021; SK, 2020) to reduce CH_4 emissions from oil and gas operations came into effect January 1, 2020. Since the regulations have been in force, natural gas production has increased by 16%, and while the number of operating oil and gas wells remained roughly constant, the number of wells drilled increased by 90%. Improving compliance with the federal and provincial regulations likely offset expected increases that might have otherwise resulted from production growth. It should be noted that vent gas volume reporting requirements in Alberta, British Columbia and Saskatchewan were updated in 2020, resulting in a methodological inconsistency that may have artificially contributed to the decline in emissions over this period. See Annex 3.2, section A3.2.2.1.5 for more details.

Integrating Top-Down and Bottom-Up Methane Estimates for the Oil and Gas Sector

Accurately estimating fugitive emissions from oil and gas operations is a challenge. The industry in Canada includes tens of thousands of facilities, hundreds of thousands of wells and millions of components with the potential to emit. Traditional "bottom-up" approaches use engineering methods to estimate emissions for individual sources based on various data including component-level emission factors and populations, process simulations, metered or calculated volumes of gas vented or flared, etc.

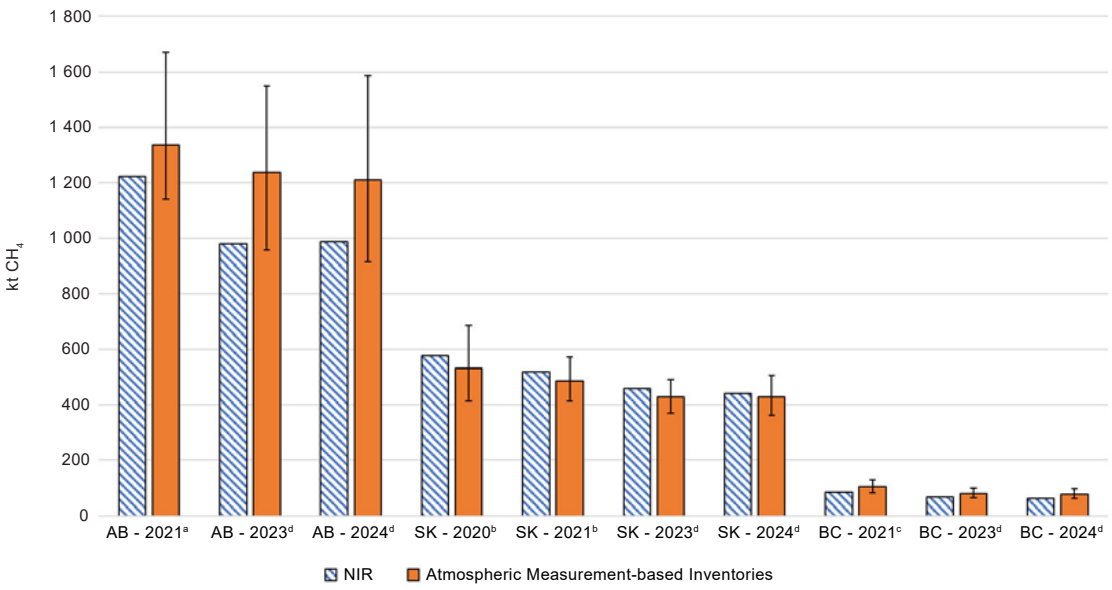
Studies in Canada that have used atmospheric measurements to derive "top-down" methane (CH_4) estimates have typically produced large-scale, regional or facility-level estimates and were not able to resolve emission sources within a facility (e.g., Atherton et al., 2017; Johnson et al., 2017; Zavala-Araiza et al., 2018; Chan et al., 2020; MacKay et al., 2021). Differences in the results from "top-down" and "bottom-up" approaches are unavoidable due to differing methodologies, data sources, level of detail, and other confounding factors. However, recent advances in measurement technology have enabled the development of a protocol to create robust source-resolved aerial measurement-based oil and gas methane inventories with defined uncertainties (Johnson et al., 2023). This protocol has been utilized to estimate methane emissions from oil and gas operations in British Columbia (Johnson et al., 2023), Alberta (Conrad et al., 2023a) and Saskatchewan (Conrad et al., 2023b).

Source-level emission estimates from aerial measurement-based inventories (Johnson et al., 2023; EERL, 2025) for unlit flares, storage tanks, compressors, wellheads, and engine sheds have been integrated into the emissions in this report, leading to improved accuracy of oil and gas methane emissions (Chan et al., 2024; MacKay et al., 2024). See Annex 3.2, section A3.2.2.1.5 for more details. Figure 2–A shows the comparison of oil and gas methane emission estimates from this inventory report with the aerial measurement-based inventories for Alberta, Saskatchewan and British Columbia. ECCC will continue to work with researchers to improve the integration of "bottom-up" inventory methods and aerial measurements with the goal of further improving the accuracy of inventory emissions and trends in future editions of this report.

9 Under the Canadian Environmental Protection Act, 1999 (CEPA), the Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector), SOR/2018-66 (the "federal methane regulations") were published in the Canada Gazette, Part II, vol. 152, no. 1 on April 26, 2018. The federal methane regulations came into force on January 1, 2020, except sections 26, 27 and 37 to 41, which came into force on January 1, 2023. Section 10 of CEPA authorizes the Minister of the Environment to enter into an equivalency agreement with a province, territory or aboriginal government if the provisions within that jurisdiction are equivalent to a regulation made under CEPA.

Equivalency agreements were established for the federal methane regulations with Alberta (ECCC, 2020a), British Columbia (ECCC, 2020b), and Saskatchewan (ECCC, 2020c).

Figure 2–A **Comparison of Aerial Measurement-based Methane Inventories with National Inventory Estimates**



Notes:
a. Conrad et al., 2023a. Subject to revision based on learnings from analysis of 2023, 2024, and future measurement campaigns.
b. Conrad et al., 2023b. Emission estimates updated by EERL (2025) to reflect revised strata, previously unsampled strata, and improved meteorological data.
c. Johnson et al., 2023. Emission estimates updated by EERL (2025) to reflect revised compressor counts, strata, and improved meteorological data.
d. EERL, 2025.

2.3.1.4. Trends in CO_2 Transport and Storage (2024 GHG Emissions, 0.65 kt)

Since 2000, the majority of captured CO_2 transport and storage activities in Canada have been associated with enhanced oil recovery (EOR) operations at Weyburn and Midale in Saskatchewan, utilizing captured CO_2 imported from the United States. In 2014, the Weyburn operations also began receiving most of the CO_2 captured at the Boundary Dam coal-fired power plant in Saskatchewan with the remaining amount transported to the Aquistore Project and its Basal Cambrian storage complex for injection directly into long-term storage (LTS).

In 2016, CO_2 capture began in Alberta for the purpose of LTS at a geological site. Shell's Quest project captures CO_2 from the Scotford upgrader and transports it 65 kilometres north to a LTS site. Since 2020, the Alberta CO_2 Trunk line has received CO_2 captured at the Nutrien fertilizer facility and Sturgeon refinery for use in EOR at a site near Clive, Alberta.

In 2024, a total of 4.32 Mt of captured CO_2 was available for LTS and EOR operations, with 3.45 Mt domestically captured and 870 kt imported (Chapter 3, Table 3–15). Domestically captured CO_2 volumes have increased by over 2900% since 2014 (3.34 Mt) while the cumulative LTS of captured CO_2 has increased by about 2600% since 2015 to 10 Mt at 2024 year-end.

Details of CO_2 capture volumes consistent with the origin of the captured CO_2 (a refinery, upgrading facility and coal-fired power plant) and these volumes are subtracted from emissions reported under Upstream Oil and Gas, and Petroleum Refining, in Alberta, and Public Electricity and Heat Production, in Saskatchewan are presented in the Relationship between GHG emissions by Canada's Economic Sectors and IPCC Sectors table in the Economic Sector folder on the Government of Canada's Open Data website.

Emissions from CO_2 transport systems in Canada are available on the Government of Canada's Open Data website in the IPCC Sector folder. In 2024, CO_2 pipeline fugitives accounted for about 0.6 kt of emissions while CO_2 injection sites accounted for 0.04 kt (see Chapter 3, Table 3–14).

2.3.2. Industrial Processes and Product Use (2024 GHG emissions, 53 Mt)

The IPPU sector includes GHG emissions that result from manufacturing processes and use of products. Subsectors include Mineral Products; Chemical Industry; Metal Production; Production and Consumption of Halocarbons, SF_6 and NF_3; Non-Energy Products from Fuels and Solvent Use; and Other Product Manufacture and Use. Emissions from the IPPU sector contributed 53 Mt (7.8%) to Canada's 2024 emissions, compared with 56 Mt (9.2%) in 1990 and 57 Mt (7.4%) in 2005. IPPU sector total emissions decreased approximately 2.5 Mt (4.4%) since 1990 and 3.5 Mt (6.2%) since 2005. Total emissions in this sector result from activities in several diverse industries. Trends in emissions reflect the combined effects of multiple drivers on various industries (Figure 2–19).

In 2024, the largest contributions to emissions in the sector originated from Metal Production (16 Mt), followed by Non-Energy Products from Fuels and Solvent Use (12 Mt) and the Production and Consumption of Halocarbons, SF_6 and NF_3 (mostly HFCs) (10 Mt) (Table 2–9).

Figure 2–19 **Trends in Canadian GHG Emissions from Industrial Processes and Product Use Sources (1990–2024)**

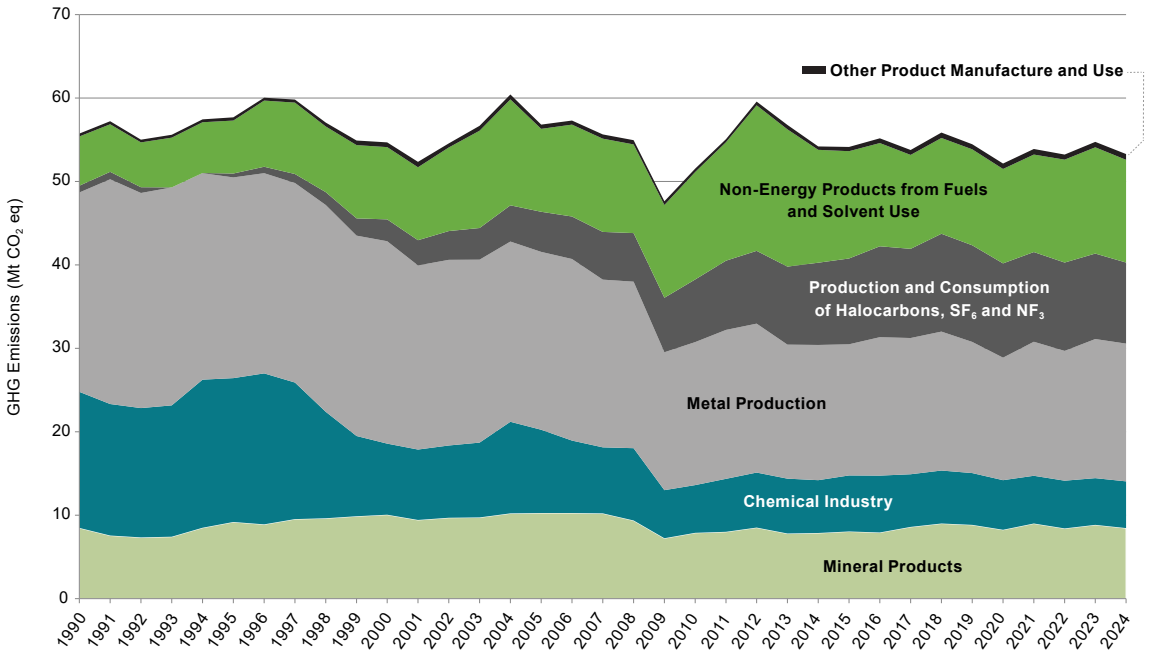


Table 2–9 **GHG Emissions from Industrial Processes and Product Use Categories, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2019	2020	2021	2022	2023	2024	1990–2024	2005–2024
TOTAL – INDUSTRIAL PROCESSES AND PRODUCT USE	**56**	**57**	**54**	**52**	**54**	**53**	**55**	**53**	**-4.4%**	**-6.2%**
Mineral Products	**8.5**	**10**	**8.9**	**8.3**	**9.0**	**8.4**	**8.9**	**8.5**	**-0.2%**	**-18%**
Cement Production	5.8	7.6	7.2	6.8	7.4	6.8	7.3	6.9	18%	-9.4%
Lime Production	1.9	1.8	1.3	1.2	1.3	1.3	1.2	1.3	-31%	-30%
Mineral Product Use	0.80	0.83	0.32	0.32	0.32	0.32	0.31	0.29	-63%	-64%
Chemical Industry	**16**	**10**	**6.2**	**5.9**	**5.7**	**5.7**	**5.6**	**5.6**	**-66%**	**-44%**
Ammonia Production	2.7	2.7	2.5	2.3	2.5	2.6	2.4	2.3	-16%	-15%
Nitric Acid Production	0.87	1.1	0.23	0.17	0.19	0.13	0.13	0.13	-85%	-88%
Adipic Acid Production	9.2	2.3	-	-	-	-	-	-	-100%	-100%
Petrochemical and Carbon Black Production	3.5	3.9	3.5	3.5	3.0	3.0	3.1	3.2	-10%	-19%
Metal Production	**24**	**21**	**16**	**15**	**16**	**16**	**17**	**16**	**-31%**	**-23%**
Iron and Steel Production	11	12	10	8.7	10	9.6	10	10	-8.2%	-12%
Aluminium Production	9.6	8.3	5.2	5.8	5.8	5.7	6.1	6.0	-38%	-28%
Magnesium and Other Metal Production	3.2	1.4	0.29	0.18	0.24	0.34	0.50	0.30	-91%	-79%
Production and Consumption of Halocarbons, SF_6 and NF_3	**0.82**	**4.8**	**12**	**11**	**11**	**11**	**10**	**9.7**	**1089%**	**102%**
Non-Energy Products from Fuels and Solvent Use	**5.9**	**9.9**	**11**	**11**	**12**	**12**	**13**	**12**	**109%**	**24%**
Other Product Manufacture and Use	**0.36**	**0.51**	**0.62**	**0.66**	**0.66**	**0.61**	**0.65**	**0.68**	**89%**	**35%**

Notes:
Totals may not add up due to rounding.
- Indicates no emissions

2.3.2.1. Mineral Products (2024 GHG Emissions, 8.5 Mt)

Cement Production dominates this subsector, accounting for 81% of emissions from Mineral Products in 2024. Interannual fluctuations over the years largely result from variations in clinker production, especially circa 2009, with some gradual recovery with the opening of a new facility in Quebec in 2017.

In 2024, emissions from Mineral Products have returned to 1990 levels, with an increase in emissions of 1.1 Mt (18%) from Cement Production being offset by decreases of 0.58 Mt (31%) and 0.51 Mt (63%) from Lime Production and Mineral Product Use source categories, respectively.

Between 2005 and 2024, emissions in this subsector decreased by 1.8 Mt (18%), largely due to decreases in clinker production and lime production.

2.3.2.2. Chemical Industry (2024 GHG Emissions, 5.6 Mt)

From 1990 to 2024, an emissions decrease of 11 Mt (66%) was observed in the Chemical Industry as a whole, with 4.4 Mt of the decrease occurring since 2005. The main driver of emission reductions in this industry was the discontinuation of adipic acid production in 2009; this alone represents a decrease of 9.2 Mt from 1990 and 2.3 Mt from 2005.[10]

Nitric acid production emissions slightly increased between 1990 and 2005 before declining following N_2O emissions abatement installations at a facility. These installations are mainly responsible for a decrease of 0.94 Mt (88%) in the subsector since 2005.

Other changes included a 0.35 Mt decrease since 1990 (0.76 Mt since 2005) in Petrochemical and Carbon Black Production due to facility closures and feedstock changes in ethylene production, as well as a small decrease of 0.45 Mt since 1990 (0.41 Mt since 2005) in Ammonia Production that is primarily attributed to carbon capture and storage activities (CCS) used for enhanced oil recovery (EOR).

2.3.2.3. Metal Production (2024 GHG Emissions, 16 Mt)

Emission reductions in the production of magnesium, aluminium, and iron and steel contributed to Metal Production overall reductions of 7.4 Mt (31%) between 1990 and 2024, with a reduction of 4.8 Mt (23%) since 2005.

The aluminium industry decreased its PFC emissions by 6.3 Mt (92%) since 1990 and 2.9 Mt (85%) since 2005, largely due to technological improvements.

10 Hendriks J. 2013. Personal communication (email from Hendriks J., Invista to the Pollutant Inventories and Reporting Division, Environment Canada, dated November 22, 2013).

The magnesium and other metal production industries also showed a decrease in emissions by 2.9 Mt (91%) since 1990 and 1.1 Mt (79%) since 2005 as a result of the replacement of SF_6 with alternative cover gases and the closure of plants over the years. Primary magnesium production in Canada ceased in 2008.

From 2005 to 2024, emissions in the iron and steel industry decreased by 1.3 Mt (12%). The main driver behind the decrease in emissions was the 2013 closures of an iron ore pellet facility and of the iron and steel production processes at an integrated mill. The decrease in emissions since 1990 was 0.91 Mt (8.2%).

2.3.2.4. Production and Consumption of Halocarbons, SF_6 and NF_3 (2024 GHG Emissions, 10 Mt)

There has never been production of HFCs, PFCs, SF_6 or NF_3 in Canada. HFC-23 was generated as a by-product of HCFC-22 production, which ended in 1992. Since then, all emissions in this subsector are associated with the consumption of HFCs, PFCs, SF_6 and NF_3 only.

The consumption of HFCs started in 1995 and emissions increased by 4.9 Mt (101%) between 2005 and 2024, as they replaced ODS, especially within refrigeration, air-conditioning, and foam blowing agent applications. HFC emissions peaked in 2018 at 12 Mt and have since decreased by 2.0 Mt (17%) to 9.7 Mt in 2024 due in part to reduced bulk imports coinciding with the implementation of the federal *Ozone-depleting Substances and Halocarbon Alternatives Regulations*. For 2019 through 2023, these regulations limited national net HFC imports (expressed in CO_2 equivalent mass) to 90% of a consumption baseline defined using 2011 to 2013 data. In 2024, net HFC imports were further restricted to 60% of the same consumption baseline (Government of Canada, 2020).

The other sources of emissions (PFCs, SF_6 and NF_3) in this subsector do not have a significant impact on emissions trends, as the next largest source (SF_6) has emissions of less than 1% of the HFC emissions value.

2.3.2.5. Non-Energy Products from Fuels and Solvent Use (2024 GHG Emissions, 12 Mt)

The Non-Energy Products from Fuels and Solvent Use category is one of the largest emission sources in the IPPU sector with its emissions increasing by 6.4 Mt (109%) since 1990, and 2.3 Mt (24%) since 2005. The observed change is mostly attributable to the emissions from the feedstock use of butane and waxes, paraffin and unfinished products, which increased by 2.1 Mt (913%) and 3.6 Mt (703%), respectively since 1990.

2.3.3. Agriculture Sector (2024 GHG Emissions, 56 Mt)

In 2024, emissions from the Agriculture sector accounted for 56 Mt, or 8.2%, of total GHG emissions in Canada, 0.3 Mt lower than 2005 levels, corresponding to an increase of 14 Mt or 32% since 1990 (Figure 2–20 and Table 2–10). In 2024, the Agriculture sector accounted for 30% of national CH_4 emissions and 76% of national N_2O emissions, up from 26% and 44% in 1990, respectively.

Generally, agricultural emissions result from losses and inefficiencies in production processes, either losses of nutrition energy during animal digestion or losses of nutrient nitrogen to the atmosphere or surface waters. All emissions reported in the Agriculture sector are from non-energy sources. Emissions from energy used during the agricultural production process and the energy and fugitive emissions occurring during the production of nitrogen fertilizers and other agricultural chemicals are discussed in Chapter 3 (Energy) and Chapter 4 (IPPU) of this report.

The main economic sectors in Canadian agriculture are livestock and crop production. GHG emissions from the livestock sector include CH_4 emissions from enteric fermentation and emissions of CH_4 and N_2O from the storage and handling of animal manure. The crop production sector includes N_2O emissions from the application of inorganic nitrogen fertilizers, crop residue decomposition, animal manure and biosolids applied as fertilizers and crop management practices; CH_4 and N_2O emissions from the burning of agricultural residues; and CO_2 emissions from agricultural use of lime and urea-based nitrogen fertilizers. In Canada, the livestock sector is dominated by beef, dairy, poultry and swine production, while crop production is mainly dedicated to the production of cereals and oilseeds.

The main drivers of the emission trend in the Agriculture sector are the fluctuations in livestock populations and continuous increases in the application of inorganic nitrogen fertilizers, mainly in the Prairie provinces. Beef, swine and poultry populations in Canada in 2024 are 42%, 37% and 48% higher, respectively, than in 1990. Since 2005, grazing cattle populations have declined relative to the production of annual crops, and this decline, together with the continued increase in fertilizer use, is driving an important change in the emissions profile of agriculture, with emissions from livestock dropping to 65% of total agricultural emissions in 2024, considerably lower than the proportion in 2005 (81%) (Figure 2–21). As a result of this shift, the proportional contribution of N_2O (mainly from crop production) to total agricultural emissions has increased steadily since 2005, offset by a decline in CH_4 (from livestock production). Emissions in 2024 are slightly lower than 2005, though the contribution of emissions from crop production has increased relative to the livestock sector. The shift in the industry from grazing cattle production to annual crop production is also reflected in a decreased carbon sink in agricultural soils observed in a land management change from perennial to annual crops reported in the LULUCF sector (Liang et al. 2020).

Figure 2–20 **Trends in Canadian GHG Emissions from Agriculture Sources (1990–2024)**

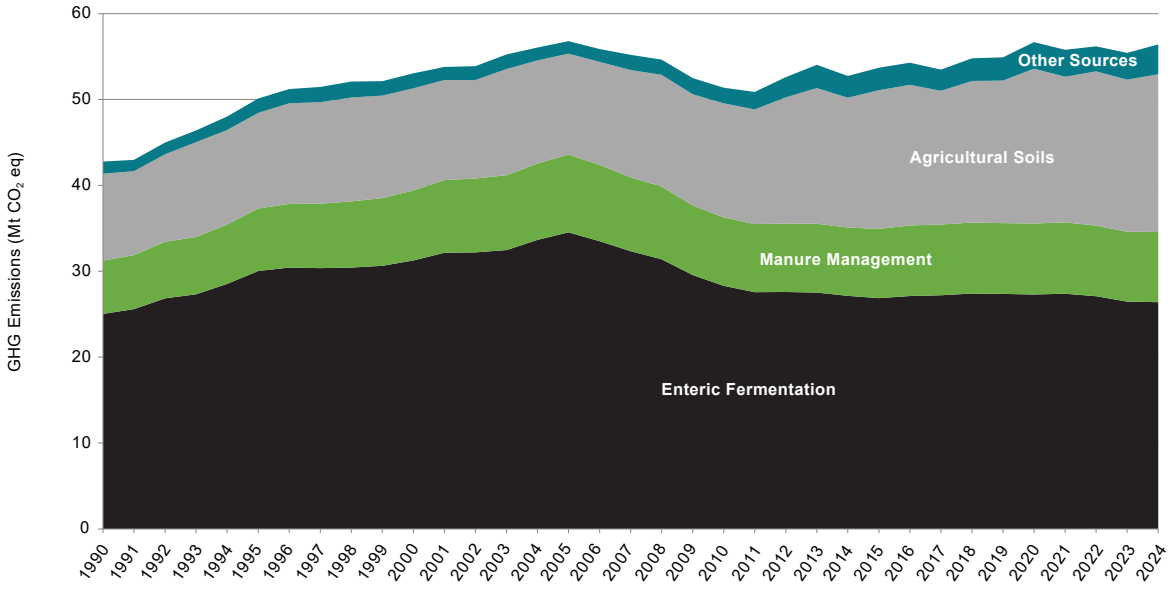


Table 2–10 **GHG Emissions from Agriculture, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2019	2020	2021	2022	2023	2024	1990–2024	2005–2024
AGRICULTURE[a]	**43**	**57**	**55**	**57**	**56**	**56**	**55**	**56**	**32%**	**-0.7%**
By IPCC Category										
Enteric Fermentation	25	35	27	27	27	27	26	26	5.4%	-24%
Manure Management	6.2	9.0	8.3	8.3	8.3	8.2	8.1	8.2	32%	-10%
Agricultural Soils	10	12	17	18	17	18	18	18	81%	56%
Field Burning of Agricultural Residues	0.24	0.05	0.05	0.06	0.04	0.05	0.05	0.05	-80%	4.3%
Liming, Urea Application and Other Carbon-Containing Fertilizers	1.2	1.4	2.7	3.0	3.1	2.8	3.1	3.4	192%	142%
By Production System										
Livestock	**33**	**46**	**38**	**38**	**38**	**38**	**37**	**37**	**11%**	**-20%**
Dairy Cows	6.1	5.3	5.9	5.9	6.0	6.0	5.9	6.0	-2.5%	12%
Beef Cattle	24	35	27	27	27	26	26	26	8.6%	-27%
Swine	2.2	3.6	3.4	3.5	3.5	3.5	3.5	3.5	59%	-2.4%
Other Livestock[b]	1.4	2.2	1.9	1.9	1.9	1.9	1.9	1.9	34%	-15%
Crop	**9.5**	**11**	**17**	**19**	**18**	**18**	**19**	**19**	**105%**	**83%**
Inorganic Nitrogen Fertilizers[c]	5.6	6.7	12	13	13	12	13	14	151%	111%
Crop Residue Decomposition	2.8	3.2	4.3	4.5	3.5	4.4	4.2	4.4	57%	37%
Other Practices[d]	1.1	0.8	1.0	1.2	1.2	1.8	0.94	1.1	-3.4%	33%

Notes :

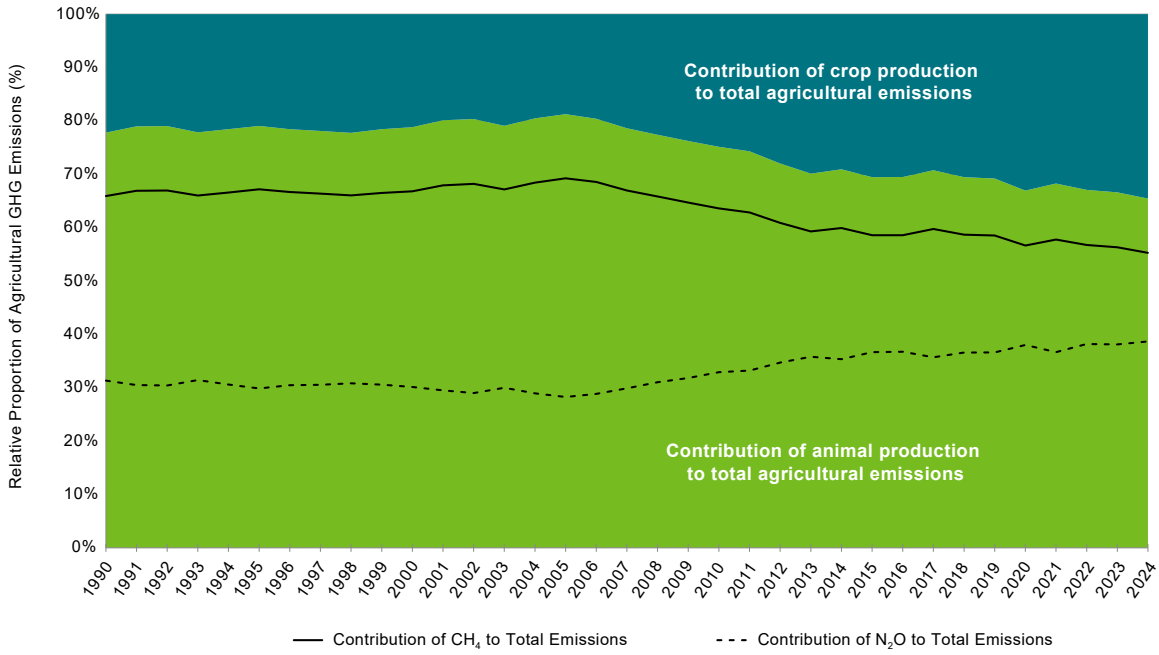
a. Totals may not add up due to rounding.

b. Other livestock includes sheep, lamb, goat, horse, bison, poultry, llamas and alpacas, mules and asses, and fur-bearing animals.

c. Inorganic fertilizers includes emissions of N_2O from the soil and the CO_2 emissions from the hydrolysis of carbon stored in urea

d. Other practices includes summerfallow, conservation tillage practices, irrigation, cultivation of organic soils, the mineralization of soil carbon, the use of lime, field burning of crop residues, and the application of biosolids.

Figure 2–21 **Proportions of Canadian Agricultural GHG Emissions Emitted as CH_4 and N_2O, or Attributed to Livestock and Crop Production (1990–2024)**



2.3.3.1. Enteric Fermentation (2024 GHG Emissions, 26 Mt)

Emissions from enteric fermentation originate almost entirely (96%) from Cattle Production in Canada. From 1990 to 2024, emissions increased from 25 Mt to 26 Mt, or 5.49%. Emissions increased from 1990 to 2005 mainly as a result of an increase in the population and weight of beef cattle, driven by high commodity prices. Beef populations peaked in 2005, and subsequently declined 30% due to a sharp decrease in prices after an outbreak of bovine spongiform encephalopathy (BSE, or mad cow disease) in 2003. In recent years beef populations and associated emissions have stabilized.

At the same time, emissions associated with dairy cows have fallen by approximately 10% since 1990, mainly due to a 31% reduction in the dairy cow population from 1990 to 2024 (StatCan, n.d.[i]). However, the average dairy cow today also consumes more feed and produces 59% more milk than in 1990, because of improved genetics and changes in feeding and/or management practices. As a result, the average dairy cow today emits more GHGs, and emission reductions associated with the decline in the dairy population have been partly offset by a 26% increase in per-animal emissions since 1990.

2.3.3.2. Manure Management (2024 GHG Emissions, 8.2 Mt)

Emissions from animal manure management systems increased from 6.2 Mt in 1990 to 8.2 Mt in 2024 (or 32%), driven by increases in livestock populations of beef, swine and poultry. The storage of manure results in both CH_4 (15% total agricultural CH_4) and N_2O (16% total agricultural N_2O). The management of beef and poultry manure produces predominantly N_2O, whereas swine manure produces predominantly CH_4. Emissions from dairy manure have shifted from mainly N_2O to mainly CH_4 due to changes in manure storage practices. As a result, CH_4 emissions correspond closely to changes in populations and practices in the swine and dairy sectors, increasing from 2.7 Mt in 1990 to 4.2 Mt (60%) in 2024. N_2O emissions closely follow the trend in beef populations, increasing from 3.6 Mt in 1990 to 4.8 Mt (+33%) in 2005 and subsequently declining to 3.9 Mt (-20%) in 2024. As was the case with enteric fermentation, the increase in beef cattle weights also contributed to the increase in N_2O emissions from manure.

2.3.3.3. Agricultural Soils (2024 GHG Emissions, 18 Mt)

Emissions from Agricultural Soils originate from the application of inorganic and organic nitrogen fertilizers to annual and perennial cropland and from crop residue decomposition; these emissions can be modified by crop management practices. Emissions increased from 10 Mt in 1990 to 18 Mt in 2024, an increase of 81%, primarily due to an increase in inorganic nitrogen fertilizer use and relative reduction in the proportion of N applied to perennial cropland.

Total emissions from the application of inorganic nitrogen fertilizers increased from 4.8 Mt in 1990 to 12 Mt in 2024, an increase of 149%, as inorganic nitrogen fertilizer consumption increased steadily from 1.2 Mt N to 3.2 Mt N over the same period. The increase in N fertilizer sales occurred mainly during two periods: between 1991 and 1997 and between 2007 and 2024. The first period was a result of the intensification of cropping systems and the reduction of summer fallow on the Canadian Prairies. The second period reflected an increase in grain prices that encouraged farmers to use more nutrient inputs and convert lands from perennial to annual crop production, coinciding with a reduction in grazing cattle operations on the Canadian Prairies. The increase in fertilizer use since 1990 also resulted in a 2.4 Mt (304%) increase in emissions of CO_2 from urea and urea ammonium nitrate.

Emissions from crop residue decomposition and mineralization of SOC ranged from a minimum of 2.2 Mt in 1991 to a maximum of 5.1 Mt in 2022, mainly depending on the impact of weather conditions on crop yield, and changes in the proportion of annual and perennial crops. Emissions declined to 3.7 Mt in 2021 because of severe drought conditions in the prairies that led to a sharp decline in crop production. Emissions have increased again since 2021 and were 4.4 Mt in 2024 as crop production, and therefore crop residue, returned to more typical levels. Though crop production demonstrates high interannual variability, production has tended to increase over the reporting period and, as a result, so have emissions from crop residue.

In 1990, cropland management practices, specifically irrigation and the adoption of conservation tillage, contributed a net 0.13 Mt to total emissions from soils. In 2024, the adoption of conservation tillage (approximately 17 million hectares of cropland since 1990) reduced emissions by 2.5 Mt, while increases in irrigation increased emissions by 1.2 Mt, for a net reduction in emissions of 1.3 Mt.

2.3.4. Land Use, Land-Use Change and Forestry Sector (2024 Net GHG Source, 4.3 Mt, Not Included in National Totals)

The LULUCF sector reports anthropogenic GHG fluxes to and from Canada's managed lands, including those associated with land-use change. Emissions of GHGs from sources and removals by sinks are estimated and reported for five categories of managed lands—Forest Land, Cropland, Grassland, Wetlands and Settlements—and for the Harvested Wood Products category, which is closely linked to Forest Land and Forest Conversion. The net LULUCF flux is calculated and presented as the sum of CO_2 and non-CO_2 emissions to the atmosphere and CO_2 removals from the atmosphere.

In 2024, LULUCF was estimated to emit 4.3 Mt to the atmosphere, compared with net emissions of 61 Mt in 1990 and 81 Mt in 2005. National totals are reported to the United Nations Framework Convention on Climate Change (UNFCCC) with and without emissions and removals in the LULUCF sector. The estimated net GHG fluxes in the LULUCF sector, when included, account for an increase of 10% in 1990, 11% in 2005 and 0.6% in 2024 (Figure 2–8).

The net fluxes reported in the LULUCF sector were positive (emissions) for all years of the time series, except 2023 when removals occurred. Emissions increased over the early part of the time series until 2005, then generally declined through 2023. Interannual fluctuations flipped back from a small sink in 2023 to a small source in 2024 (Table 2–11). Over the first half of the time series increasing net CO_2 emissions from the Forest sector were partially attenuated by increasing net CO_2 removals in Cropland and a decrease in emissions from the conversion of forest to other land use. The increasing net emissions by the land sector to the atmosphere reported over the first fifteen years of the reporting period are driven by a sustained expansion of forest harvest in combination with increased insect mortality in the mid-2000s. Since 2005, the decline and subsequent stabilization of harvest rates have resulted in a reduction in net CO_2 emissions from Forest Land. During this period Cropland removals, though undergoing interannual variability, have not demonstrated a clear trend, with increasing removals resulting from increased annual crop productivity being offset by decreasing removals associated with the loss of perennial land cover and recent increases in rates of agricultural deforestation. The peak in emissions in 2022 resulted from the extensive drought in western Canada that occurred in 2021 as emissions from decomposition of existing soil organic carbon (SOC) significantly exceeded new carbon input to soils (Figure 2–22), however normal yields in 2022 returned soils to a net sink in 2023 and that sink, though smaller, still remained in 2024.

Table 2–11 **GHG Emissions and Removals from LULUCF, Selected Years**

Sectoral Category		Net GHG Flux (Mt CO_2 eq)[a]									
		1990	2005	2019	2020	2021	2022	2023	2024	Change 1990–2024	Change 2005–2024
LAND USE, LAND-USE CHANGE AND FORESTRY TOTAL		**61**	**81**	**16**	**26**	**14**	**46**	**-8.7**	**4.3**	**- 57**	**-77**
a.	Forest Land	79	150	36	36	29	15	1.3	-1.2	-80	-150
b.	Cropland	5.6	-20	-12	-10	-14	24	-21	-3.6	-9.2	16
c.	Grassland	0.0007	0.0009	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0006	0.0004
d.	Wetlands	10	7.0	5.6	5.6	6.0	5.7	5.5	5.4	-4.7	-1.6
e.	Settlements	4.9	5.1	5.0	4.7	4.6	4.5	4.6	4.3	-0.62	-0.77
g.	Harvested Wood Products	-39	-57	-18	-10	-11	-3.0	0.73	-0.63	38	56

Notes:
Totals may not add up due to rounding.
a. Negative sign indicates net removals of CO_2 from the atmosphere.

2.3.4.1. Forest Land and Harvested Wood Products (2024 GHG Gains, 1.8 Mt)

The Forest Land and Harvested Wood Products categories combined include GHG fluxes between the atmosphere and Canada's managed forests and the transfers to the global harvested wood products (HWP) category originating from domestic harvest and subsequent changes in carbon stored as wood products in use. The total net flux from managed forests and resulting HWP amounted to an estimated net gain of 1.8 Mt in 2024 (Figure 2–22), which combines net gains of 1.2 Mt from Forest Land and net gains of 0.6 Mt in HWP from forest harvest.

Net losses reported in Forest Land—after separating GHG fluxes associated with severe natural disturbances from anthropogenic fluxes—increased from 79 Mt in 1990 to 150 Mt in 2005. The predominant anthropogenic trend directly associated with human activities in managed forests is a 34% increase in the carbon removed from forests through harvest and transferred to HWP between 1990 and the peak harvest year, 2004. This trend represents an increase in estimated annual area harvested from 0.9 Mha in 1990 to 1.4 Mha in 2004. Of that annual harvest area 11%, 8.8% and 3.0% was harvested as clear-cut with slash burning and further, there were an estimated 73 kha, 84 kha and 58 kha of commercial thinning in 1990, 2005 and 2024 respectively. The rest of annual harvest was clear-cut leaving residue to decompose in place.

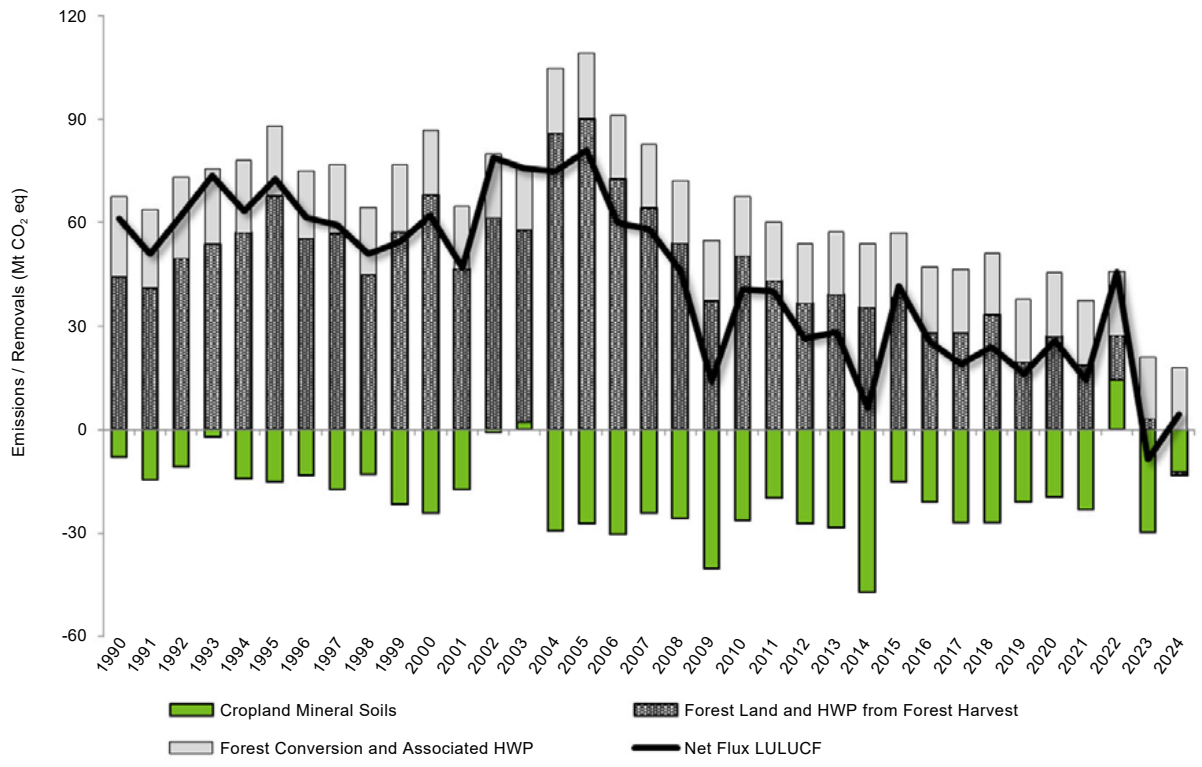
Since 2005, net losses from Forest Land decreased to a net gain of 1.2 Mt in 2024, as the area of mature forest has increased a greater proportion of past harvest disturbance is switching from a net source to a net sink. Conventional harvest levels have remained relatively constant in recent years, with 2024 levels still 44% below their peak in 2004. Emissions from slash burning have decreased in recent years reaching their lowest levels throughout the time series. This recent trend of reduced harvest is the combined effect of changing global markets and consumer preferences, as well as growing demand for non-traditional products, e.g., bioproducts and, more recently, due to a significant decline in global demand in traditional paper markets as digital media options replaced many paper products, a trend that was accelerated by the COVID-19 pandemic (NRCan, 2022). Further, the indirect effect of exceptionally high wildfires in several years of the last decade, mainly in western Canada, have impacted the commercially mature forest area in some regions and result in Forest Management agencies re-evaluating rates of harvest.

The decrease in net losses nationally from Forest Land is dominated by trends in the Montane Cordillera, Boreal Plains and Boreal East. Severe insect outbreaks in the Montane Cordillera in the early 2000s and subsequent high rates of harvest on impacted forest stands transferred significant amounts of carbon to the HWP pool, reset large areas of previously productive forest to younger age classes when trees absorb and store less biomass carbon and additional residue from harvest increases decomposition emissions. In addition, forest stands in the Montane Cordillera ecozone were affected by insect infestations that caused low levels of tree mortality over large areas resulting in a generalized increase in emissions of CO_2 from decomposition. Likewise, on the Boreal Plains, sustained harvest transferred carbon out of the forest ecosystem and insect outbreaks and fire combined to reset large areas of previously productive forest to younger age classes, though impacts were partially offset by increased areas of mature forest in reporting. The combination of reduced net rates of storage of CO_2 in biomass and increased emissions of CO_2 from decomposition resulted in a net increase in losses from forests of these regions—primarily between 1990 and 2005—that was significant enough to influence the national trend. Further, severe wildfires have recently impacted some of these areas reducing the commercially mature forest land base. The trend towards decreasing carbon losses in the Boreal East partially offsets the increasing losses of carbon occurring in other regions, driven by the growth of the area of mature forest over the 1990s and early 2000s which subsequently levels off in recent years. At the same time, increased insect disturbance has increased emissions from decomposition. Since 2005, all ecozones have tended towards decreasing carbon losses driven largely by reduced harvest rates. Although emissions and removals associated with severe natural disturbances are differentiated from anthropogenic fluxes, low-level mortality insect disturbances nevertheless influence reported GHG fluxes. Though not reported in the anthropogenic reporting component, the impact of fire on the Canadian managed forest cannot be ignored. Since 2018, wildfires have emitted an average of 270 Mt CO_2 eq per year, impacting forest age-class structure and carbon storage capacity. In 2023 and 2024—the two largest wildfire years over the reporting period—approximately 7.9 Mha, and 2.6 Mha of forest areas were burned, including large areas of commercially mature stands. These disturbed areas are expected to remain net sources of carbon emissions for several years.

Gains and losses of HWP reflect the net change in long-term storage of carbon in wood harvested in Canada's forests. Annual transfers of carbon to the HWP pool from harvest are balanced against annual losses, either emissions from oxidation (decomposition or combustion) or disposal of products at the end of their useful life, which provides the net change in carbon stored globally as Canadian HWP. Approximately one third of HWP losses (36% in 2024) result from long-lived wood products reaching the end of their useful life and being transferred to the waste stream decades after the wood was harvested. End-of-life disposal and emissions from short-lived products, namely pulp and paper and bioenergy products, accounted for 25% and 37% of annual HWP losses, respectively, in 2024. These same products accounted for 31% and 40% in 1990 and 35% and 40% in 2005. Wood processing waste in 1990 accounted for 14% of annual HWP losses prior to the now-common practice of using wood waste for bioenergy production. Fluctuations in transfers of short-lived wood products generally reflect recent trends in forest harvest rates. As a result of these fluctuations, annual losses from HWP in emissions and disposals have ranged from a low of 130 Mt in 2009 (corresponding to the lowest harvest year), to a peak of 150 Mt in 1995. Net carbon storage increased in the HWP category every year throughout the time series except for 2009 and 2023 when harvest rates were at their lowest level and losses from the HWP carbon pool exceeded transfers to the category.

In 2005 and 2024, bioenergy transfers and combustion of carbon from Forest Land were 59 Mt and 44 Mt, respectively, for residential and industrial bioenergy. Industrial bioenergy is primarily sourced from waste produced during the processing of wood in the creation of products. In these years, wood processing waste was 4 Mt with nearly all of it diverted to energy production.

Figure 2–22 **LULUCF Sector Net GHG Flux and Major Emission and Removal Components, 1990–2024**



2.3.4.1.1. Emissions from Forest Harvesting

Canada has an important forest industry and improving the estimates of forest harvesting impacts will enhance informed decision-making. Harvesting of the forest occurs within a broader suite of management activities and decisions which are carried out by provinces and territories according to sustainable forest management principles (NRCan, 2023). Forest management activities include forest inventory and planning, harvesting, thinning, burning, site preparation, regeneration, stand tending, fertilization, weeding, fire suppression and prevention, and pest management. These activities, and harvesting within them, are integrated into forest management plans to ensure that the productive capacity of the forest is maintained; thus, the real impact of forestry cannot be isolated to the act of harvesting and is monitored as the net change in managed forest carbon stocks in accordance with IPCC guidelines (IPCC, 2006).

As is the case with all industries, the scope of activities associated with forest harvesting is broad, spanning multiple sectors of this National Inventory Report (NIR), namely LULUCF, Energy, Industrial Processes and Product Use and Waste. To the extent possible within the current version of data and systems supporting the NIR, the emissions/removals to/from the atmosphere, fluxes between pools and subsequent carbon stock changes for activities associated with forest harvesting are separately reported in Table 2–12.

During the year in which harvest takes place, pre-existing dead organic matter (DOM) and harvest residues decompose and, as a result, carbon dioxide is emitted to the atmosphere; while removals associated with regrowth of the stand are negligible (Table 2–12, Net Emissions from harvested lands, new; Emissions from deforestation for forestry roads, direct). After the initial year of harvest, emissions from decomposition continue; and removals increase over time as the regrowing forest becomes more productive (Table 2–12, Net emissions from harvested lands, historic; Emissions from deforestation for forestry roads, residual). The current version of Carbon Budget Model of the Canadian Forest Service (CBM-CFS3) does not support emission tracking that differentiates decomposition emissions for pre-existing DOM and new inputs from the harvesting event. Sites with higher DOM stocks prior to harvest (e.g., after insect attack) will have high decomposition emissions regardless of whether harvesting took place.

Fluxes of carbon occur with harvested wood products (HWP) at the production, use, and disposal stages. The production of milled wood products, including pulp and paper, involves machinery with emissions reported in the Energy-Stationary Combustion sector (Table 2–12, Non-CO_2 gases from bioenergy production). Wood is consumed to provide bioenergy for residential (e.g., home heating) and industrial purposes (e.g., heat & power) resulting in emissions (Table 2–12, Residential bioenergy emissions, industrial bioenergy emissions). As long- and short-lived wood products from Canadian wood are

retired and disposed of across the globe, the carbon in the products is reported as a flux (Table 2–12, Carbon flux from disposal of HWP products) according to their respective lifespans. These products remain intact for years if disposed of in landfills and become an important source of methane reported in the country of disposal (Moreau et al. 2023).

Carbon harvested from the forest remains sequestered in wood products for decades, contributing to a growing global pool of stored carbon (Table 2–12, cumulative stocks in products). As carbon remains stored in wood products, the managed land that was harvested regenerates, contributing an active carbon sink and a renewable product source. Carbon in the forest was originally removed from the atmosphere through photosynthesis, i.e., the biotic carbon cycle. Therefore, when carbon from the forest re-enters the atmosphere, it does not represent a net gain to CO_2 concentrations in the way that fossil fuels do. Wood-based bioenergy and commodities replace other more emissions-intensive alternatives such as coal, oil, concrete or steel in other economic sectors (e.g., energy, manufacturing, construction, etc.) (Smyth et al. 2017).

Fuel use by harvesting machinery is calculated and reported in the Energy-Transport sector (Table 2–12, Forestry activities). Fuel use associated with the transport of harvested timber off site is, however, unavailable due to the level of aggregation in the Energy-Transport sector.

Table 2–12 **Emissions, Removals and Carbon Stock Changes Associated with Forest Harvesting Activities, Selected Years**

GHG Source Category	GHG Fluxes and Stocks							
	1990	2005	2019	2020	2021	2022	2023	2024
FOREST LAND								
Net Emissions and Removals, Forest Harvest (Mt CO_2 eq)								
Net emissions from harvested lands	110	120	52	50	45	39	31	25
Net emissions from harvested lands, new[a]	33	48	36	36	34	31	28	28
Net emissions and removals from harvested lands, historic[b]	73	72	16	14	11	7.0	3.0	-3.0
Deforestation Forestry Roads	1.1	0.83	0.28	0.26	0.26	0.22	0.21	0.19
Emissions from deforestation for forestry roads, direct	0.29	0.22	0.05	0.04	0.05	0.04	0.04	0.04
Emissions from deforestation for forestry roads, residual	0.79	0.6	0.23	0.22	0.2	0.18	0.17	0.15
HARVESTED WOOD PRODUCTS (HWP)								
Emissions and Fluxes – HWP (Mt CO_2 eq)								
Carbon flux from disposal of HWP commodities[c]	76	87	81	83	80	79	76	75
Industrial Bioenergy Emissions[d]	35	46	33	37	38	39	34	34
Residential Bioenergy Emissions	15	11	12	10	9.0	10	9.0	9.0
Carbon Stocks and Fluxes (Mt C)								
Carbon transfers from forest to HWP[e]	44	54	39	38	38	36	32	32
Commercial harvest	40	51	36	35	35	33	30	30
Residential firewood harvest	4.1	3.1	3.2	2.8	2.5	2.7	2.5	2.3
Cumulative Stocks in Products	330	510	600	600	600	600	600	600
Solid Wood[f]	280	460	560	560	570	570	570	570
Pulp and paper	46	55	37	35	34	32	30	29
Carbon flux from use and disposal of HWP commodities	34	39	34	36	35	35	33	32
Solid Wood[f]	5.4	9.0	11	11	11	11	12	12
Pulp and paper	11	14	10	10	9.0	8.8	8.3	7.9
Unused mill residues	4.5	1.0	0.80	1.6	1.3	1.2	0.90	0.90
Industrial Bioenergy	9.6	13	9.0	10	10	11	9.2	9.2
Residential Bioenergy	4.1	3.1	3.4	2.9	2.6	2.8	2.6	2.4
EMISSIONS REPORTED IN OTHER SECTORS[g]								
Fossil Fuel and Industrial Process Emissions (Mt CO_2 eq)								
Forestry Activities[h]	3.0	2.8	2.6	2.2	2.4	2.4	2.2	2.1
Pulp and Paper Production	15	8.7	7.9	6.9	7.2	7.3	7.1	6.4
Non CO_2 gases from bioenergy production (Mt CO_2 eq)	0.29	0.35	0.3	0.26	0.27	0.28	0.26	0.25

Notes:
Please refer to NIR methodological annexes (Annex 3) for detailed information about data sources and methods.
a. Consists of net emissions from harvested forest land from decomposition, minus regrowth in the initial year of harvest. Includes slashburning, prescribed burning, and reforestation.
b. Consists of net emissions from decomposition and regrowth from previously harvested stands.
c. Wood retired to landfills is represented as an instantaneous flux to the atmosphere for reporting purposes.
d. Includes uncombusted carbon remaining in ash.
e. 1990-2024 carbon transfers from deforestation for forestry roads to HWP of 2.1 Mt C (0.13% of total 1990-2024 C transfers) are excluded. Current HWP modelling does not allow emissions associated with specific deforestation activities to be reported separately.
f. Solid wood includes sawn wood, composite wood (i.e., wood panels) and other industrial solid wood products.
g. Detailed information can be found in cross-sectional tables published on the Government of Canada's Open Data Portal.
h. Emissions from on block machinery and wood processing, does not include transport of harvested roundwood to mill.

2.3.4.2. Forest Conversion (2024 GHG Source, 19 Mt)

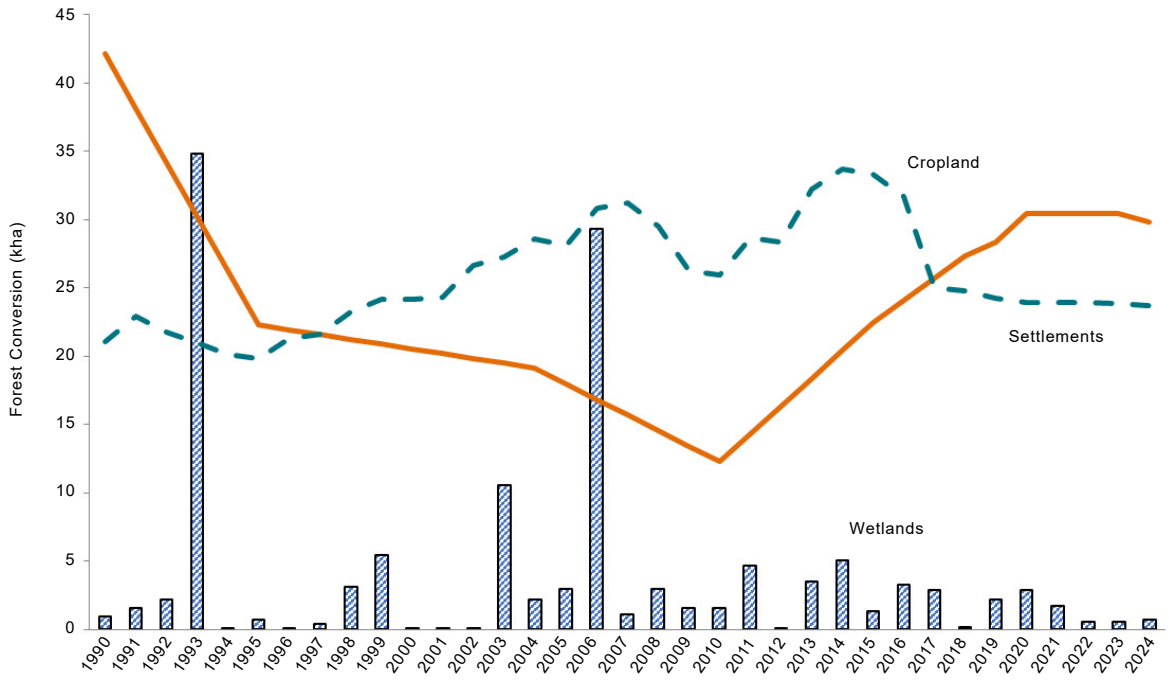
Forest conversion[11] is not a reporting category per se, since it overlaps with the subcategories of Land Converted to Cropland, Land Converted to Wetlands and Land Converted to Settlements. It also includes carbon transfers to HWP resulting from forest conversion activities since 1990, which contribute to carbon stocks in wood products globally. Emissions due to forest conversion declined from 27 Mt in 1990 to 19 Mt in 2024.

The conversion of forests to other land uses remains a prevalent practice in Canada, driven by a range of regional factors, including policy and regulatory frameworks, market forces and resource endowment. Since 1990, 1.9 million hectares of forest have been converted to other land uses in Canada. The highest average annual conversion rates occur in the Boreal Plains (25 kha per year) and the Boreal Shield East (8 kha per year), accounting for 47% and 15%, respectively, of the total forest area loss in Canada.

Forest clearing for agricultural expansion (Cropland) is the largest driver of forest conversion, accounting for 30 kha or 55% of all forest area lost in 2024. Annual rates declined steadily from 42 kha in 1990 to 12 kha in 2010, predominantly in the Boreal Plains, Subhumid Prairies and Montane Cordillera of western Canada, following a period of active agricultural expansion in earlier decades. After 2010, annual rates increased steadily, reaching 30 kha by 2020. Since 2020, estimates of conversion rates have remained relatively stable at around 30 kha, reflecting continued agricultural expansion primarily in the Boreal Plains, Subhumid Prairies, and Mixedwood Plains, which accounted for 60%, 15%, and 8% of agricultural expansion in 2024, respectively.

With a current annual conversion rate of 24 kha, Forest Land Converted to Settlements represents the second-largest driver of forest loss, accounting for 44% of the total loss in 2024—up from 33% in 1990 and down from 57% in 2005 (Figure 2–23). This increase is mostly driven by an increasing trend in forest conversion for oil and gas infrastructure during the period from 1990 to 2006, as well as mining operations and industrial development between 2004 and 2015. Significantly higher rates of forest conversion for hydro infrastructure around the years 2013 to 2015 have also contributed to this trend. The highest average annual rate of forest conversion to settlements occurs in the Boreal Plains (11 kha per year), followed by the Boreal Shield East (4.0 kha per year).

Figure 2–23 **Trends in Annual Rates of Forest Conversion to Cropland, Wetlands and Settlements**



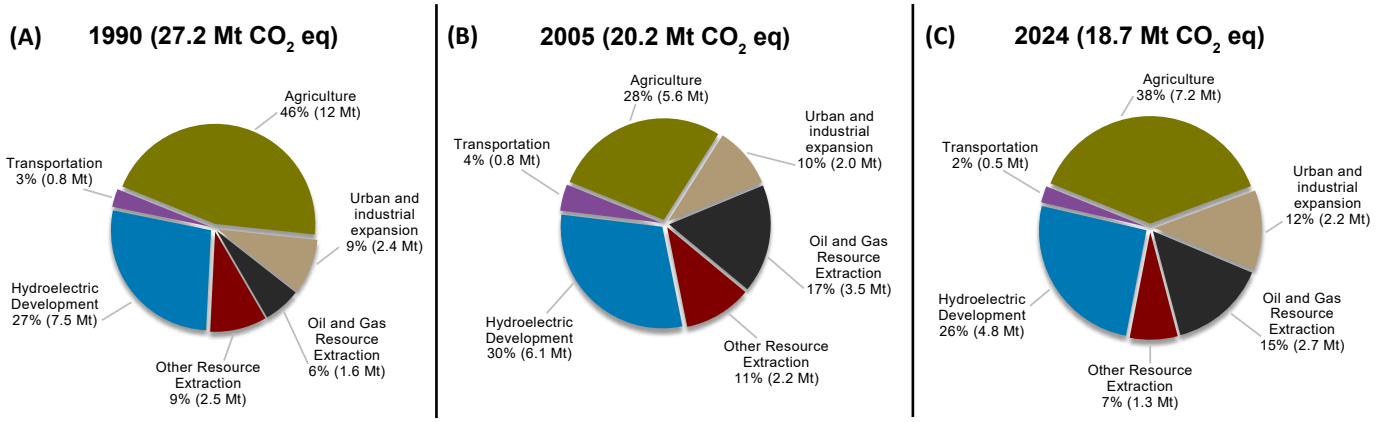
11 Forest conversion emissions are incorporated within sums of emissions of other land-use categories; therefore, the 19 Mt reported in this section is included in the sums associated with the other land-use category totals.

Forest conversion to Wetlands is mainly driven by hydroelectric development (flooded land) and is episodic, corresponding to the occasional impoundment of large reservoirs (e.g., LaForge-1 in 1993 and Eastmain-1 in 2006, Figure 2–23). Since 1990, cumulative areas of forest converted for the creation of hydro reservoirs and associated infrastructure totals 230 kha, accounting for 13% of total forest conversion areas over the reporting period. Hydroelectric-driven forest conversion occurs mainly in the Taiga Shield East and the Boreal Shield East.

Emissions associated with deforestation reflect these conversion rate trends (see Figure 2–24). Emissions from agricultural expansion were the highest in 1990 at 12 Mt, (46% of total deforestation emissions), declined to 5.4 Mt (27%) in 2005, and reached a low of 4.1 in 2010. Since 2010, increases in agricultural expansion led to a rise in emissions to 7.2 Mt, comparable to levels observed in the late 1990s. Similarly, emissions from hydroelectric reservoir development were high in 1990 at 7.5 Mt (27%), and have continuously declined to 4.8 Mt (25%) in 2024. In contrast, emissions associated to oil and gas development increased from 1.6 Mt (6%) in 1990 to 2.7 Mt (15%) in 2024, highlighting the growing influence of this sector on forest conversion. Whereas other resource extraction (mining, renewable resources and peat extraction) emissions gradually declined from a peak of 2.5 Mt in 1990 to 1.3 Mt in 2024. Emissions associated with urban and industrial expansion maintained a steady trend with minor fluctuations, averaging 2.1 Mt annually from 1990 to 2024. This reflects Canada's consistent urban growth despite overall deforestation emissions decreasing since 1990. Similarly, emissions from deforestation during the construction of transportation lines such as roads and railways remained stable, averaging 0.7 Mt throughout the reporting period.

These trends highlight shifting drivers of land use change over the past 30 years, which together have contributed to the overall decline in emissions from forest conversion in Canada over the first two decades of monitoring. In recent years increases in agricultural expansion and the growing influence of oil and gas infrastructure contribute towards higher emissions, however, these effects have been partially offset by a sustained decline in emissions from hydroelectric development. The combined result is a downward trend in deforestation emissions that levelled off and has recently begun to climb again as a result of changing pressure across land uses.

Figure 2–24 **Trends in Annual Emissions of Forest Conversion to Cropland, Wetlands and Settlements**



2.3.4.3. Cropland (2024 GHG Removals, 4 Mt)

The Cropland category includes the effect of agricultural practices on CO_2 emissions from, and removals by, arable soils as well as the immediate and long-term impacts of forest and grassland conversion to cropland.

Cropland contributed net emissions of 5.6 Mt in 1990, net removals of 20 Mt in 2005 and net removals of 3.6 Mt in 2024, to the land sector estimates. This land category has net removals ranging from 1.9 to 40 Mt in all years except 1990, 1992, 1993, 2002, 2003, and 2022 where drought conditions in previous years decreased the crop production resulting in net emissions of 5.6, 0.8, 8.2, 6.8, 9.7 and 24 Mt, respectively. Interannual variability occurs throughout the time series, reflecting weather-related impacts to crop production. In particular, severe drought on the prairies 2021 has resulted in significant emissions from cropland soils in 2022 as decomposition of native SOC was not offset by adequate inputs of fresh residue carbon resulting in net loss of carbon from soils across the prairies for this year. In 2023 and 2024, the soil sink recovered resulting in net removals again.

For most years, net removals have increased, on average, as a result of improved soil management practices including conservation tillage and an overall gradual increase in crop productivity and reduced summer fallow acreage and, as a result, carbon inputs to the soils. In general, the underlying changes in agricultural land management practices in western Canada, such as the extensive adoption of conservation tillage practices drove the increase in removals from Cropland from 1990 to 2006. However, carbon in soils is highly susceptible to fluctuations in the weather and subsequent variations in yield. Since 2006, an inverse trend is observed, mainly due to the increase in the conversion of perennial to annual crops that coincided with a reduction in grazing cattle populations on the prairies indicative of the ties between agricultural production systems and soil carbon (Liang et al. 2020).

Since 2005, the decline in net removals that results from a decrease in perennial land cover has largely offset removals resulting from increasing yields and there is subsequently no clear trend. Recent trends are impacted by periodic high crop production and subsequently peak removals in 2009 (-34 Mt) and 2014 (-40 Mt). The decline in emissions from Forest Land Converted to Cropland also contributed to the trend of the increasing removals during the period from 1990 to 2010, but emissions have since increased to mid-1990s levels (see section 2.3.4.2).

2.3.4.3.1. Relationship between Agricultural Emissions and Cropland Carbon

In agricultural ecosystems crop and livestock production compete for the same land, creating trade-offs between the two systems that, in turn, impact GHG emissions and removals as well as soil carbon. Canada reports agricultural emissions in different sectors—Agriculture, LULUCF, and Energy—according to IPCC reporting requirements. Taking an integrated approach to examining emissions from both crop production and livestock helps to better understand trends (Figure 2–25).

From the 1990s to the mid-2000s, an increase in cattle populations led to a 39% rise in emissions from the livestock sector. During the same period, a reduction of summer fallow in annual crop production resulted in increased use of inorganic fertilizers, which contributed to a 13% rise in emissions. However, carbon storage in cropland soils, driven by improved yields and soil management in annual crop production, increased perennial cover, and a significant reduction in land conversions (including agricultural deforestation and grassland conversion) largely offset these emissions.

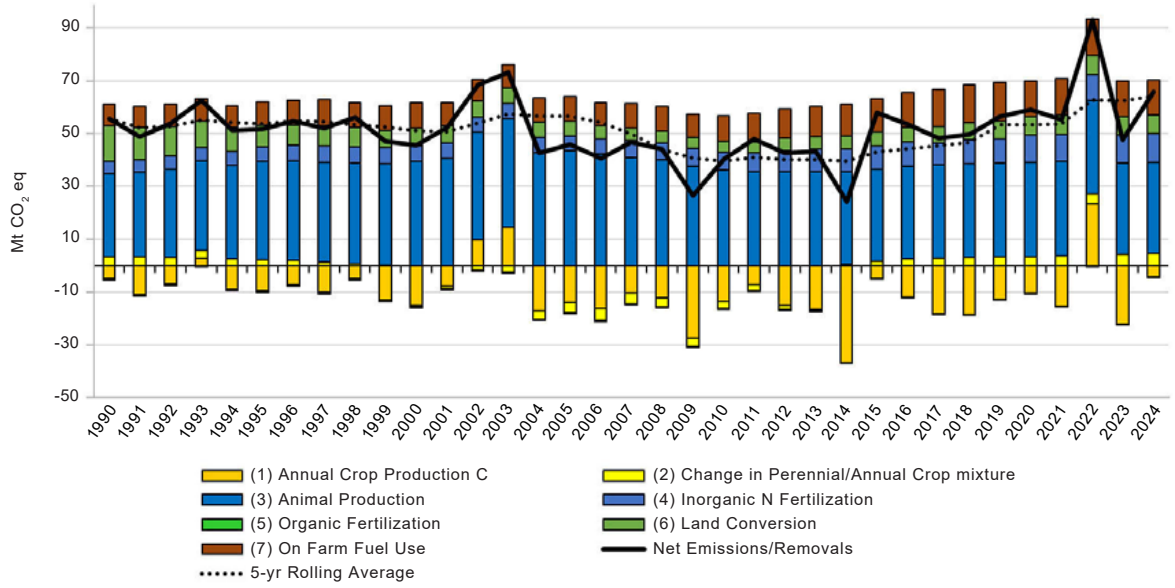
Between 2005 and 2011, cattle populations declined sharply, leading to a 19% reduction in emissions, which have since stabilized at around 32 Mt. During this time and continuing into the present, the conversion of perennial cover to annual crop production has become a net source of CO_2, reversing the previous carbon removal effect (a change of 8.3 Mt). Emissions from land conversions have also increased by 29%.

In parallel, emissions from inorganic fertilizer use during crop production and agricultural fuel use have continued to rise steadily, increasing by 111% and 42%, respectively since 2005. Carbon storage from increasing yields in annual crop production has not shown a clear trend since 2005, and carbon removals from improved soil management have plateaued.

When assessed together, considering landscape carbon impacts, net emissions from agricultural operations generally have fluctuated around 50 Mt since 1990, looking at a five-year rolling average of emissions. Emissions peaked at 93 Mt in 2022, due to severe drought on the prairies and were at their lowest in 2014 (24 Mt) because of high crop yields boosting the soil sink. Interannual variations in soil carbon fluxes driven by fluctuations in crop yield resulting from weather patterns, make trends more difficult to interpret.

Examining the historic changes in the emission profile of agricultural production in Canada as land management has changed since 1990, where one emission source has increased when another decline, demonstrates that looking at one individual emission source in isolation may provide incomplete information on the broader impacts of a given change in agricultural practices on total emissions from the sector supporting the need for a comprehensive analysis of emission profiles.

Figure 2–25 **Integrated Assessment of Emissions and Removals from Agricultural Operations**



Notes:
Emissions and removals are grouped here into:
(1) "Annual Crop Production C" – tillage practices, crop residues, field burning of crop residues, cultivation of organic soils, residual emissions, liming, and urea applications (C alone),
(2) "Change in Perennial/Annual Crop mixture" – conversion of perennials to annuals and perennials to annuals,
(3) "Animal Production" – Enteric Fermentation and Manure Management,
(4) "Inorganic N fertilization" – direct and indirect emissions,
(5) "Organic Fertilization" – direct and indirect emissions from animal manure C and N, biosolids N, and pasture, range and paddock,
(6) "Land Conversion" – forest land to cropland conversion and grassland to cropland conversions, and
(7) "On-Farm Fuel" – emissions from the fuel use by farm vehicles and machinery and stationary combustion on farm.

2.3.4.4. Other LULUCF Sources/Sinks (2024 GHG Source, 9.7 Mt)

Other LULUCF sources/sinks include Wetlands, Settlements and Grassland, which contributed 5.4 Mt, 4.3 Mt and 1.3 kt, respectively, to their combined net emissions of 9.7 Mt reported in 2024, down from 15 Mt in 1990. This long-term decline is largely driven by decreasing emissions from wetland conversions (flooded land) over the time series.

The Settlements category includes removals from urban tree growth and emissions from Land Converted to Settlements including emissions from forest land conversion, resource extraction in the Oil Sands Region and Northern land-use change. Urban trees have provided average annual removals of 4.0 Mt per year since 1990. Over the same period, emissions from Land Converted to Settlements averaged 9.0 Mt. In 2024, the conversion of forest land, grasslands and wetlands to settlement contributed 7.9 Mt, 0.31 Mt and 0.14 Mt respectively, highlighting that forest land conversion is the primary driver of land-use change emission trends in settlements. Net emissions from the Settlements category were 4.3 Mt in 2024.

The Wetlands category includes emissions from peatlands managed for peat extraction, flooded lands (hydroelectric reservoirs and other reservoirs) and removals from peatlands impacted by resource extraction in the Oil Sands Region. Emissions from peat extraction have gradually increased, rising from 0.6 Mt in 1990 to 1.6 Mt in 2024, driven by continued demand for peat products in the horticulture industry. Emissions from flooded lands are strongly influenced by historical land-use activities, particularly the construction of large hydroelectric reservoirs. While most major reservoirs were built before the 1990s, some new construction continues. Flooded lands produce high emissions shortly after initial inundation, which then decline over time. As a result, emissions from flooded lands decreased from 9.5 Mt in 1990 to 3.9 Mt in 2024, reflecting the aging of most reservoirs. More specific details on the trend in emissions from Forest Land Converted to Settlements and flooded lands can be found in section 2.3.4.2. Peatlands impacted by resource extraction in the Oil Sands Region Emissions have seen a small increase in removals since 1990, with 0.1 Mt in 2024. Overall net emissions in wetlands decreased from 10 Mt in 1990 to 5.4 Mt in 2024.

2.3.5. Waste Sector (2024 GHG Emissions, 23 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from the Waste sector contributed 23 Mt (3.3%) to Canada's total emissions in 2024, comparable to emission levels of 21 Mt in 1990 (3.5% of total emissions) and of 23 Mt (3.1%) in 2005 (Figure 2–26 and Table 2–13). In 2024, landfilling (including municipal solid waste and industrial wood waste landfills) accounted for 19 Mt (or 85% of total Waste sector emissions), while Biological Treatment of Solid Waste (composting and anaerobic digestion) accounted for 0.6 Mt, Wastewater Treatment and Discharge accounted for 2.6 Mt, and Incineration and Open Burning of Waste (excluding CO_2 emissions from incineration of biomass material) contributed 0.16 Mt.

Figure 2–26 **Trends in Canadian GHG Emissions from Waste (1990–2024)**

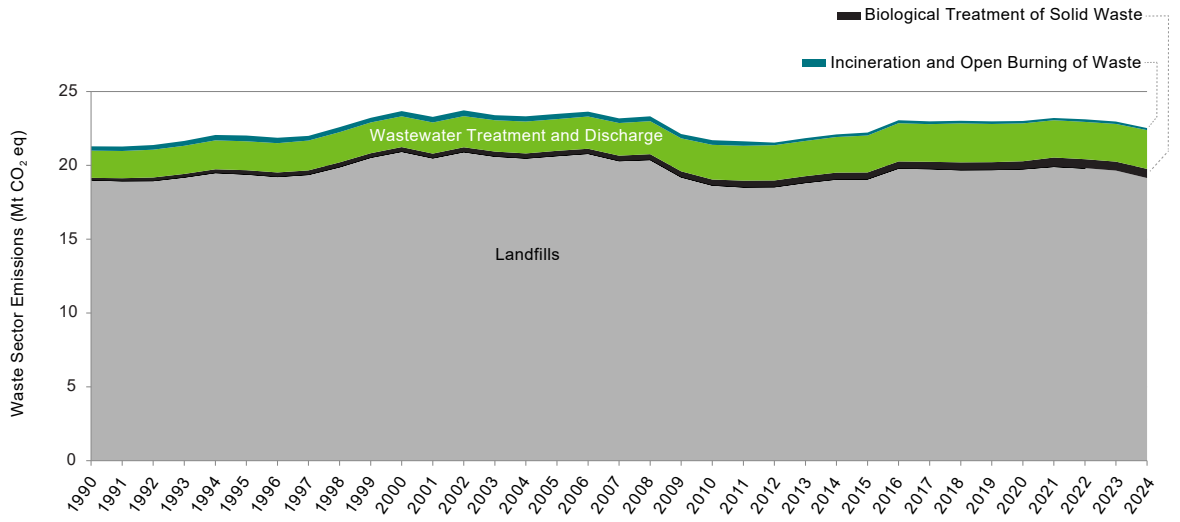


Table 2–13 **GHG Emissions from Waste, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2019	2020	2021	2022	2023	2024	1990–2024	2005–2024
WASTE SECTOR	**21**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**5.8%**	**-4.1%**
Municipal Solid Waste Landfills	18	20	19	19	19	19	19	18	1.9%	-6.0%
Industrial Wood Waste Landfills	0.91	1.0	0.79	0.77	0.75	0.74	0.72	0.70	-22%	-32%
Biological Treatment of Solid Waste	0.15	0.33	0.51	0.51	0.60	0.61	0.61	0.61	309%	86%
Incineration and Open Burning of Waste	0.29	0.35	0.17	0.16	0.15	0.17	0.16	0.15	-49%	-58%
Municipal Wastewater Treatment and Discharge	1.4	1.7	2.2	2.2	2.2	2.3	2.3	2.4	68%	38%
Industrial Wastewater Treatment and Discharge	0.41	0.41	0.41	0.37	0.35	0.28	0.24	0.23	-43%	-44%

Note: Totals may not add up due to rounding.

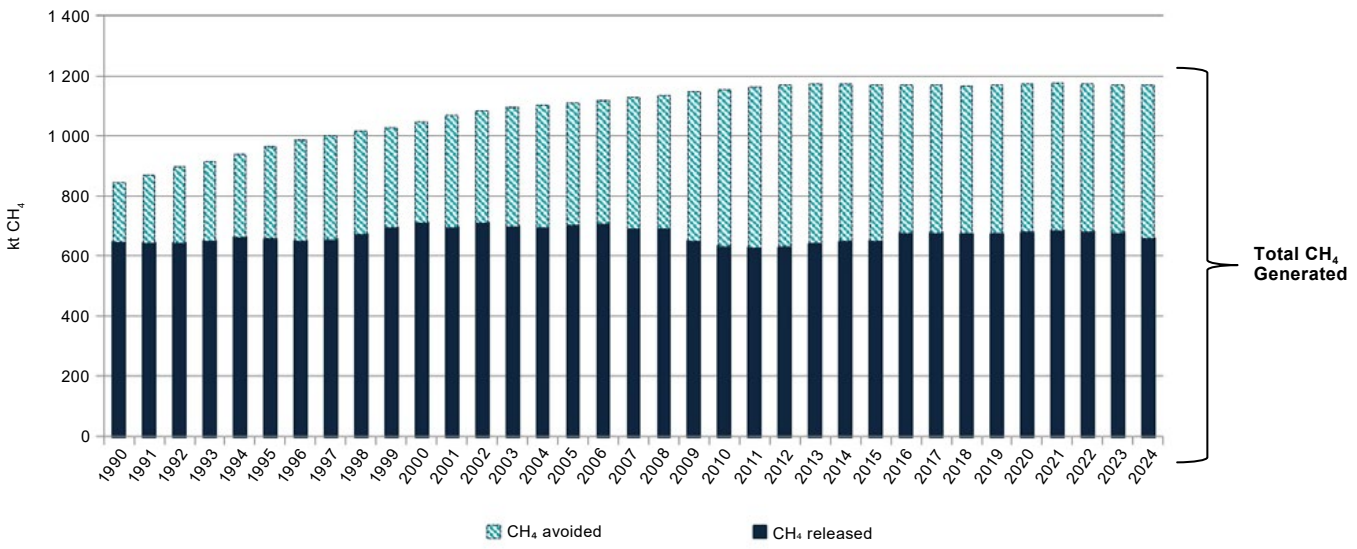
2.3.5.1. Landfills (2024 GHG Emissions, 19 Mt)

GHG emissions from landfills are released in landfill gas (LFG) generated by the anaerobic decomposition of buried organic waste. LFG consists mostly of CO_2 and CH_4, though only the release of CH_4 is reported in the Waste sector. The CH_4 production rate at a landfill is a function of several factors, including the mass and composition of waste being landfilled and the moisture entering the site from rainfall. The net amount of CH_4 released from landfill sites is further influenced by the presence of oxidizing landfill covers and the use of LFG capture technologies.

In 2024, emissions from municipal landfills were 18 Mt, while emissions from wood waste landfills were 0.70 Mt. Emissions from municipal landfills increased by 2% from 1990 to 2025 and have decreased by 6% from 2005 to 2024. Emissions from wood waste landfills decreased by 22% from 1990 to 2024 and by 32% from 2005 to 2024.

The amount of CH_4 generated in municipal landfills has increased since 1990, primarily as a result of an increasing waste deposition over time, but has remained relatively stable since around 2015. Methane recovery was 3.5 times higher in 2024 than in 1990 but has decreased from the peak in 2012. In 2024, 37% of the LFG generated in landfills was recovered through LFG capture technologies, compared with 15% in 1990 (Figure 2–27).

Figure 2–27 **Methane Generated, Avoided and Released from MSW Landfills**



Note: Avoided CH_4 represents the amount of CH_4 that is not released from the landfill because it is captured (and either flared or utilized), and/or oxidized as it passes through the landfill cover.

2.3.5.2. Other Waste Sources (2024 GHG Emissions, 3.4 Mt)

Over the 1990–2024 period, emissions from the Biological Treatment of Solid Waste (anaerobic digestion and composting), Wastewater Treatment and Discharge (municipal and industrial wastewater treatment), and Incineration and Open Burning subcategories collectively increased by 20% (Figure 2–26 and Table 2–13).

An increase in Wastewater Treatment and Discharge emissions reflects the increase in the Canadian population. A decrease in total incineration emissions (from the incineration of MSW, sewage sludge, hazardous and clinical waste) was due mainly to the closure of aging MSW incinerators.

Since 1990, many municipalities in Canada have opened centralized composting facilities to reduce the quantity of organics sent to landfills. These practices have contributed to an increase in emissions from the Biological Treatment of Solid Waste category.

2.4. Emissions by Canadian Economic Sector

In this report, emission estimates are primarily grouped into the activity sectors defined by the IPCC (section 2.3). While this categorization is consistent with the reporting requirements, reallocating emissions into economic sectors is more suitable for the purpose of analyzing trends and policies relative to a particular economic activity (e.g., producing electricity, farming or driving a car). This section reports emissions according to the following Canadian economic sectors: Oil and Gas, Electricity, Transport, Heavy Industry, Buildings, Agriculture, and Waste and others (Table 2–14).

This reallocation simply recategorizes emissions under different headings but does not change the overall magnitude of Canadian emission estimates. It takes the relevant proportion of emissions from various IPCC categories to create a comprehensive emission profile for a specific economic sector. Examining the historical Canadian GHG emissions by economic sector results in a better understanding of the connection between economic activities and emissions for the purposes of analyzing trends and for policy and public analysis. For example, the Transport sector represents emissions arising from the cars, trucks, trains, aircraft and ships fulfilling mobility requirements of people, as well as mobility service emissions from heavy-duty trucks and other commercial vehicles. Unlike the IPCC categorization, the Transport economic sector does not contain off-road transportation emissions related to farming, mining, construction, forestry, pipelines or other industrial activities, which are allocated to their corresponding economic sectors. Furthermore, if there were any upward trend in farming or mining activity, emissions arising from the increased use of mobile farming machinery or mining trucks would be reflected in the economic sector estimates for Agriculture or Heavy Industry (mining).

A series of tables which show the distribution of national emissions by Canadian economic sector for the complete time series (1990–2024) and the relationship between economic and IPCC sectors for the latest data year are available in the Economic Sector folder on the Government of Canada's Open Data website.[12] Similar tables for provinces and territories can be found in the same folder. Each Canadian economic sector includes all applicable emissions from energy-related and non-energy-related processes. Specifically:

- the Oil and Gas sector represents all GHGs emitted during the extraction, distribution, refining and upgrading of oil and gas products;
- the Electricity sector represents all emissions from electric utility generation and transmission for residential, industrial and commercial users;
- the Transport sector represents all emissions arising from the tailpipes of domestic passenger and freight transport;
- the Heavy Industry sector represents emissions arising from metal and non-metal mining activities, smelting and refining, the production and processing of industrial goods such as paper or cement, and biofuel manufacturing;
- the Buildings sector represents emissions arising directly from residential homes and commercial buildings;
- the Agriculture sector represents all emissions arising from farming activities, including those related to energy combustion for farming equipment as well as those non-CO_2 related to crop and animal production; and finally,
- the Waste and others sector represents emissions that arise from solid and liquid waste, waste incineration, and coal production, light manufacturing, construction and forestry activities.

2.4.1. Emissions Trends by Canadian Economic Sector

Overall, GHG emissions trends since 2005 have remained consistent with those described for IPCC sectors, with emission increases in the Oil and Gas (10 Mt or 5.1%) and Agriculture (3.6 Mt or 5.4%) economic sectors being offset by decreases in other sectors, notably Electricity (-66 Mt or -57%), but also Heavy Industry, Waste and others, and Buildings. From 2005 to 2020, Transport emissions generally increased. After a notable decrease in 2020, emissions in this sector increased before stabilizing in recent years at levels below those of 2005.

Oil and Gas

In 2024, the Oil and Gas sector produced the largest share of GHG emissions in Canada (30%) (Figure 2–28). Between 1990 and 2024, emissions from this sector increased by 89 Mt (76%). While fluctuations due to economic conditions (e.g., crude oil and natural gas prices) caused short-term increases and decreases in emissions between 1990 and 2024, emissions from this sector have generally increased steadily from 118 Mt in 1990, reaching a maximum of 230 Mt in 2014. Most of the increase between 1990 and 2024 is due to considerable expansion in Canada's oil sands. Since 1990, oil sands production has increased by over 900% and emissions have increased by over 77 Mt (~530%). From 2014 to 2019, emissions were relatively stable with some interannual variability due to economic conditions and the 2016 wildfires that impacted oil sands production around Fort McMurray, Alberta. This period was followed by a significant decrease of 15 Mt (6.8%) between 2019 and 2024. This decrease coincides with federal regulations to reduce methane emissions from the upstream oil and gas industry, which came into effect January 1, 2020, and equivalent provincial regulations in Saskatchewan, Alberta and British Columbia. Oil and Gas emissions increased 10 Mt or 5.1% since 2005. Section 2.3 and the 'Trends in the Oil and Gas Sector' text box discuss the historical drivers of Oil and Gas sector emissions trends in more detail.

Transport

Canada's Transport sector is the second-largest contributor to Canada's GHG emissions, accounting for 22% of total emissions in 2024 (Figure 2–28). Between 1990 and 2024, emissions rose by 34 Mt (29%). From 1990 to 2020, emissions from this sector have increased gradually, apart from a significant decrease between 2019 and 2020, largely due to fewer kilometers driven during the first year of the COVID-19 pandemic. Transport emissions stabilized in recent years and in 2024 are now slightly below 2005 levels (-4.8 Mt or -3.1% since 2005). Section 2.3 discusses the main drivers of historical emissions trends associated with passenger and freight transport.

12 https://data-donnees.az.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory?lang=en

Electricity

In 2024, the Electricity sector (excluding industrial and commercial cogeneration) contributed 7.2% to total Canadian emissions (Figure 2–28). Between 1990 and 2024, emissions decreased by 45 Mt (47%). Emissions from the Electricity sector increased in parallel with the rising demand for electricity both domestically and to satisfy exports to the United States over the earlier years of the reporting period but have fallen significantly during the latter years. Electricity emissions decreased by 66 Mt or 57% since 2005, despite the 7% increase in demand. Section 2.3 discusses the main historical drivers of emissions trends associated with electricity generation.

Heavy Industry

Emissions from this sector were responsible for 16% of total Canadian emissions in 1990, falling to 11% in 2024 (Figure 2–28). The Heavy Industry sector experienced some fluctuations and overall decreases in emissions over the reporting period, and similar to other sectors of the economy, a notable decrease in the 2008–2009 recessionary period. The emissions decreased by 20 Mt (21%) between 1990 and 2024, and by 11 Mt (13%) between 2005 and 2024. In more recent years, emissions have fallen further as a result of reduced economic activity and the continued evolution of Canadian production towards other sectors and services.

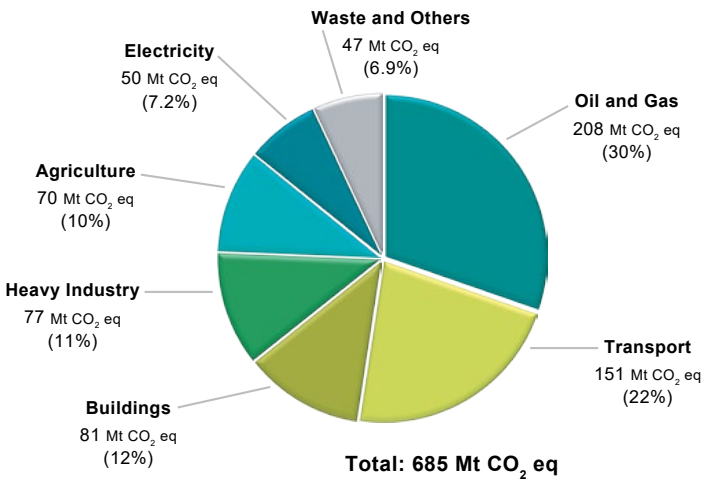
Buildings

In 2024, the Buildings sector contributed 12% to total Canadian emissions (Figure 2–28). Emissions from residential fuel combustion decreased 6.0 Mt (14%) since 1990, which was offset by a 16 Mt (58%) increase in emissions from the service industry. Since 2005, the Buildings sector emissions decreased by 3.3 Mt or 3.8%. GHG emissions from the Buildings sector have fluctuated throughout the time series but, have remained relatively stable since 2005 despite population growth and commercial development.

Agriculture and Waste and Others

Emissions from the Agriculture sector continued a gradual upward trend throughout the reporting period, rising from 51 Mt in 1990 to 66 Mt in 2005, and 70 Mt in 2024 (Figure 2–28). Emissions from the Waste and others sector decreased by 10 Mt (17%) since 1990 and 6.4 Mt (12%) since 2005. Overall, Waste emissions fluctuated and slightly increased over the time series, from 21 Mt in 1990 to 23 Mt in 2024. Section 2.3 discusses the main historical drivers of emissions trends associated with Agriculture and Waste.

Figure 2–28 **Breakdown of Canada's GHG Emissions by Economic Sector (2024)**



Note: Totals may not add up due to rounding.

Table 2–14 **Trends in GHG Emissions by Canadian Economic Sector**

Economic Sector	GHG Emissions (Mt CO_2 eq)									
	1990	2005	2019	2020	2021	2022	2023	2024	1990–2024	2005–2024
NATIONAL TOTAL	**608**	**763**	**748**	**681**	**691**	**696**	**687**	**685**	**13%**	**-10%**
Oil and Gas	**118**	**198**	**223**	**203**	**209**	**206**	**204**	**208**	**76%**	**5.1%**
Upstream Oil and Gas	**97**	**174**	**203**	**185**	**191**	**187**	**185**	**188**	**93%**	**8.5%**
Natural Gas Production and Processing	38	75	61	58	59	54	52	52	36%	-31%
Conventional Oil Production	33	53	48	36	35	33	32	34	3.6%	-37%
Conventional Light Oil Production	19	22	29	22	20	20	19	20	10%	-5.0%
Conventional Heavy Oil Production	14	30	17	13	13	12	12	12	-15%	-61%
Frontier Oil Production	0.26	1.7	1.8	1.6	1.4	1.3	1.3	1.6	517%	-3.3%
Oil Sands and Thermal Heavy Oil Production	15	33	84	82	87	88	89	92	529%	177%
Mining and Extraction	2.8	6.9	17	16	17	17	17	18	533%	162%
In Situ Thermal Extraction	4.0	10	43	42	46	47	48	49	1122%	409%
Upgrading	7.8	17	24	24	24	24	24	25	225%	51%
Oil, Natural Gas and CO_2 Transmission	12	12	10	8.9	10	11	11	11	-7.3%	-8.8%
Downstream Oil and Gas	**21**	**24**	**20**	**18**	**19**	**19**	**19**	**19**	**-7.6%**	**-20%**
Petroleum Refining	19	22	19	17	18	18	18	18	-4.6%	-18%
Natural Gas Distribution	1.6	1.7	1.0	1.0	1.0	0.94	0.91	0.89	-44%	-46%
Electricity	**94**	**116**	**62**	**54**	**52**	**49**	**51**	**50**	**-47%**	**-57%**
Transport	**118**	**156**	**169**	**141**	**147**	**153**	**152**	**151**	**29%**	**-3.1%**
Passenger Transport	**80**	**96**	**104**	**83**	**86**	**92**	**93**	**93**	**15%**	**-3.5%**
Cars, Trucks and Motorcycles	71	85	90	75	77	79	80	80	13%	-5.5%
Bus, Rail, Marine and Aviation	9.5	11	13	8.3	8.7	12	13	13	33%	12%
Freight Transport	**29**	**47**	**51**	**45**	**47**	**48**	**46**	**45**	**55%**	**-3.3%**
Heavy-Duty Trucks, Rail	25	42	46	41	43	44	42	42	66%	-1.0%
Aviation and Marine	4.0	4.5	4.3	4.5	4.3	3.5	3.3	3.4	-16%	-24%
Other: Recreational, Commercial and Residential	**8.2**	**14**	**15**	**13**	**14**	**14**	**14**	**14**	**66%**	**0.3%**
Heavy Industry	**98**	**89**	**80**	**77**	**79**	**80**	**79**	**77**	**-21%**	**-13%**
Mining	**7.8**	**8.8**	**11**	**11**	**11**	**12**	**10**	**10**	**33%**	**17%**
Smelting and Refining (Non-Ferrous Metals)	**17**	**14**	**10**	**10**	**10**	**10**	**11**	**10**	**-45%**	**-33%**
Pulp and Paper	**15**	**9.0**	**8.2**	**7.2**	**7.4**	**7.5**	**7.3**	**6.6**	**-56%**	**-26%**
Iron and Steel	**17**	**16**	**15**	**13**	**15**	**14**	**14**	**15**	**-12%**	**-10%**
Cement	**10**	**13**	**11**	**11**	**11**	**10**	**11**	**10**	**1.8%**	**-18%**
Lime and Gypsum	**2.9**	**3.5**	**2.3**	**2.2**	**2.2**	**2.5**	**2.2**	**2.2**	**-25%**	**-38%**
Chemicals, Fertilizers and Biofuel Manufacturing	**28**	**24**	**22**	**23**	**23**	**23**	**23**	**24**	**-14%**	**-1.3%**
Buildings	**72**	**85**	**94**	**88**	**85**	**88**	**83**	**81**	**14%**	**-4%**
Service Industry	**28**	**40**	**50**	**47**	**45**	**46**	**44**	**43**	**58%**	**9%**
Residential	**44**	**45**	**44**	**41**	**40**	**42**	**38**	**38**	**-14%**	**-15%**
Agriculture	**51**	**66**	**69**	**70**	**70**	**70**	**69**	**70**	**37%**	**5%**
On-Farm Fuel Use	**8.2**	**9.4**	**15**	**13**	**14**	**14**	**14**	**13**	**63%**	**42%**
Crop Production	**9.5**	**11**	**17**	**19**	**18**	**18**	**19**	**19**	**105%**	**83%**
Animal Production	**33**	**46**	**38**	**38**	**38**	**38**	**37**	**37**	**11%**	**-20%**
Waste and Others	**57**	**54**	**51**	**48**	**49**	**50**	**49**	**47**	**-17%**	**-12%**
Waste	**21**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**6.0%**	**-3.9%**
Coal Production	**4.7**	**2.9**	**3.4**	**2.8**	**3.0**	**3.0**	**3.2**	**2.8**	**-39%**	**-3.8%**
Light Manufacturing, Construction and Forest Resources	**31**	**27**	**25**	**22**	**23**	**24**	**23**	**22**	**-30%**	**-19%**

Notes:

Totals may not add up due to rounding.

For the allocation between IPCC and economic sectors, see the Relationship between GHG emissions by Canada's Economic Sectors and IPCC Sectors table in the Economic Sector folder on the Government of Canada's Open Data website.

Complete emission estimates by economic sectors at the province and territory level are available on the Government of Canada's Open Data website.

Estimates presented here are under continual improvement. Historical emission estimates may be changed in future publications as new data becomes available and methods and models are refined and improved.

Trends in the Oil and Gas Sector

Emissions in the Canadian Oil and Gas (O&G) economic sector include flaring, venting, unintentional leaks, industrial processes and all combustion-related emissions (stationary combustion, off-road transportation, utility and industrial generation of electricity and steam), excluding captured CO_2, to provide a complete emission profile of the industry.

In 2024, the largest contributor to O&G emissions was the Oil Sands and Thermal Heavy Oil Production category[13] (92 Mt, or 44%), followed by Natural Gas Production and Processing (52 Mt, or 25%), Conventional Oil Production (34 Mt, or 16%) and Petroleum Refining (18 Mt, or 9%). The primary drivers of emissions within the O&G sector are production growth and emission intensity (defined as the average amount of GHG emissions generated per barrel of oil equivalent).

Production Growth

From 1990 to 2024, the production of total crude oil increased by 221%. The increase was driven almost entirely by Canada's oil sands operations (mining, thermal in situ extraction and crude bitumen upgrading) with total oil sands output (non-upgraded bitumen and synthetic crude oil production) increasing by over 900% since 1990, accounting for 76% of total crude oil production growth. Consistent with the production increase, emissions from oil sands increased by 71 Mt (about 510%). In contrast, conventional crude oil production (including primary extraction in designated oil sands areas) increased by 38% over the same period, but emissions from Conventional Oil Production have recently declined to levels similar to 1990.

Emissions from Natural Gas Production and Processing have increased by 14 Mt (36%) since 1990, consistent with a 66% increase in gross production volumes. Most of this growth has occurred in northeastern British Columbia, which has accounted for 74% of the national production growth.

Emission Intensity

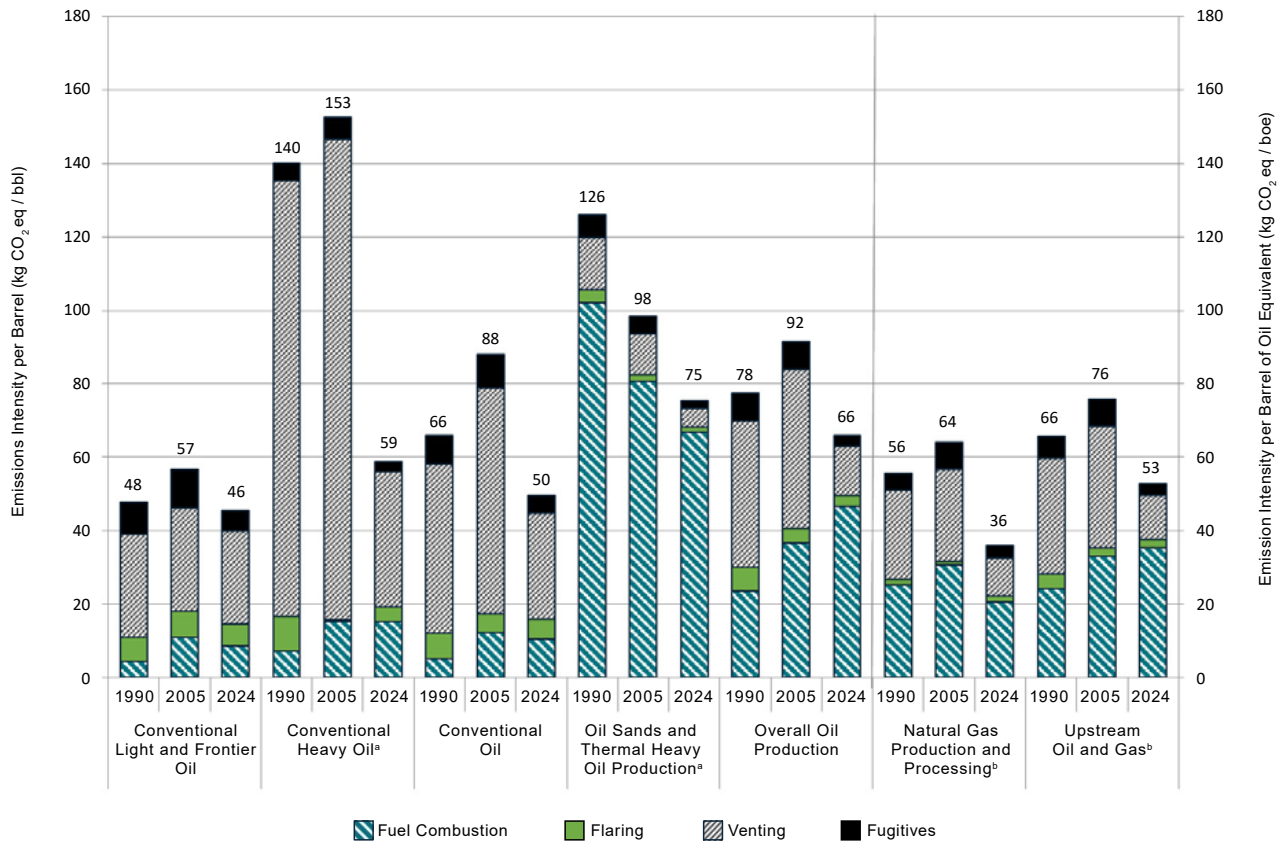
The emission intensity of overall oil production in Canada decreased by 15% between 1990 and 2024, from 78 to 66 kg CO_2 eq per barrel (Figure 2–B) with the most notable decrease of 28% occurring since 2014 where intensity was 92 kg CO_2 eq per barrel. Contributors to this trend include decreasing reserves of easily removable crude oil, along with increasing reliance on reserves requiring more energy- and GHG-intensive extraction methods. These include more difficult-to-extract crude oil and crude bitumen, including those extracted using enhanced oil recovery operations such as steam-assisted gravity drainage (SAGD). The increased use of horizontal wells and multi-stage fracturing techniques also increases emissions and the amount of energy required for drilling and well-completion activities. Fuel combustion emissions have increased by nearly 100% per barrel of oil extracted (24 kg CO_2 eq per bbl in 1990 to 47 kg CO_2 eq per bbl in 2024), which is indicative of increased oil sands production that requires large quantities of steam, generally produced from combusting natural gas.

The rising quantity of petroleum extracted from Canada's oil sands has had the largest impact on increasing the emission intensity of overall oil production. However, the intensity of Oil Sands and Thermal Heavy Oil Production operations have declined steadily from 126 kg CO_2 eq per barrel in 1990 to 75 kg CO_2 eq per barrel in 2024. The emission intensity in the oil sands has continued to decline as the industry has reduced the fuel combustion requirements per barrel of oil extracted. Emissions vented per barrel extracted at thermal in situ bitumen facilities have also decreased due to the impact of Alberta's Directive 60. Furthermore, increased crude bitumen production without the additional processing step of upgrading to synthetic crude oil (SCO) has also contributed to decreasing the overall emissions intensity. This is particularly evident since 2010, where non-upgraded bitumen production increased by over 200% while SCO production increased by only 50%. The additional energy required to process the crude bitumen (and resulting emissions) is transferred downstream, mainly to export markets where the bitumen is processed at petroleum refineries. Since 2015, almost 10 Mt of CO_2 emissions from the Scotford Upgrader have been captured and transported to an underground storage site, contributing to the reduction in oil sands emissions intensity.

In contrast to combustion emissions, venting, flaring and fugitive emissions per barrel of oil extracted have decreased by 66%, 56% and 59%, respectively, since 1990. These reductions are partially due to increased oil sands and thermal heavy oil production, which produce much fewer fugitive emissions per barrel than conventional oil production. This shift is particularly clear in the period since 2005, where conventional cold heavy oil production decreased by about 17%, while at the same time, lower methane intensity production techniques like SAGD were adopted in heavy oil producing regions (including those designated as oil sands), and overall thermal in situ production in Alberta and Saskatchewan grew by nearly 470%.

13 The Oil Sands and Thermal Heavy Oil Production category includes oil sands mining and extraction, crude bitumen and heavy oil upgrading, and thermal in situ crude bitumen and heavy oil extraction activities that occur in both Alberta and Saskatchewan.

Figure 2–B **Emissions Intensity by Source Type for Oil and Gas (1990, 2005 and 2024)**

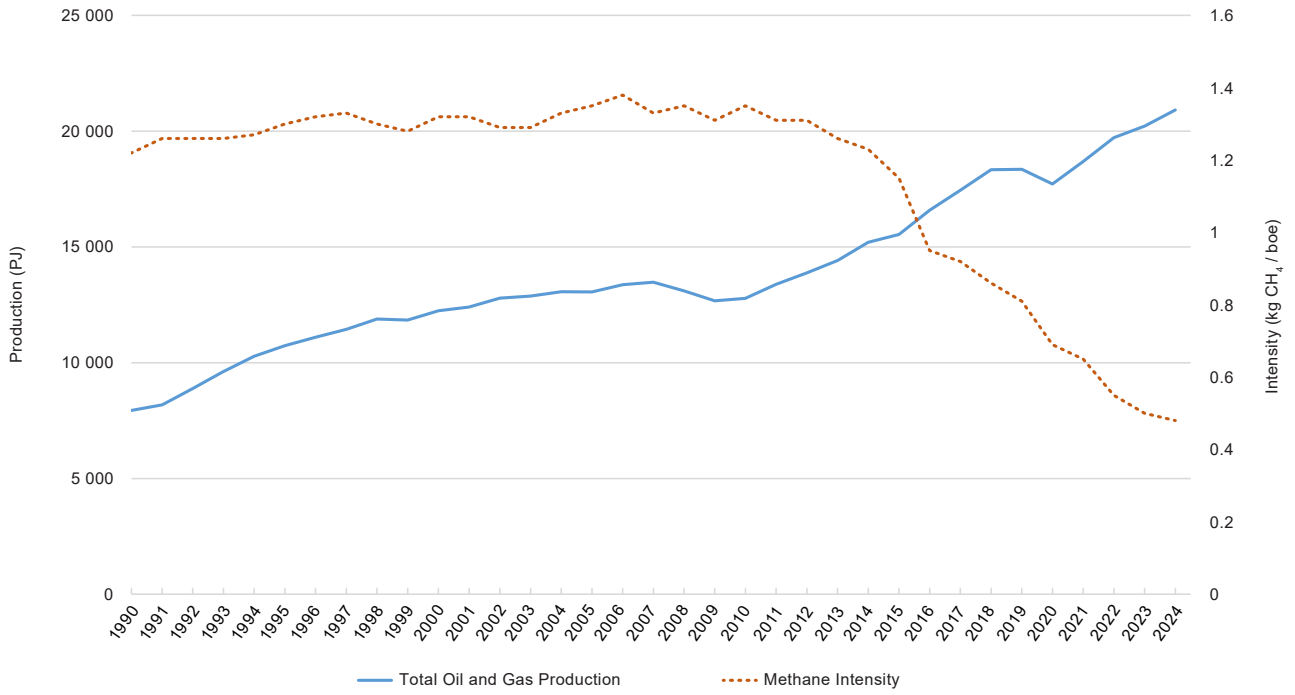


Notes:
Intensities are based on total subsector emissions and relevant production amounts. They represent overall averages, not facility intensities.
a. Emissions and production associated with primary extraction of crude bitumen in designated oil sands areas (i.e. Athabasca, Cold Lake, Peace River) are included in Conventional Heavy Oil.
b. Calculated on a barrel of oil equivalent (boe) basis by converting production volumes to energy basis and then dividing by energy content of light crude oil (6.1215 GJ/bbl).
[1 barrel (bbl) = 0.159 m^3]
Production data sources = Natural Gas: StatCan (1990–); Crude Oil: NB NRED (2024), SK MER (1990–2008, 2009–2011, 2012–), StatCan (n.d.[d], n.d.[h]); Oil Sands and Thermal Heavy Oil: AER (n.d.), Cenovus (2021-), Petrinex (n.d.).

Methane intensity reductions have also resulted from initiatives such as Alberta's Directive 60 (AER, 2014), British Columbia's Flaring and Venting Reduction Guideline (BCOGC, 2015), Saskatchewan's Directive S-10, and the Canadian Association of Petroleum Producers (CAPP) Best Management Practice for Fugitive Emissions (CAPP, 2007). More recently, the federal regulations to reduce methane from upstream oil and gas (ECCC, 2018) and equivalent provincial regulations in Alberta (AB, 2018; ECCC, 2020a), British Columbia (BC, 2021; ECCC, 2020b), and Saskatchewan (SK, 2020; ECCC, 2020c), which came into effect January 1, 2020, have also had an impact.

These factors have collectively contributed to a 63% decrease in the methane intensity of total oil and gas production (Figure 2–C) since 2012. Over that same period, total Canadian oil and gas production increased by 51%. In fact, since 2012, efforts in all three major oil and gas producing provinces (Alberta, British Columbia and Saskatchewan) have resulted in decreases in methane emissions intensity. In Alberta, methane intensity decreased by 63% while production increased by 45%. Similarly, in British Columbia, the intensity decreased by 81% at the same time as a 140% increase in production. In Saskatchewan, both methane intensity (-43%) and production (-9%) have decreased since 2012. This shows that efforts by industry and regulators have had positive impacts on emissions intensity, which puts downward pressure on emission levels while competing against the upward pressure of production increases.

Figure 2–C **Methane (CH_4) Emission Intensity Versus Total Oil and Gas Production, Canada**



Notes:
boe = barrel of oil equivalent; calculated by converting production volumes to energy basis and then dividing by energy content of light crude oil (6.1215 GJ/bbl)
[1 barrel (bbl) = 0.159 m^3]

ENERGY (CRT SECTOR 1)

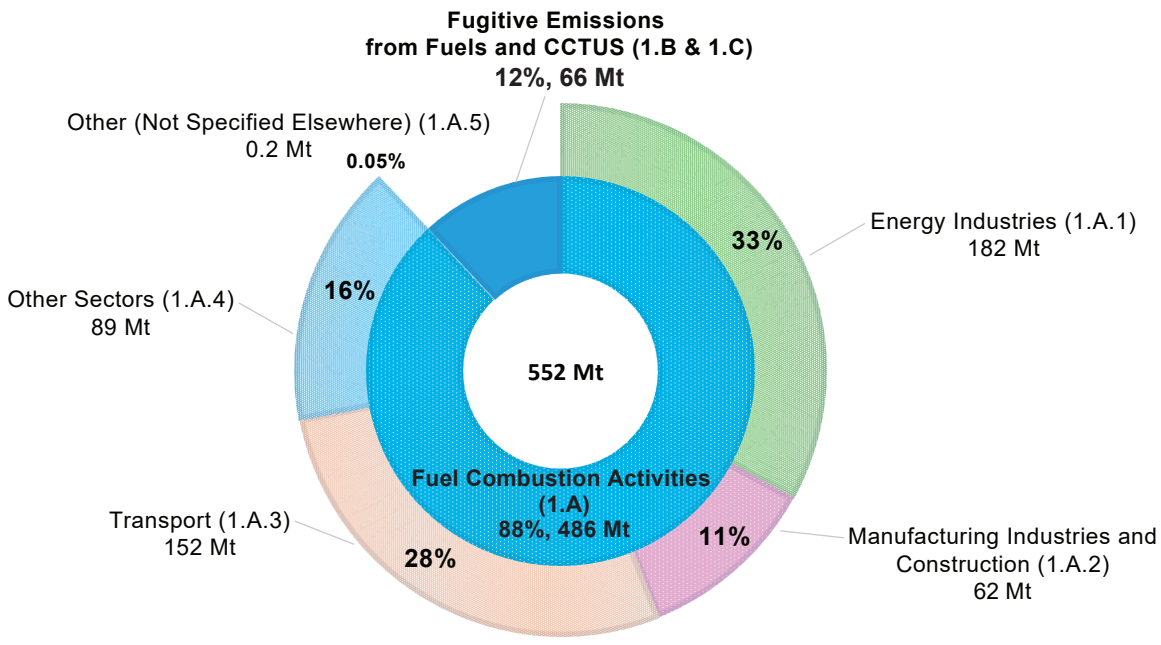
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3.1. Overview

In 2024, the Energy sector contributed 552 Mt (81%) to Canada's total greenhouse gas (GHG) emissions (Figure 3–1 and Table 3–1). This includes carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions from: all fuel combustion activities, fugitive sources, and CO_2 leakage from carbon capture, transport, use and storage (CCTUS) activities.[1]

The combustion of fossil and biomass fuels generated 486 Mt (88%) of the Energy sector's GHG emissions while the remaining 66 Mt (12%) are fugitive emissions from fossil fuel industries and CCTUS. Fuel combustion emissions are split into the five categories shown in Figure 3–1: Energy Industries, Manufacturing Industries and Construction, Transport, Other Sectors, and Others. Specific details are presented in their respective sections, refer to sections 3.2.1 to 3.2.5.

Figure 3–1 **2024 Energy Sector Emission Contribution by Category**



Note: CCTUS = Carbon capture, transport, use and storage

1 The Industrial Processes and Product Use sector reports emissions associated with the non-energy use of fossil fuels.

Fugitive emissions from the fossil fuel industry are intentional (e.g., operational/process venting) or unintentional (e.g., leaks, accidents) releases of GHGs resulting from production, processing, transmission, and storage activities. The Fugitive category includes emissions from flaring by the oil and gas industry since this activity does not produce useful heat or mechanical work (IPCC, 2006). Refer to section 3.3.

Currently, captured CO_2 from industrial operations is transported and used for enhanced oil recovery (EOR) or injected into long-term storage (LTS). Section 3.4 has details of the capture volumes and emissions associated with CCTUS.

Table 3–1 **Overview of GHG Emissions from the Energy Sector, Selected Years**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
Energy Sector TOTAL	**488 000**	**626 000**	**616 000**	**549 000**	**558 000**	**563 000**	**554 000**	**552 000**
Fuel Combustion Activities (1.A)	**422 000**	**526 000**	**530 000**	**475 000**	**484 000**	**495 000**	**488 000**	**486 000**
Energy Industries (1.A.1)	143 000	206 000	191 000	178 000	181 000	179 000	181 000	182 000
Manufacturing Industries and Construction (1.A.2)	74 600	68 200	68 500	62 300	64 200	65 600	63 600	62 400
Transport (1.A.3)	118 000	157 000	167 000	140 000	146 000	154 000	153 000	152 000
Other Sectors (1.A.4)	86 000	94 200	103 000	95 300	92 700	96 300	90 800	89 400
Other (Not Specified Elsewhere) (1.A.5)	260	290	260	210	220	220	210	230
Fugitive Emissions from Fuels (1.B)	**66 000**	**100 000**	**85 000**	**74 000**	**74 000**	**68 000**	**66 000**	**66 000**
CO_2 Transport and Storage (1.C)	**NO**	**0.09**	**0.28**	**0.49**	**0.65**	**0.64**	**0.65**	**0.65**

Notes:
NO = Not occurring
Totals may not add up due to rounding.

3.1.1. Recalculations

Continuous methodological improvements and revised activity data resulted in several recalculations of GHG emissions in the Energy sector; refer to Table 3–2. An overview of improvements is presented below, while the subsequent sections of Chapter 3 present explanations of activities resulting in recalculation of emission estimates. Chapter 8 provides a summary of recalculations for all sectors.

Table 3–2 **Summary of Recalculations for the Energy Sector, Selected Years**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
Energy Sector TOTAL								
Previous Submission (2025 NIR)	487 000	623 000	615 000	616 000	552 000	562 000	568 000	562 000
Current Submission (2026 NIR)	488 000	626 000	616 000	616 000	549 000	558 000	563 000	554 000
Change in Emissions	740	3 100	770	-240	-2 930	-3 940	-5 150	-8 510
	0.15%	0.50%	0.12%	-0.04%	-0.53%	-0.70%	-0.91%	-1.5%
Fuel Combustion (1.A)								
Previous Submission (2025 NIR)	422 000	525 000	527 000	532 000	477 000	487 000	498 000	494 000
Current Submission (2026 NIR)	422 000	526 000	527 000	530 000	475 000	484 000	495 000	488 000
Change in Emissions	520	910	-750	-1 340	-1 730	-2 980	-3 160	-5 610
	0.12%	0.17%	-0.14%	-0.25%	-0.36%	-0.61%	-0.63%	-1.1%
Fugitive (1.B) and CO_2 Transport & Storage (1.C)								
Previous Submission (2025 NIR)	66 000	98 000	88 000	84 000	75 000	75 000	70 000	69 000
Current Submission (2026 NIR)	66 000	100 000	89 000	85 000	74 000	74 000	68 000	66 000
Change in Emissions	220	2 180	1 520	1 100	-1 200	-950	-1 980	-2 910
	0.33%	2.2%	1.7%	1.3%	-1.6%	-1.3%	-2.8%	-4.2%

Note: Totals may not add up due to rounding.

Overall, recalculations resulted in a downward revision of 8.51 Mt compared to the 2025 UNFCCC submitted value for 2023. Recalculations are grouped as follows:

Activity data: Revisions to activity data resulting from quality assurance/quality control (QA/QC) checks, data corrections, reallocations, or new information.

- Revisions to fuel consumption data in the *Report on Energy Supply and Demand in Canada* (RESD) (StatCan, n.d.) generally result in recalculations to multiple fuel combustion categories and subcategories. Revised 2023 RESD data have been incorporated (as per standard practice) as an update to the 2023 preliminary data[2] along with corrections to some historical data utilized in last year's national inventory submission to the UNFCCC. Revisions to the RESD consist of:
  - 2017 and 2023 aviation turbo fuel data
  - 2021 to 2022 butane data
  - 2014 to 2023 coal data
  - 2011 to 2023 diesel fuel oil data
  - 2022 to 2023 heavy fuel oil data
  - 1999 to 2023 light fuel oil data
  - 2011 to 2023 motor gasoline data
  - 2018 to 2023 natural gas data
  - 2021 to 2022 propane data
  - 2021 to 2023 solid wood waste data
  - 1990 to 2023 still gas data
- Revisions of non-RESD data consist of:
  - 2023 aircraft movement statistics
  - 2023 vehicle registration data
  - 2004 to 2023 volumes of flared gas subtracted from stationary combustion to avoid double counting
  - 2021 to 2023 quantity of digester gas combusted
  - 1995 to 2023 quantity of landfill gas combusted
  - 1990 to 2023 quantity of municipal solid waste and medical waste combusted
  - 2021 to 2023 quantity of residential firewood combusted
  - 1990 to 2023 quantity of sludge gas combusted

Methodology: Recalculations resulting from methodological improvements through refinement/updates via new knowledge and information, application of higher IPCC Tier methods, and additional methods for new emission sources.

- updates to model parameters used to estimate fugitive equipment leaks in the UOG sector (refer to section A3.2.2.1.3)
- improvements to produced natural gas composition data used to estimate fugitive emissions in the British Columbia UOG sector (refer to section A3.2.2.1.2 for a detailed description)
- methodological updates for the thermal heavy oil production sector in Saskatchewan and related updates to historical fugitive estimates for heavy oil production (described in sections A3.2.2.1.1 and A3.2.2.1.2)
- methodological updates to CH_4 emissions from abandoned oil and gas wells (refer to section A3.2.2.6 for a description of the method)
- methodological updates by integrating petroleum refinery reported flaring emissions to better reflect technological and operational changes over the past 20 years (refer to section A3.2.2.3)
- methodological updates to modelled renewable fuel content of transportation fuels (refer to section A3.1.4.2 for more details)
- methodological updates to the marine model (refer to section A3.1.4.2 for more details)
- methodological updates to the off-road model (refer to section A3.1.4.2 for more details)

2 Statistics Canada annually publishes a revised, final version of the previous year's (preliminary) energy data. Currently, energy data for 2024 are preliminary and are subject to revision in 2026.

Emission Factors: Recalculations resulting from revisions to emission factors (complete discussion of emission factors is presented in Annex 6) of:

- CH_4 emission factors for still gas stationary fuel combustion; and
- CO_2 and CH_4 emission factors for producer-consumed natural gas stationary fuel combustion in British Columbia, Alberta, and Saskatchewan.

Reallocation: Recalculations resulting from the reallocation of emissions to a more appropriate CRT category, where the methodology, activity data and emission factors are not revised.

- Reallocation of GHG emissions from CRT category 1.A.2.c Chemicals, 1.A.2.g.viii Other Manufacturing, and 1.A.1.b Petroleum Refining to 1.A.1.c.iii Other Energy Industries for biofuel manufacturing fuel-use.

Other improvements impacted the UOG sector, including updates to aerial measurement-based CH_4 estimates to incorporate revised emissions data (refer to section A3.2.2.1.5 for more details). Finally, new reported emissions data for the natural gas transmission, storage, and distribution sectors was incorporated into fugitive estimates for 2023 (refer to sections A3.2.2.2 and A3.2.2.4 for detailed descriptions).

Memo Items and Emission Allocation

- Only the CH_4 and N_2O emissions from the combustion of biomass and biofuels are included while their CO_2 emissions appear as a memo item in UNFCCC inventory reporting tables.
- GHGs from international aviation and international navigation activities are also reported as a memo item.
- Off-road emissions from vehicles and machinery, including fishing vessels, appear in the separate and distinct mobile subcategories where they occur within the Manufacturing Industries and Construction (1.A.2) or Other Sectors (1.A.4). Military aviation and navigation are reported under the Other (1.A.5) subcategory.
    - Allocation of emissions in this chapter is consistent with the Intergovernmental Panel on Climate Change (IPCC) and UNFCCC Common Reporting Tables (CRT) categorization, and differs from the emissions allocation presented in Chapter 2 and on the Government of Canada's Open Data website, where emissions from off-road transportation, fishing, military aviation and military navigation are included under general transport.
- In Canada peat is produced, exported, and used for horticultural purposes only. Peat is not used as a fuel to support combustion activities. Information on peat is presented in the Land Use, Land-Use Change, and Forestry (LULUCF) sector (Chapter 6, section 6.1) and the fuel used to harvest and produce peat is included in the Agriculture/Forestry/Fishing subcategory within Other Sectors (1.A.4).

3.1.2. Key Categories

The following categories were identified as key categories using both level and trend assessments following an IPCC Tier 1 quantitative approach:

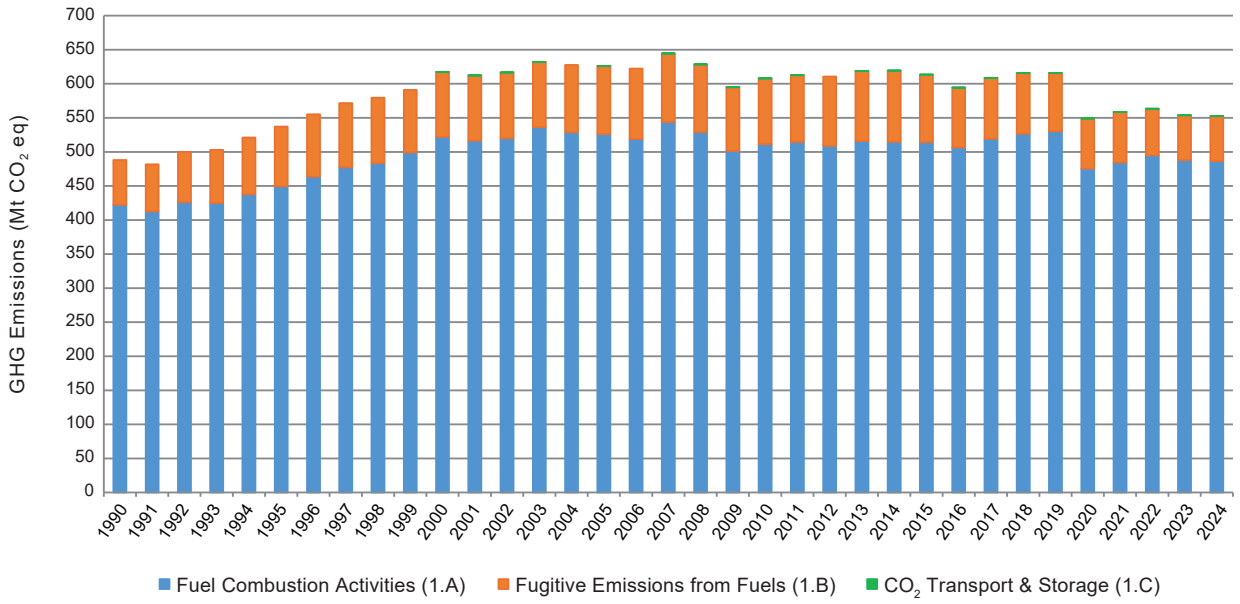
- Energy Industries (1.A.1) – CO_2, CH_4
- Manufacturing Industries and Construction (1.A.2) – CO_2
- Domestic Aviation (1.A.3.a) – CO_2
- Road Transportation (1.A.3.b) – CO_2, N_2O
- Railways (1.A.3.c) – CO_2
- Domestic Navigation (1.A.3.d) – CO_2
- Other Transportation (1.A.3.e) – CO_2
- Other Sectors (1.A.4) – CO_2
- Fugitive Emissions from Solid Fuels (1.B.1) – CH_4
- Fugitive Emissions from Fuels – Oil (1.B.2.a) – CH_4
- Fugitive Emissions from Fuels – Natural Gas (1.B.2.b) – CH_4
- Fugitive Emissions from Fuels – Venting and Flaring (1.B.2.c) – CO_2, CH_4

More detailed information about the methodology used to identify key categories as well as key categories by fuel type can be found in Annex 1.

3.1.3. Emission Trends

In 2024, about 552 Mt (81%) of Canada's GHG emissions were from the Energy sector. Overall, GHG emissions from the Energy sector have increased by 64 Mt (13%) since 1990. Between 1990 and 2024, emissions from Fuel Combustion Activities (1.A) have increased by 64 Mt (15%) and Fugitive Emissions from Fuels (1.B) have increased by 0.25 Mt (0.37%). CO_2 Transport & Storage (1.C) first started in 2000, and emissions have increased by 0.0006 Mt (660%) compared to 2024 (see Figure 3–2).

Figure 3–2 **GHG Emissions from the Energy Sector**



3.1.4. Methodologies

Annex 3.1, Methodology and Data for Estimating Emissions from Fossil Fuel Combustion, presents the methods used to calculate emissions from fuel combustion. Annex 3.2, Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution, presents the methods used to calculate emissions from fugitive sources. The estimation methods are consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) Tier 1, Tier 2, and Tier 3 approaches, with country-specific emission factors and parameters. A summary of the methodology tiers used in the estimation of each GHG category is provided in Chapter 1, Table 1–5.

3.1.5. QA/AC and Verification

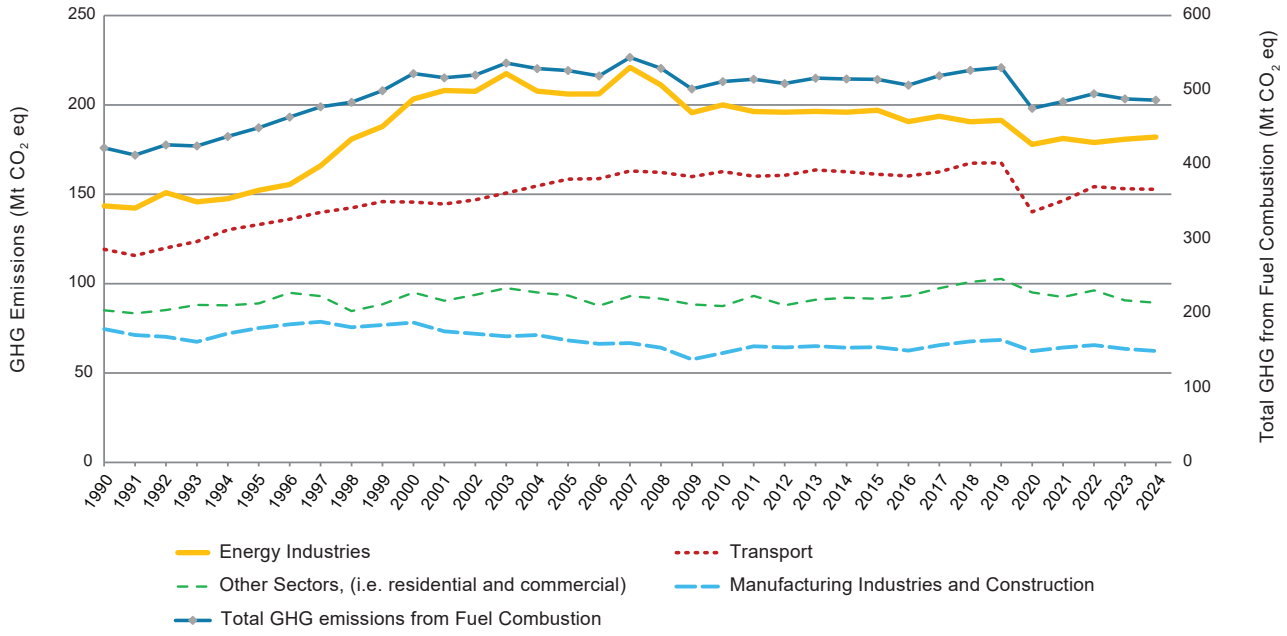
The completed quality control checks conducted for every CRT category were consistent with the 2006 IPCC Guidelines. Elements of the QC checks included a review of the estimation models, activity data, emission factors, time-series consistency, transcription accuracy, reference material, conversion factors and unit labelling, and sample emission calculations. Any mathematical, referencing or data errors found during QC checks were corrected prior to publication. The data, methodologies, and changes related to the QC activities are documented and archived. Category specific QA/QC and verification is outlined in each section.

3.2. Fuel Combustion Activities (CRT Category 1.A)

Emission sources in the Fuel Combustion Activities category include all GHG emissions from the combustion of fossil and biomass fuels, excluding the CO_2 emissions from biomass fuels such as residential fuel wood and biodiesel. Instead, CO_2 from biomass combustion appears in the memo item section of the CRT. See section 3.5.2 for more details. Major categories under Fuel Combustion Activities include Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors.

In 2024, about 486 Mt (71%) of Canada's GHG emissions were from the combustion of fossil and biomass fuels (Table 3–1). Overall, GHG emissions from Fuel Combustion activities have increased by 15% since 1990. Between 1990 and 2024, emissions from the Energy Industries (1.A.1) category increased by 27% (38.6 Mt), the Manufacturing Industries and Construction (1.A.2) category decreased by 16% (-12.2 Mt), the Transport (1.A.3) category increased by 29% (34.4 Mt), and the Other Sectors (1.A.4) category increased by 4.0% (3.42 Mt) (see Figure 3–3).

Figure 3–3 **GHG Emissions from Fuel Combustion Activities**



3.2.1. Energy Industries (CRT Category 1.A.1)

3.2.1.1. Category Description

The Energy Industries category has three subcategories: Public Electricity and Heat Generation, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries. The Energy Industries category is a key category for CO_2 and CH_4 (refer to section 3.1.2 for more details).

In 2024, the Energy Industries category accounted for 182 Mt (27%) of Canada's total GHG emissions, with a 27% (38.6 Mt) increase in total GHG emissions since 1990. The Public Electricity and Heat Generation subcategory accounted for 32% (57.5 Mt) of the GHG emissions from Energy Industries, while the Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries subcategories contributed 8.0% (14.6 Mt) and 60% (110 Mt), respectively (Table 3–3). Chapter 2, Emissions Trends, has further discussion of trends in emissions from the Energy Industries category.

Table 3–3 **Energy Industries GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
Energy Industries TOTAL (1.A.1)	**143 000**	**206 000**	**191 000**	**178 000**	**181 000**	**179 000**	**181 000**	**182 000**
Public Electricity and Heat Generation	94 100	123 000	69 600	62 300	61 600	58 100	59 000	57 500
Petroleum Refining	18 300	20 000	14 900	13 800	14 000	14 600	14 400	14 600
Manufacture of Solid Fuels and Other Energy Industries	31 000	63 100	107 000	102 000	106 000	106 000	107 000	110 000

Note: Totals may not add up due to rounding.

The Energy Industries category includes all GHG emissions from stationary fuel combustion sources related to utility electricity generation and combined heat and power generation, as well as the production, processing and refining of fossil fuels.

Although associated with the Energy Industries, emissions from venting and flaring activities related to the production, processing and refining of fossil fuels are reported as fugitive emissions (refer to section 3.3, Fugitive Emissions from Fuels [CRT category 1.B]).

Public Electricity and Heat Generation (CRT Category 1.A.1.a)

In accordance with the 2006 IPCC Guidelines, the Public Electricity and Heat Generation subcategory includes the GHG emissions associated with the production of electricity and heat from the combustion of fuel in public or privately owned utility thermal power plants whose primary activity is supplying electricity to the public. The estimated GHG emissions from this subcategory do not include emissions from non-utility industrial generation; rather, these emissions are allocated to specific industrial sectors under the Manufacturing Industries and Construction category.

The electricity supply grid in Canada includes combustion-derived electricity as well as hydro, nuclear and other renewables (wind, solar and tidal power). Total power generated by wind, tidal and solar resources is small relative to that generated by Canada's significant hydro and nuclear installations. Nuclear, hydro, wind, solar and tidal electricity generators only emit small quantities of GHGs, generally from diesel generators providing backup power. In the case of hydroelectric generation facilities, reported emissions from associated hydro reservoirs (due to the flooding of land) appear in the Land Use, Land-Use Change and Forestry Sector (section A3.5.6.2). In the case of nuclear facilities, uranium fuel production and processing occur at separate facilities, so any GHG emissions associated with these facilities appear under Manufacturing Industries and Construction. Emissions from the mining of uranium are reported under Mining.

The GHG estimates in the Public Electricity and Heat Generation category therefore only reflect emissions from combustion-derived electricity. Steam generation and internal combustion engines are the primary systems used to generate electricity through thermal processes. Steam turbine boilers burn coal, petroleum coke, refined petroleum products (RPPs), natural gas or biomass, while gas turbines use natural gas or RPPs. Reciprocating engines can use natural gas and/or a combination of RPPs.

Petroleum Refining (CRT Category 1.A.1.b)

The Petroleum Refining subcategory includes fuel combustion emissions from the production of petroleum products from a raw feedstock. Conventional or synthetic crude oil is refined into petroleum products such as heavy fuel oil, residential fuel oil, aircraft fuel, gasoline, and diesel by distillation and other processes. These processes use heat from combusting internally generated fuels (such as still gas and petroleum coke) and purchased fuels (such as natural gas). Following IPCC guidance (IPCC, 2019), emissions from the controlled burn-off of catalyst coke during catalyst regeneration processes are reported under 1.A.1.b. The Fugitive Emissions from Fuels category (section 3.3) includes CO_2 generated by refineries during the production of hydrogen by steam reforming of natural gas, as well as fugitive emissions from all other refining operations including flaring.

Manufacture of Solid Fuels and Other Energy Industries (CRT Category 1.A.1.c)

The Manufacture of Solid Fuels and Other Energy Industries subcategory comprises stationary fuel combustion emissions associated with the crude oil, natural gas, oil sands mining, bitumen extraction, crude bitumen/heavy oil upgrading, coal mining, and biofuel manufacturing industries. Emissions from pipeline transmission appear in the Pipeline Transport subcategory (1.A.3.e.i), while off-road transport emissions that occur in the mining and oil and gas extraction industries appear in Manufacturing Industries and Construction – Off-Road Vehicles and Other Machinery (1.A.2.g.vii).

Upgrading facilities produce synthetic crude oil from a feedstock of crude bitumen produced by oil sands mining, extraction and in situ recovery activities (e.g., thermal extraction) or conventional heavy oil. Synthetic (or upgraded) crude oil has a hydrocarbon composition like conventional crude oil and can be refined to produce RPPs such as gasoline and diesel. Like petroleum refineries, upgrading facilities rely on natural gas and internally generated fuels such as still gas and petroleum coke for their operation, which results in both combustion and fugitive related emissions.

Biofuel manufacturers produce a variety of biofuels, including ethanol, biodiesel, renewable diesel, biogas, renewable natural gas, alternative aviation fuel, biocrude, and wood pellets. These biofuels are made from renewable inputs such as oilseeds, grains, oils, starch, animal materials, and woodwaste/sawdust. Biofuel manufacturers use both fossil fuels and biofuels for combustion purposes to generate biofuels.

3.2.1.2. Methodological Issues

The methodology described in section A3.1.4.1 calculates emissions, for all source categories, using primarily fuel consumption data reported in the RESD. The method is consistent with the IPCC Tier 2 approach, with country-specific emission factors.

Public Electricity and Heat Generation (CRT Category 1.A.1.a)

Fuel-use data in the RESD differentiates industrial electricity generation from utility generation but aggregates industrial generation data into one category titled Transformed to Electricity by Industry. Reallocating GHG emissions from industrial electricity generation to their respective industrial subcategories uses the detailed industry information that feeds the RESD. See section A3.1.4.1 for methodological details.

The 2006 IPCC Guidelines divide the Public Electricity and Heat Generation subcategory into three additional subcategories: Electricity Generation (1.A.1.a.i), Combined Heat and Power Generation (1.A.1.a.ii), and Heat Plants (1.A.1.a.iii). The RESD does not report fuel-use data using these subcategories; rather, they aggregate data into one category titled Transformed to Electricity by Utilities. Disaggregating GHG emissions, from the RESD Transformed to Electricity by Utilities category, into the Electricity Generation and Combined Heat and Power Generation CRT subcategories, uses the RESD input data.[3] See section A3.1.4.1 for methodological details.

The RESD aggregates fuel-use data for industrial wood wastes and spent pulping liquors combusted for energy purposes into one national total. Reallocating emissions of CH_4 and N_2O from the combustion of biomass to their respective categories uses the RESD feeder survey data. CO_2 emissions from biomass combustion are not included in totals but rather reported separately in the UNFCCC CRT as a memo item.

Petroleum Refining (CRT Category 1.A.1.b)

Calculated emissions for this subcategory use all fuel attributed to the petroleum refining industry, including all petroleum products reported as producer-consumed/own consumption as well as natural gas purchased for fuel-use. The fuel-use data in the RESD include volumes of flared fuels; however, the volume of fuel flared and resultant emissions are calculated and reported separately in the Fugitive Emissions from Fuels category to avoid double counting. See section A3.2.2.8, for more details.

Manufacture of Solid Fuels and Other Energy Industries (CRT Category 1.A.1.c)

Calculated emissions for this subcategory use all fuel attributed to fossil fuel and biofuel producers. The fuel-use data in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the Fugitive Emissions from Fuels category. To avoid double counting, Stationary Combustion Sources do not include fuel-use and emission data associated with flaring. See section A3.2.2.8, for more details.

Fossil fuel producers often combust unprocessed, non-marketable, natural gas. This fuel has a higher CO_2 emission factor than marketable natural gas (see section A6.1.1), since it contains a larger percentage of complex hydrocarbons, resulting in higher carbon content. Likewise, the energy content of non-marketable natural gas is higher than that of marketable natural gas.

The RESD does not report fuel-use data for biofuel manufacturing in a single line. Data for this subcategory appears in the Chemicals, Other Manufacturing, and Petroleum Refining industries, depending on the biofuel. Reallocating fuel-use data from these categories into Other Energy Industries uses the RESD input data. See section A3.1.4.1.2 for methodological details.

3.2.1.3. Uncertainty Assessment and Time-Series Consistency

The estimated uncertainty range for the Energy Industries category is ±3% for CO_2, CH_4 and N_2O combined and ±2% for CO_2 alone.

Uncertainties for the Energy Industries category depend on data collection methods and the representativeness of a specific fuel's emission factor. Data collection for taxation purposes means commercial fuel volumes and properties are generally accurate, with greater uncertainty surrounding both the reported quantities and the properties of non-marketable fuels (e.g., own use of natural gas from producing wells and still gas consumption by refineries). For example, in the Petroleum Refining subcategory, the CO_2 emission factors for non-marketable fuels, such as still gas, petroleum coke, and catalytic coke, have a greater impact on the uncertainty estimate than the CO_2 factors for commercial fuels. Coal CO_2 emission factors were developed using statistical methods and 95% confidence intervals.

3 The RESD "input data" is sourced from the surveys that feed the RESD. The RESD aggregates and summarizes the data from these surveys.

The estimated uncertainty for CH_4 (±110%) and N_2O (±280%) emissions for the Energy Industries category is influenced by the uncertainty associated with the emission factors (ICF Consulting, 2004). Additional expert elicitation is required to improve the CH_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by ICF Consulting. The estimates for the Energy Industries category are consistent over time and calculated using the same methodology. Section 3.2.1.5, Recalculations, includes a discussion of RESD activity data.

Approximately 30% of the emissions from the Manufacture of Solid Fuels and Other Energy Industries subcategory are associated with the consumption of non-marketable natural gas in the natural gas production and processing, conventional crude oil production, and in situ bitumen extraction industries. The uncertainty estimates for emissions from the combustion of this fuel is influenced by the CO_2 (-1.4 to +2.0% for Alberta; ±6% for all other provinces) and CH_4 (0% to +240%) emission factor uncertainties for the consumption of unprocessed natural gas. Emission estimates, for the oil and gas industry, use provincially-weighted natural gas emission factors because plant-level information on the composition of unprocessed natural gas (which will vary from plant to plant) is unavailable.

Consistent method and data sources were used throughout the time series, thus, ensuring the time-series consistency.

3.2.1.4. QA/QC and Verification

General QA/QC and verification activities that occurred for the Energy Industries category are outlined in section 3.1.5.

Shared quality control responsibilities across working groups (for the RESD and feeder surveys, such as the Industrial Consumption of Energy [ICE] survey) also contributes to annual improvements in the national energy balance and, in turn, the National Inventory.

As described in Chapter 1 section 1.4.4, Canada's Greenhouse Gas Reporting Program (GHGRP) has collected GHG emission data from facilities that released emissions of 10 kt CO_2 eq or more starting in 2017, and from those that released emissions of 50 kt CO_2 eq or more between 2004 and 2016. Where coverage of a specific sector is complete, or close to complete, the GHGRP data allows for a comparison between industry-reported values and Canadian inventory emission estimates. This is possible for the Petroleum Refining and Public Electricity subcategories, and oil sands mining and upgrading, due to near complete coverage of these industries.

3.2.1.5. Recalculations

Several improvements and activity data revisions have contributed to increased data accuracy and comparability, as well as consistency with the 2006 IPCC Guidelines and MPGs. Revisions to emission estimates occurred for all years as a result of the following:

- revised RESD data, including updates to coal, diesel, heavy fuel oil, light fuel oil, natural gas, still gas, petroleum coke, and propane resulted in recalculations between 1990 and 2023 (emissions change ranged from -0.11 Mt in 2022 to +2.0 Mt in 2012 and 2023 saw a +0.48 Mt increase)
- revised CO_2 and CH_4 emission factors for producer-consumed natural gas in British Columbia, Alberta, and Saskatchewan resulted in recalculation from 1990 to 2023 (emissions change ranged from -0.56 Mt in 2010 to -0.05 Mt in 1992)
- revised CO_2 and CH_4 emission factors for petroleum coke and still gas resulted in recalculations between 1990 and 2023 (emissions change ranged from -0.0001 Mt in 1994 to +0.01 Mt in 2023)
- revised emissions reallocated to Flaring between 2004 and 2023 (emissions change ranged from 1.0 Mt in 2022 to -0.15 Mt in 2004)
- emissions reallocated to Other Energy Industries from Chemicals, Other Manufacturing and Petroleum Refining between 1990 and 2023 (emissions change ranged from +0.07 Mt in 2023 to +0.96 Mt in 2013)

3.2.1.6. Planned Improvements

Environment and Climate Change Canada (ECCC), Natural Resources Canada (NRCan), and Statistics Canada (StatCan) continue to collaborate on improvements to the quality of the national energy balance and the disaggregation of fuel-use data via a Trilateral Energy Working Group. Discussions of recalculations resulting from improvements to the energy balance are found in their respective sections or in the general overview section of this chapter.

StatCan is responsible for implementing improvements, conducting feasibility assessments of projects and recommending approaches to collect new data. StatCan has assessed and modernized some surveys to better capture supply and demand for fossil and renewable fuels. These updates will improve the quality and enhance the transparency of RESD data. Examples of refinements include:

1. collection of the Monthly Renewable Fuels and Hydrogen Survey, on types of biofuels and hydrogen produced in Canada
2. improvements to data collection methods regarding the movement of fossil and renewable fuels via rail and marine vessels

Canada is focused on developing country-specific emission factors with improvements that prioritize fuels having the largest GHG contribution. In recent years, new test results and studies have provided the basis for updates to the CO_2 emission factors and heating values for coal, gasoline, diesel, and marketable and non-marketable natural gas. Section A6.1 of this report presents the results of these improvement activities. Canada will continue to assess and identify additional fuels for improvement.

3.2.2. Manufacturing Industries and Construction (CRT Category 1.A.2)

3.2.2.1. Category Description

This category is composed of emissions from the combustion of purchased fossil fuels by all mining, manufacturing and construction industries. The following subsections present the six UNFCCC assigned subcategories under the Manufacturing Industries and Construction category. The Manufacturing Industries and Construction category is a key category for CO_2 (refer to section 3.1.2 for more details).

In 2024, the Manufacturing Industries and Construction category accounted for 62.4 Mt (9.1%) of Canada's total GHG emissions, with a 16% (12.2 Mt) decrease in overall emissions since 1990 (refer to Table 3–4 for more details). Within the Manufacturing Industries and Construction category, 36.3 Mt (58%) of the GHG emissions are from the Other subcategory, which is made up of mining, construction, off-road (associated with manufacturing, mining and construction) along with other manufacturing activities. This subcategory is followed by, in order of decreasing contributions, Chemicals (9.37 Mt, 15%), Pulp, Paper and Print (5.79 Mt, 9.3%), Iron and Steel (4.60 Mt, 7.4%), Non-metallic Minerals (3.33 Mt, 5.3%), and Non-ferrous Metals (2.93 Mt, 4.7%) subcategories. GHG emissions from Food Processing, Beverages and Tobacco are included in the Other Manufacturing subcategory due to a lack of disaggregated fuel-use data.

GHG emissions, resulting from fuel combustion for the generation of electricity or steam by an industry, are assigned to the corresponding industrial subcategory (see section A3.1.4.1). The Industrial Processes and Product Use sector reports GHG emissions from the non-energy use of fossil fuels, such as coal coke used for iron ore reduction and various other fuels used as feedstocks and chemical reagents.

Table 3–4 **Manufacturing Industries and Construction GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
Manufacturing Industries and Construction TOTAL (1.A.2)	**74 600**	**68 200**	**68 500**	**62 300**	**64 200**	**65 600**	**63 600**	**62 400**
Iron and Steel	**4 940**	**5 020**	**5 010**	**4 290**	**4 820**	**4 520**	**4 530**	**4 600**
Non-ferrous Metals	**3 530**	**3 800**	**3 430**	**3 240**	**3 010**	**3 170**	**3 110**	**2 930**
Chemicals	**8 130**	**8 170**	**9 360**	**9 410**	**9 210**	**9 120**	**9 350**	**9 370**
Pulp, Paper and Print	**14 460**	**8 580**	**7 100**	**6 410**	**6 730**	**6 760**	**6 490**	**5 790**
Food Processing, Beverages and Tobacco[a]	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
Non-metallic Minerals	**3 940**	**5 050**	**4 170**	**3 680**	**3 540**	**3 630**	**3 530**	**3 330**
Other	**39 600**	**37 600**	**39 500**	**35 300**	**36 900**	**38 400**	**36 600**	**36 300**
Mining (excluding fuels) and Quarrying	4 140	3 920	5 380	4 910	5 280	5 770	5 200	5 290
Construction	1 880	1 440	1 440	1 410	1 420	1 560	1 510	1 560
Off-road Manufacturing, Mining and Construction	12 400	16 200	20 100	17 200	18 200	18 300	17 500	17 500
Other Manufacturing	21 200	16 000	12 500	11 700	12 000	12 800	12 300	12 000

Notes:
IE = Included elsewhere
Totals may not add up due to rounding.
a. Food Processing, Beverages and Tobacco emissions are included under Other Manufacturing.

3.2.2.2. Methodological Issues

Calculation of GHG emissions, from fuel combustion for each subcategory within the Manufacturing Industries and Construction category, uses the methodology described in section A3.1.4, which is consistent with IPCC Tier 2 and Tier 3 approaches. GHG emissions generated from the consumption of transportation fuels (e.g., diesel and gasoline) appear under Off-Road Vehicles and Other Machinery (1.A.2.g.vii) of the Manufacturing Industries and Construction category.

The RESD aggregates fuel-use data for industrial wood wastes and spent pulping liquors combusted for energy purposes into one national total. The reallocation of CH_4 and N_2O emissions from the combustion of biomass to their respective categories relies on RESD feeder survey data. CO_2 emissions from biomass combustion are not included in totals but appear separately in the UNFCCC CRT as a memo item. Refer to section 3.5.2 for more information.

See the following for methodological issues specific to each manufacturing subcategory.

Iron and Steel (CRT Category 1.A.2.a)

There are currently three integrated iron and steel facilities producing all the coal-based metallurgical coke in Canada. These facilities are structured such that by-product gases from the integrated facilities (e.g., coke oven gas, blast furnace gas) are used in a variety of processes throughout the facility (e.g., boilers, blast furnace, coke oven) and, for that reason, emissions from coke production are included in the Iron and Steel subcategory. StatCan reports all coke oven gas produced and consumed at these integrated facilities in the RESD. Determining the specific amount of coke oven gas flared is not feasible, but since StatCan includes quantities of fuel flared in RESD consumption totals, these fugitive emissions appear as combustion estimates in the inventory.

The Industrial Processes and Product Use sector reports all emissions associated with the use of metallurgical coke and natural gas as a reagent for the reduction of iron ore in blast furnaces.

Non-Ferrous Metals (CRT Category 1.A.2.b)

The RESD provides all fuel-use data for this subcategory.

Chemicals (CRT Category 1.A.2.c)

The Industrial Processes and Product Use sector reports emissions resulting from fuels used as feedstocks.

Pulp, Paper and Print (CRT Category 1.A.2.d)

The RESD provides all fuel-use data for this subcategory.

Food Processing, Beverage and Tobacco (CRT Category 1.A.2.e)

Fuel-use data for this subcategory is not available in a disaggregated form. GHG emissions from this subcategory are included in the Other Manufacturing subcategory.

Non-Metallic Minerals (CRT Category 1.A.2.f)

The RESD provides all fuel-use data for this subcategory, except for waste fuel, which from 1990 to 2016 comes from annual industry data supplied by the Canadian Energy and Emissions Data Centre (CEEDC) and from 2017 onward comes from the GHGRP.

Other (Mining, Construction and Other Manufacturing) (CRT Category 1.A.2.g)

This subcategory covers the remaining industrial sector emissions, including the mining, construction, vehicle manufacturing, textiles, food, beverage, and tobacco subcategories.

Related on-site off-road emissions are reported here under Off-Road Vehicles and Other Machinery (1.A.2.g.vii), including off-road emissions attributable to mining, construction, and oil and gas operations.

3.2.2.3. Uncertainty Assessment and Time-Series Consistency

The estimated uncertainty for the Manufacturing Industries and Construction category is ±1% for CO_2, CH_4 and N_2O combined.

The underlying fuel quantities and CO_2 emission factors have low uncertainty because they are predominantly commercial fuels, which have consistent properties, and a more accurate tracking of quantity purchased for consumption.

As mentioned in the uncertainty discussion for the Energy Industries category, additional expert elicitation is required to improve the CH_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF Consulting study (ICF Consulting, 2004).

The estimates for the Manufacturing Industries and Construction category have been prepared in a consistent manner over time using the same methodology, thus, ensuring time-series consistency. Section 3.2.2.5, Recalculations, presents a discussion on updated RESD fuel-use data.

3.2.2.4. QA/QC and Verification

General QA/QC and verification activities that occurred for the Manufacturing Industries and Construction category are outlined in section 3.1.5.

3.2.2.5. Recalculations

Revisions to emission estimates occurred for all years as a result of the following:

- revised RESD data, including coal, heavy fuel oil, light fuel oil, natural gas, petroleum coke, propane, and solid wood waste which affected 1990 to 2023 (emissions change ranged from -0.11 Mt in 2006 to +0.9 Mt in 2022, and 2023 saw a 0.05 Mt increase)
- emissions reallocated to Other Energy Industries from Chemicals and Other Manufacturing between 1990 and 2023 (emissions change ranged from -0.07 Mt in 2023 to -0.96 Mt in 2013)
- revised off-road activity data between 1990 and 2023 because of updates to the off-road model, RESD data, renewable fuel content, and road vehicle populations

3.2.2.6. Planned Improvements

ECCC, NRCan, and StatCan continue to collaborate on improvements to the quality of the national energy balance and to the disaggregation of fuel-use data via a Trilateral Energy Working Group. Refer to section 3.2.1.6, Planned Improvements for more detail on StatCan and the Trilateral Energy Working Group's activities.

Planned updates to off-road emissions modelling inputs are discussed in section 3.2.3.6, Planned Improvements.

3.2.3. Transport (CRT Category 1.A.3)

In 2024, transport-related GHG emissions total 152 Mt, accounting for about 22% of Canada's total GHG emissions (Table 3–5). The most significant emission growth since 1990 has been observed in light-duty gasoline trucks (LDGTs) and heavy-duty diesel vehicles (HDDVs), with growth of 28.8 Mt (117%) for LDGTs and 19.0 Mt (118%) for HDDVs. A long-term decrease in emissions has occurred from light-duty gasoline vehicles (LDGVs, i.e., cars) and propane and natural gas vehicles, for a combined decrease of 21.2 Mt (47%) since 1990. Since 1990, emissions from the Transport category have increased 34.4 Mt (29%) and have contributed to the equivalent of 45% of the total overall growth in emissions observed in Canada.

3.2.3.1. Category Description

The Transport category comprises the combustion of fuel by all forms of transportation in Canada. The category is divided into five distinct subcategories:

- Domestic Aviation
- Road Transportation
- Railways
- Domestic Navigation
- Other Transportation

Table 3–5 **Transport GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
Transport TOTAL (1.A.3)	**118 000**	**157 000**	**167 000**	**140 000**	**146 000**	**154 000**	**153 000**	**152 000**
Domestic Aviation[a]	**7 270**	**7 450**	**8 340**	**4 560**	**5 400**	**7 460**	**8 190**	**7 850**
Road Transportation	**92 100**	**122 000**	**132 000**	**111 000**	**116 000**	**120 000**	**119 000**	**118 000**
Light-Duty Gasoline Vehicles	44 100	40 700	31 100	24 200	24 900	25 300	24 700	23 600
Light-Duty Gasoline Trucks	24 600	41 000	55 800	47 300	48 900	51 000	52 500	53 400
Heavy-Duty Gasoline Vehicles	4 790	4 620	4 580	4 210	4 170	3 880	3 990	4 070
Motorcycles	204	460	959	752	800	749	765	781
Light-Duty Diesel Vehicles	367	665	430	313	334	365	314	295
Light-Duty Diesel Trucks	988	748	798	642	771	982	910	874
Heavy-Duty Diesel Vehicles	16 200	34 300	38 700	33 400	36 100	37 900	35 700	35 200
Propane and Natural Gas Vehicles	761	23	140	150	157	173	160	159
Railways	**6 100**	**6 510**	**6 530**	**6 020**	**5 840**	**5 790**	**5 810**	**5 850**
Domestic Navigation[a, b]	**2 200**	**3 060**	**3 830**	**3 540**	**2 780**	**3 190**	**3 190**	**3 310**
Other Transportation[c]	**10 400**	**17 900**	**16 000**	**14 700**	**15 800**	**17 100**	**16 600**	**17 100**
Off-Road	3 470	7 740	7 540	6 940	7 100	6 990	6 870	6 780
Pipeline Transport	6 920	10 100	8 500	7 760	8 740	10 100	9 740	10 300

Notes:
Totals may not add up due to rounding.
a. Excludes emissions from military equipment reported in the Other (Not Specified Elsewhere) category (CRT 1.A.5).
b. Excludes emissions from fishing vessels reported in the Agriculture/Forestry/Fishing subcategory (CRT 1.A.4.c).
c. Excludes emissions from off-road equipment reported in the Manufacturing Industries and Construction and Other Sectors categories (CRT 1.A.2 and 1.A.4).

3.2.3.2. Methodological Issues

Fuel combustion emissions associated with the Transport category are calculated using various adaptations of Equation A3.1–1 in Annex 3.1. However, because of the many different types of vehicles, activities and fuels, the emission factors are numerous and complex. To cope with this complexity, transport emission estimates are calculated using the Motor Vehicle Emissions Simulator (MOVES) model, NONROAD, and the Aviation Greenhouse Gas Emission Model (AGEM). These models incorporate a version of the IPCC-recommended methodology for vehicle modelling (IPCC, 2006) and are used to calculate all transport emissions except for those associated with marine navigation, railways, and pipelines (i.e., the energy necessary to transport liquid or gaseous products through pipelines). Refer to Annex 3.1 for a detailed description of Transport methodologies.

Domestic Aviation (CRT Category 1.A.3.a)

This subcategory includes all GHG emissions from domestic air transport (commercial, private, agricultural, etc.). In accordance with the 2006 IPCC Guidelines (IPCC, 2006), military air transportation emissions are reported in the Other (Not specified elsewhere) – Mobile subcategory (CRT category 1.A.5.b). Emissions from transport fuels used at airports for ground transport are reported under Other Transportation/Other (1.A.3.e.ii). Emissions arising from flights that have their origin in Canada and destination in another country are considered international in nature and are reported separately under Memo Items – International Bunkers (CRT category 1.D.1.a), see section 3.5.1 for more details.

The methodology for the Domestic Aviation subcategory follows a modified IPCC Tier 3 approach. Emission estimates employ a mix of country-specific, aircraft-specific and IPCC default emission factors. The estimates are generated using AGEM and are calculated using the reported quantities of aviation gasoline and turbo fuel consumed that are published in the RESD. Most aircraft fuel volumes reported in the RESD represent aircraft fuels sold to Canadian airlines, foreign airlines, and public administration and commercial/institutional sectors.

Road Transportation (CRT Category 1.A.3.b.i-v)

The methodology used to estimate road transportation GHG emissions is a detailed IPCC Tier 3 method, as outlined in IPCC (2006). MOVES calculates energy consumption by a range of vehicle classifications based on country-specific fleet information and driving rates, which are then applied to country-specific emission factors. MOVES output is reconciled with NONROAD output such that the resulting fuel combustion estimates are consistent with RESD data associated with road vehicles and off-road vehicles/equipment. Proportions of RESD data reported under railways and determined not to be used in locomotives are attributed to this category.

Railways (CRT Category 1.A.3.c)

The procedure used to estimate GHG emissions from the Railways subcategory adheres to an IPCC Tier 2 methodology for CO_2 emissions and an IPCC Tier 1 methodology for CH_4 and N_2O emissions (IPCC, 2006). Fuel combustion data from the Railway Association of Canada (RAC) are reconciled with RESD data reported under railways. The resulting fuel combustion estimates are then multiplied by country-specific emission factors. Amounts of RESD data reported under railways that were determined to not be used in locomotives, because of reconciling with RAC data, were distributed amongst select road transportation and off-road subcategories.

Total emissions from steam train operations are considered insignificant and are not included in the inventory. An assessment of Canadian operations found that they collectively produce about 0.5 kt CO_2 eq, below specified MPGs reporting requirements of 0.05% of total emissions, and less than the 500 kt threshold.

Domestic Navigation (CRT Category 1.A.3.d)

This subcategory includes all GHG emissions from domestic marine transport. Emissions arising from fuel used for international voyages are reported separately under Memo Items – International Bunkers (CRT category 1.D.1.b), see section 3.5.1 for more details. Emissions from fuel consumed by fishing vessels are reported under Agriculture/Forestry/Fishing – CRT category 1.A.4.c. Emissions from fuel consumed by military vessels are reported under Other (Not specified elsewhere) – Mobile subcategory (CRT category 1.A.5.b). Emissions occurring at berth from vessels travelling internationally are attributed to the departing voyage so that all emissions occurring while at berth at a Canadian port are fully captured in the inventory.

The methodology complies with an IPCC Tier 2 approach for CO_2 emissions and an IPCC Tier 1 approach for CH_4, and N_2O emissions (IPCC 2006). Fuel consumption data from the RESD are reconciled with the fuel consumption data from the Marine Emission Inventory Tool (MEIT) and the results are multiplied by country-specific or IPCC default emission factors.

Pipeline Transport (CRT Category 1.A.3.e.i)

Pipelines[4] represent the only non-vehicular transport in this sector. They use combustion engines to power motive compressors that propel hydrocarbon-based products. In the case of natural gas pipelines, the fuel used is primarily natural gas. While oil pipelines tend to use electric motors to operate pumping stations, some consumption of refined petroleum, such as diesel fuel, occurs as a backup during power failures.

An IPCC Tier 2 methodology with country-specific emission factors and fuel consumption data from the RESD is applied.

Other Transportation (Off-Road) (CRT Category 1.A.3.e.ii)

This subcategory comprises vehicles and equipment not licensed to operate on roads or highways and not allocated to one of the following categories:

- Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery (1.A.2.g.vii)
- Other Sectors/Commercial-Institutional/Off-Road Vehicles and Other Machinery (1.A.4.a.ii)
- Other Sectors/Residential/Off-Road Vehicles and Other Machinery (1.A.4.b.ii)
- Other Sectors/Agriculture-Forestry-Fishing/Off-Road Vehicles and Other Machinery (1.A.4.c.ii)

Non-road or off-road transport[5] (ground, non-rail vehicles and equipment) includes GHG emissions resulting from fuel combustion. Vehicles in this subcategory include airport ground support equipment, railway maintenance equipment, and off-road recreational vehicles.

Off-road emissions are calculated using an IPCC Tier 3 approach. NONROAD calculates fuel combustion by vehicle/equipment type using country-specific fleet information and engine operation profiles, which are then applied to country-specific emission factors. NONROAD output is reconciled with MOVES output such that the resulting fuel combustion estimates are consistent with RESD data associated with road vehicles and off-road vehicles/equipment. Proportions of RESD data reported under railways and determined not to be used in locomotives are attributed to this subcategory.

4 Transporting either oil and/or gas through high-pressure pipeline systems.

5 Referred to as non-road or off-road vehicles. The terms “non-road” and “off-road” are used interchangeably.

3.2.3.3. Uncertainty Assessment and Time-Series Consistency

Transport

The overall uncertainty of the 2024 estimates for the Transport category (not including pipelines) was estimated to be ±1.1% for CO_2, CH_4 and N_2O combined.

Emissions from Domestic Aviation

The uncertainty associated with overall emissions from domestic aviation was estimated to be ±5.5%. The Domestic Aviation subcategory only contributed approximately 5% to total Transport GHG emissions in 2024 and therefore did not significantly influence overall uncertainty levels.

Emissions from Road Transportation

The uncertainty related to the overall emissions from on-road vehicles was estimated to be ±1.7%, driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO_2 emissions. Conversely, the high uncertainties associated with CH_4 and N_2O emissions, as well as biofuel activity data, did not significantly influence the analysis because of their comparatively minor contributions to the inventory.

Emissions from Railways

The uncertainty associated with emissions from rail transport was estimated to be ±19%. The greatest influence was exerted by the high N_2O emission factor uncertainty (-50% to +200%), whereas the relatively low uncertainties in diesel fuel activity data and CO_2 emission factors contributed very little. The railway subcategory only accounted for approximately 4% of total Transport GHG emissions in 2024 and therefore did not significantly influence the overall uncertainty results.

Emissions from Domestic Navigation

The uncertainty associated with emissions from the Domestic Navigation category was estimated to be ±2.6%, driven primarily by the relatively low uncertainties in fuel activity data and their related CO_2 emissions. Conversely, the high uncertainties associated with CH_4 and N_2O emissions did not significantly influence the analysis because of their comparatively minor contributions to the subcategory. The domestic navigation subcategory only contributed approximately 2% of total Transport GHG emissions in 2024 and therefore did not significantly influence the overall uncertainty results.

Emissions from Pipeline Transport

The estimated uncertainty for pipeline transport is ±3.5% for CO_2, CH_4 and N_2O combined. Table A2–1 and Table A2–2 on the Government of Canada's Open Data website show specific uncertainties from pipelines, by GHGs.

Emissions from Off-Road

The uncertainty associated with all off-road sources was estimated to be ±1.7%, driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO_2 emissions.

Consistent methods and data sources were used throughout the time series, thus ensuring the time-series consistency.

3.2.3.4. QA/QC and Verification

General QA/QC and verification activities that occurred for the Transport category are outlined in section 3.1.5.

In addition to the general QC procedures, category-specific QC procedures were performed on all transport subcategories in accordance with Volume 1, section 6.7, of the 2006 IPCC Guidelines as all Transport subcategories were identified as a key category. In particular, the additional category-specific checks outlined in Volume 2, Chapter 3, of the 2006 IPCC Guidelines were followed for Transport subcategories.

3.2.3.5. Recalculations

Transportation estimates were revised for the 1990–2023 period as follows.

- **RESD fuel**: Revisions include updating preliminary 2023 RESD data for all fuels as revised fuel volumes for reporting years 2011 and later. The revision mainly impacted the On-Road and Off-Road subcategories.
- **Renewable Fuel Content**: Revisions are due to a new data source of renewable fuels that are applicable to all Transport subcategories that consume motor gasoline and diesel fuel oil. The new data source provides additional biofuel use details such as differentiating biofuel types and provincial disposition. In addition, the Rail Association of Canada started collecting biofuel consumption from locomotives which was incorporated in the railway model. As a result, this improved the accuracy of emissions associated with biofuels.
- **Aviation**: Revisions are due to updated 2023 aircraft movement statistics from Statistics Canada.
- **Navigation**: Revisions are due to methodology improvements to the marine model. An additional data source containing auxiliary engine information was incorporated into the MEIT improving the accuracy of estimates and regression equations used to address information gaps. In addition, all at berth emissions associated with inbound international voyages that occur at Canadian ports are now reported under international marine which increases the coverage of emissions.
- **Off-Road**: Revisions are partly due to the porting of the NONROAD model from a Microsoft Disk Operating System (MS-DOS) environment to a Structured Query Language (SQL) environment, which resulted in minor improvements to modelled fuel consumption rates.
- **On-Road**: Revisions are partly due to updated 2023 vehicle registration data from Statistics Canada.

3.2.3.6. Planned Improvements

Planned improvements have been identified for the Transport category and are summarized in Table 8–5. Current high priorities include making improvements to on-road vehicle population estimates and adopting the latest version of MOVES. Updates to off-road emissions modelling inputs are also planned, which include updates to CH_4 and N_2O emission factors and updates to the provincial/territorial distributions used to allocate national off-road vehicle and equipment population data. Work is underway to recompile the vessel movement data from the MEIT to improve the allocation of emissions (nationally and provincially).

3.2.4. Other Sectors (CRT Category 1.A.4)

3.2.4.1. Category Description

The Other Sectors category consists of three subcategories: Commercial/Institutional, Residential, and Agriculture/Forestry/Fishing. The Commercial/Institutional subcategory also includes GHG emissions from the public administration subcategory (i.e., federal, provincial and municipal establishments). GHG emissions for these subcategories are from fuel combustion, primarily related to space and water heating. The Other Sectors category is a key category for CO_2 (refer to section 3.1.2 for more details).

Biomass combustion is a significant source of GHG emissions in the Residential subcategory, where firewood provides a primary or supplementary heating source for many Canadian homes. Combustion of firewood results in CO_2 as well as technology-dependent CH_4 and N_2O emissions. The main types of residential wood combustion devices are stoves, fireplaces, furnaces, and other equipment (e.g., pellet stoves). Biomass used to generate electricity is a small source of emissions in the Commercial/Institutional subcategory. CH_4 and N_2O emissions are included in the subcategory estimates, with CO_2 emissions reported separately in the CRT as memo items and not included in Energy sector totals. See section 3.5.2 for more details.

In 2024, the Other Sectors category contributed 89.4 Mt (13%) of Canada's total GHG emissions, with an overall growth of about 4.0% (3.42 Mt) since 1990. Within the Other Sectors category, the Commercial/Institutional subcategory contributed 38.5 Mt (43%), the Residential subcategory contributed 35.5 Mt (40%), and the Agriculture/Forestry/Fishing subcategory contributed 15.4 Mt (17%). Since 1990, GHG emissions have grown by 26% (7.97 Mt) in the Commercial/Institutional subcategory and 29% (3.44 Mt) in the Agriculture/Forestry/Fishing subcategory, while GHG emissions in the Residential subcategory have declined by about 18% (7.98 Mt). Refer to Table 3–6 for additional details. Chapter 2 has further discussion of trends for the Other Sectors category.

Table 3–6 **Other Sectors GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
Other Sectors TOTAL (1.A.4)	**86 000**	**94 200**	**103 000**	**95 300**	**92 700**	**96 300**	**90 800**	**89 400**
Commercial/Institutional	**30 500**	**36 900**	**44 000**	**40 500**	**38 800**	**40 900**	**39 100**	**38 500**
Commercial and Other Institutional	26 200	32 400	38 100	35 200	33 000	35 000	33 300	32 400
Off-Road Commercial & Institutional	4 310	4 510	5 890	5 290	5 790	5 860	5 870	6 020
Residential	**43 500**	**44 400**	**41 800**	**39 200**	**37 900**	**39 500**	**35 900**	**35 500**
Stationary Combustion	43 200	43 200	40 700	38 300	36 900	38 600	35 000	34 800
Off-Road Residential	368	1 228	1 020	960	910	840	830	760
Agriculture/Forestry/Fishing	**12 000**	**12 900**	**17 100**	**15 600**	**16 000**	**16 000**	**15 800**	**15 400**
Agriculture and Forestry	2 410	2 180	3 340	3 070	3 200	3 310	3 250	3 440
Off-Road Agriculture/Forestry/Fishing	9 570	10 740	13 760	12 510	12 840	12 680	12 520	11 970

Note: Totals may not add up due to rounding.

3.2.4.2. Methodological Issues

Emission calculations for these source categories use the methodology described in section A3.1.4.1, which is an IPCC Tier 2 approach, with country-specific emission factors. The following sections provide methodological issues specific to each category. Emissions from the combustion of transportation fuels (e.g., diesel and gasoline) are estimated using methods described in the Transport category (see section 3.2.3).

Commercial/Institutional (CRT Category 1.A.4.a)

Emission estimates in this category use RESD commercial and public administration fuel-use data. In the case of landfill gas (LFG), sludge gas from wastewater treatment, and digester gas from centralized anaerobic digesters, ECCC collects production volumes. CH_4 and N_2O emissions from the combustion of LFG are included in this category, with CO_2 emissions excluded from totals and reported separately in the UNFCCC CRT as a memo item. In the case of waste incineration for energy purposes, ECCC collects consumption quantities of municipal solid waste and medical waste. See section A3.6.3 for further details. The CH_4 and N_2O emissions from the biogenic portion of the waste are included, along with CO_2, CH_4 and N_2O combustion emissions from the non-biogenic portion of the waste. National GHG totals exclude CO_2 emissions from the biogenic portion of the waste; these numbers appear separately in the UNFCCC CRT as a memo item. Refer to section 3.5.2 for more information.

Related on-site off-road emissions are reported under Off-Road Vehicles and Other Machinery (1.A.4.a.ii) in accordance with CRT categorization. Emissions from commercial and industrial lawn and garden maintenance, snow removal equipment, pumps, compressors, welders, and generator sets are also included here.

Residential (CRT Category 1.A.4.b)

Emission estimates in this category use RESD residential fuel-use data, except for biomass data which StatCan, ECCC and NRCan collect using a periodic stand-alone survey. Section A3.1.4.1.4 details the methodology for biomass combustion from residential firewood. The CH_4 and N_2O emissions from firewood combustion are reported here, and CO_2 emissions, while not accounted for in the national residential GHG total, are reported as a memo item (see section 3.5.2).

Related off-road mobile emissions are reported under Off-Road Vehicles and Other Machinery (1.A.4.b.ii) in accordance with CRT categorization. Emissions from residential lawn and garden maintenance equipment are also included here.

Agriculture/Forestry/Fishing (CRT Category 1.A.4.c)

This subcategory includes emissions from fuel combustion in the agriculture, forestry and fishing industries. Emissions estimated for this category are from fishing boats, on-site machinery operation and heating, and use RESD marine, agriculture and forestry fuel-use data. While emissions associated with fishing vessels are included here, emissions from land-based fish processing activities are currently included under the Other Manufacturing (i.e., food processing) subcategory. Section A3.1.4.2.3, Domestic Navigation, discusses the method to reallocate RESD data and estimate emissions from fishing vessels operating in Canadian waters.

Related on-site off-road emissions for agriculture and forestry are reported under Off-Road Vehicles and Other Machinery (1.A.4.c.ii) in accordance with CRT categorization.

3.2.4.3. Uncertainty Assessment and Time-Series Consistency

The estimated uncertainty range for the Other Sectors category is ±3% for CO_2, CH_4 and N_2O combined and ±2% for CO_2 alone.

The underlying fossil fuel quantities and non-biomass CO_2 emission factors have low uncertainties, since they are predominantly commercial fuels that have consistent properties and accurately tracked quantities, as compared to residential biomass data. As stated in section 3.2.1.3, additional expert elicitation will improve the associated CH_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions.

These estimates use the same methodology and are consistent over the time series. Section 3.2.4.5, Recalculations, presents a discussion of fuel-use data.

3.2.4.4. QA/QC and Verification

General QA/QC and verification activities that occurred for the Other Sectors category are outlined in section 3.1.5.

3.2.4.5. Recalculations

Revised methods and activity data contributed to recalculations and improved accuracy of the emissions for the Other Sectors category for all years, because of:

- revised RESD data, including motor gasoline, diesel fuel oil, heavy fuel oil, kerosene & stove oil, natural gas, and propane, which affected 1999 to 2023 (emissions change ranged from +0.04 Mt in 1999 to +0.1 Mt in 2023);
- revised digester gas, landfill gas, municipal waste, residential firewood and sludge gas data, which affected the entire time series (emissions change ranged from -15 kt to +7.2 kt); and
- revised off-road activity data between 1990 and 2023 because of updates to emissions models, RESD data, renewable fuel content data, and road vehicle population data. Refer to section 3.2.3.5 for further details.

3.2.4.6. Planned Improvements

Although improvements were implemented to the RESD (refer to section 3.1.1), ECCC, NRCan, and StatCan continue to work jointly to improve the underlying quality of the national energy balance and to further disaggregate fuel-use information. Refer to 3.2.1.6 for more detail on the StatCan and the Trilateral Energy Working Group's activities.

Several updates to off-road emissions modelling inputs are also planned. Refer to 3.2.3.6 for further details.

3.2.5. Other (Not Specified Elsewhere) (CRT Category 1.A.5)

3.2.5.1. Category Description

The Other (Not Specified Elsewhere) category consists of two subcategories: Stationary and Mobile. The MPGs assign mobile military fuel combustion to CRT category 1.A.5.b. Emissions generated by military aviation are estimated by AGEM whereas emissions generated by military water-borne navigation are estimated by MEIT. Emissions related to military vehicles have been included in the Transport category, whereas stationary military fuel use has been included in the Commercial/Institutional subcategory (section 3.2.4) in accordance with the RESD fuel data. See Table 3–7 for additional details.

3.2.5.2. Methodological Issues

Refer to sections A3.1.4.2.2 and A3.1.4.2.3 for the methodologies for aviation and navigation respectively.

3.2.5.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty associated with overall emissions from mobile military fuel combustion was estimated to be ±0.1% for CO_2, CH_4 and N_2O combined.

Consistent method and data sources were used throughout the time series, thus, ensuring the time-series consistency.

Table 3–7 **Other (Not Specified Elsewhere) GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
Other (Not Specified Elsewhere) TOTAL (1.A.5)	**262**	**286**	**258**	**206**	**221**	**217**	**215**	**234**
Stationary	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
Mobile	**262**	**286**	**258**	**206**	**221**	**217**	**215**	**234**
Military Aviation	233	259	242	184	201	195	199	219
Military Marine	28	27	15	21	21	22	16	15

Note: Totals may not add up due to rounding.

3.2.5.4. QA/QC and Verification

General QA/QC and verification activities that occurred for mobile military fuel combustion are outlined in section 3.1.5.

3.2.5.5. Recalculations

Recalculations were made for the 2009–2023 period because of updates to the marine model and updates to renewable fuel content data. Refer to section 3.2.3.5 for further details.

3.2.5.6. Planned Improvements

No improvements are currently planned for this category.

3.2.6. Comparison of the Sectoral Approach with the Reference Approach (CRT Category 1.A[b] and 1.A[c])

A full discussion of reference and sectoral approach analysis is included in Annex 4 and Table A4–1 summarizes the results.

3.2.7. Feedstocks and Non-Energy Use of Fuels (CRT Category 1.A[d])

Aside from combustion for generating heat or work, fossil fuels are also used for non-energy purposes, such as reducing iron or producing waxes, solvents, and lubricants, and as feedstock to produce fertilizers, rubber, plastics and synthetic fibres. Emissions from the non-energy use of fossil fuels are included in the Industrial Processes and Product Use sector (Chapter 4 of this report).

3.3. Fugitive Emissions from Fuels (CRT Category 1.B)

Fugitive emissions from fossil fuels are intentional or unintentional releases of GHGs from the production, processing, transmission, storage and delivery of fossil fuels.

Fugitive emissions include released gas that is combusted before disposal (e.g., flaring of natural gases at oil and gas production facilities). However, combustion emissions associated with heat generated for internal use (e.g., heating) or sales are reported in the appropriate fuel combustion category.

The two subcategories under 1.B Fugitive Emissions from Fuels are: 1.B.1 Solid fuels, which represents fugitive emissions associated with activities related to the coal mining industry (active and abandoned coal mines) and 1.B.2 Oil and natural gas, which encompasses activities related to the oil and natural gas industry.

In 2024, the Fugitive Emissions from Fuels category accounted for 66 Mt (9.6%) of Canada's total GHG emissions, with a 0.4% (0.25 Mt) growth in emissions since 1990. Fugitive emissions from oil and natural gas increased by 3.3% (2.0 Mt) and those from solid fuels decreased by 57% (-1.8 Mt) since 1990. The oil and gas production, processing, transmission, and distribution activities contributed 98% of the fugitive emissions. Refer to Table 3–8 for more details.

Table 3–8 **Fugitive GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
Fugitive Emissions from Fuels TOTAL (1.B)	**66 000**	**100 000**	**85 000**	**74 000**	**74 000**	**68 000**	**66 000**	**66 000**
Solid Fuels – Coal Mining (1.B.1)	**3 200**	**1 500**	**1 600**	**1 400**	**1 400**	**1 400**	**1 600**	**1 400**
Underground – Mining activities	1 700	100	190	80	NO	20	150	NO
Abandoned Underground Mines	210	190	70	120	110	100	120	90
Surface – Mining activities	1 300	1 300	1 400	1 200	1 300	1 300	1 400	1 300
Oil and Natural Gas (1.B.2)	**63 000**	**98 000**	**84 000**	**72 000**	**73 000**	**67 000**	**64 000**	**65 000**
Oil[a]	4 700	7 300	8 100	5 800	5 900	5 900	5 900	6 000
Natural Gas[a]	11 000	13 000	9 000	8 000	8 000	8 000	8 000	8 000
Venting[b]	42 000	72 000	61 000	51 000	51 000	45 000	42 000	42 000
Flaring[b]	5 370	5 550	6 300	6 900	7 700	7 670	7 840	8 410

Notes:
NO = Not occurring
Totals may not add up due to rounding.
a. All other fugitives except venting and flaring.
b. Both oil and gas activities.

3.3.1. Solid Fuels (CRT Category 1.B.1)

3.3.1.1. Category Description

Canada's fugitive emissions from the solid fuels category are inclusive of active surface and underground coal mines along with abandoned underground mines. Combustion emissions in CRT category 1.A.2.a., include fugitive emissions from coke manufacturing (flaring). Other sources of solid fuel transformation emissions are insignificant and noted as 'not estimated' as per the MPGs. The Fugitive Emissions from Solid Fuels category is a key category for CH_4 (refer to section 3.1.2 for more details).

Coal Mining and Handling

Sources of CH_4 mining emissions include exposed coal surfaces, coal rubble, and venting from within the deposit along with post-mining activities such as preparation, transportation, storage, and final processing prior to combustion. In 2024, emissions from active surface mines contributed 93% (1.3 Mt). No underground coal mines were operating in 2021 and 2024.

Abandoned Underground Mines

Abandoned underground coal mines are sites where active mining and ventilation management have ceased, but fugitive methane emissions continue to occur. In 2024, emissions from abandoned mines were approximately 94 kt CO_2 eq.

Solid Fuel Transformation

Solid fuel transformations include activities such as the production of charcoal briquettes, or activated carbon, from coal. There is currently only one facility in Canada engaged in this activity and reliable data was only available for a year when the plant's peak production of 100 kt occurred. Using the default IPCC EF values of 1,570 g CO_2/kg and 40.3 g CH_4/kg from IPCC guidelines (IPCC, 2019 vol. 4, chap. 4.3.2.1, p.4.103), this source would produce approximately 260 kt CO_2 eq. This is below the reporting threshold of 0.05% of Canada's national total emissions, and below 500 kt CO_2 eq, so in accordance with the latest reporting requirements (MPGs), an NE notation key is reported in the CRT for this source.

3.3.1.2. Methodological Issues

Coal Mining and Handling

King (1994) developed an inventory of fugitive emissions from coal mining operations, providing the basis for some of the coal mining fugitive emission estimates. Dividing the emission estimates from King (1994) by the known coal production values provided appropriate emission factors. These factors are available in section A3.2.1.1 Coal Mining.

King (1994) estimated emission rates from coal mining using a modified procedure from the Coal Industry Advisory Board. It is a hybrid IPCC Tier 2 and Tier 3 methodology, depending on the availability of mine-specific data. Due to data limitations, post-mining activity emissions cannot be reported separately, but are included in the estimates for underground and surface mining activity emissions. Section A3.2.1. Solid Fuels provides a more detailed description of the methodology.

In late February 2014, a field-testing campaign measured fugitive emissions of CH_4, CO_2, and VOCs at four coal mines:

- Sites 1 & 2: two subbituminous coal mines in central Alberta
- Site 3: one bituminous coal mine in northeast British Columbia
- Site 4: one bituminous coal mine in northwest Alberta

Methane (CH_4) emissions were measured remotely using a ground-based mobile plume transect system (MPTS) for area sources and tracer tests for volume and point sources (Cheminfo Services and Clearstone Engineering 2014). The CH_4 emission factors of 7 of the 23 producing mines in Canada were updated using data from this field-testing. Annex 3.2 has additional discussion of the methodology.

There were no CO_2 emissions from flaring or drainage activities at any mine in Canada.

Abandoned Underground Mines

The 2006 IPCC Guidelines provide a suggested set of parameters and equations for estimating emissions from abandoned coal mines. Estimates were generated using a hybrid IPCC Tier 2 and Tier 3 methodology. The Tier 3 emission factors and rates used for these estimates are mine-specific values which are currently also used to estimate coal mining fugitive emissions for active mines. Activity data used in the model is from provincial ministries and agencies.

Methane emission rates follow time-dependent decline curves (IPCC, 2006) influenced by various factors. The most prominent factors are:

- time since abandonment
- coal type and gas absorption characteristics
- mine flooding
- methane flow characteristics of the mine
- openings and restrictions such as vent holes and mine seals

Changes in the number of abandoned mines, and the effects of the applied decline curve, drive yearly variations in emissions. See Annex 3.2, Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution, for further discussion of the methodology.

3.3.1.3. Uncertainty Assessment and Time-Series Consistency

Coal Mining and Handling

The estimated range of CH_4 uncertainty for fugitive emissions from coal mining is -30% to +130% (ICF Consulting, 2004). The production data have low uncertainty (±2%), while emission factors have high uncertainty (-50% to +200%). In the absence of specific data or study, Canada's country-specific emission factors use IPCC default uncertainty values.

Abandoned Underground Mines

The assumed uncertainty for emission estimates from abandoned coal mines is the IPCC (2006) default of -50% to +200%.

3.3.1.4. QA/QC and Verification

General QA/QC and verification activities that occurred for the Solid Fuels category are outlined in section 3.1.5.

3.3.1.5. Recalculations

Coal Mining and Handling

No recalculations occurred for this category for the current inventory edition.

Abandoned Underground Mines

No recalculations occurred for this category for the current inventory edition.

3.3.1.6. Planned Improvements

Coal Mining and Handling

No improvements are currently planned for this category, although the University of British Columbia is conducting field measurements to support mine-specific GHG estimation methodological updates of facilities located in the southeastern region of the province. This research is expected to be completed in a couple of years, and depending on its findings, new EFs may be applicable for inventory usage or direct use by mines that participated in the study to improve the accuracy of their GHG emissions.

Abandoned Underground Mines

No improvements are currently planned for this category.

3.3.2. Oil and Natural Gas (CRT Category 1.B.2)

3.3.2.1. Category Description

Fugitive emissions in the Oil and Natural Gas category include emissions from oil and gas production, processing, oil sands mining, bitumen extraction, in situ bitumen production, heavy oil/bitumen upgrading, abandoned oil and gas wells, petroleum refining, natural gas transmission and storage, natural gas distribution, and post-meter fugitives from natural gas consumption. Fuel combustion emissions from facilities in the oil and gas industry (when used for energy) are included under the Petroleum Refining, Manufacture of Solid Fuels and Other Energy Industries, and Pipeline Transport subcategories. The Fugitive Emissions from Fuels – Oil and Natural Gas category and Fugitive Emissions from Fuels – Venting and Flaring category are key categories for CH_4 and CO_2, and CH_4, respectively (refer to section 3.1.2 for more details).

The Oil and Natural Gas category has three main components: upstream oil and gas (UOG), oil sands/bitumen, and downstream oil and gas.

Upstream Oil and Gas

UOG includes all fugitive emissions from the exploration, production, processing, and transmission of oil and natural gas, excluding those from oil sands mining and heavy oil/bitumen upgrading activities. Emissions may result from designed equipment leakage (bleed valves, fuel gas-operated pneumatic equipment), imperfect seals on equipment (flanges and valves), and accidents, spills and deliberate vents.

The emission sources fall into these major groups.

Oil and Gas Well Drilling and Associated Testing: Oil and gas well drilling is a minor emission source. The emissions are from drill stem tests, release of entrained gas in drilling fluids and volatilization of invert drilling fluids.

Oil and Gas Well Servicing and Associated Testing: Well servicing is also a minor source of fugitive emissions, mainly from venting and flaring. Emissions from fuel combustion for well servicing and testing are included in Fuel Combustion emissions. Venting and flaring emissions are divided into three service operation types: unconventional service work (i.e., hydraulic fracturing), conventional service work (e.g., well repairs and inspections, cementing operations), and blowdown treatments for shallow natural gas wells. Although flaring and venting volumes are reported directly to provincial regulators, the provincial data sources do not consistently allocate the volume records to the correct subsector. For example, well completion emissions resulting from flowback at hydraulically fractured wells may be reported under well drilling, servicing, testing or production phases. Assumptions include that fugitive emissions from leaking equipment have no significant potential and are negligible from absolute open flow tests.

Natural Gas Production: Natural gas production occurs exclusively at gas wells or in combination with conventional oil, heavy oil and crude bitumen production wells with gas conservation schemes. The emission sources associated with natural gas production are wells, gathering systems, field facilities and gas batteries. Most emissions result from equipment leaks, such as leaks from seals; however, venting from the use of fuel gas to operate pneumatic equipment and line-cleaning operations are also significant sources.

Light/Medium Oil Production: Light and medium crude oils have a density of less than 900 kg/m^3. Fugitive emissions arise from wells, flow lines and batteries (single, satellite and central). The largest sources of emissions are the venting of solution gas and losses from storage tanks.

Heavy Oil Production: Heavy oil has a density above 900 kg/m^3. Production of this viscous liquid requires special infrastructure. There are generally two types of heavy oil production systems: primary and thermal. The emission sources for both types are wells, flow lines, batteries (single and satellite) and cleaning plants. The largest source is venting of casing and solution gas.

In-Situ Bitumen Production: Crude bitumen is a dense and highly viscous liquid that cannot be removed from a well using primary production means. Enhanced heavy oil recovery is required to recover the hydrocarbons from the formation (e.g., cold heavy oil production with sand, cyclic steam stimulation, steam-assisted gravity drainage, and experimental methods, such as toe-to-heel air injection, vapour extraction process and combustion overhead gravity drainage). The sources of emissions are wells, flow lines, batteries, and cleaning plants. The main source of emissions is the venting of casing gas.

Natural Gas Processing: Natural gas processing occurs before entering transmission pipelines to remove water vapour, contaminants and condensable hydrocarbons. There are four different types of natural gas plants: sweet plants, sour plants that flare waste gas, sour plants that extract elemental sulphur, and straddle plants. Straddle plants are located on transmission lines and recover residual hydrocarbons. They have a similar structure and function to other gas plants. The largest source of emissions is equipment leaks.

Natural Gas Transmission: Pipelines move virtually all natural gas produced in Canada from the processing plants to the gate of the local distribution systems. The volumes transported by truck are insignificant and assumed to be negligible. Emission sources in the gas transmission system include process vents and equipment leaks. Process vent emissions include emissions from activities such as compressor start-up and purging of lines during maintenance. The largest source of emissions is equipment leaks.

Liquid Product Transfer: The transport of liquid products from field processing facilities to refineries or distributors produces emissions from the loading and unloading of tankers, storage losses, equipment leaks and process vents. The transport systems included are liquefied petroleum gas (LPG) systems (both surface transport and high-vapour-pressure pipeline systems), pentane-plus systems (both surface transport and low-vapour-pressure pipeline systems) and crude-oil pipeline systems.

Accidents and Equipment Failures: Fugitive emissions can result from human error or extraordinary equipment failures in all segments of the conventional UOG industry. Major emission sources include pipeline ruptures, well blowouts and spills. Emissions from the disposal and land treatment of spills are not included owing to insufficient data.

Surface Casing Vent Flow and Gas Migration: At some wells, fluids will flow into the surface casing from the surrounding formation. The fluids can be collected, sealed in the casing, flared or vented. At some wells, particularly in the Lloydminster (Alberta) region, gas may migrate outside of the well, either from a leak in the production string or from a gas-bearing zone that was penetrated but not produced. The emissions from gas flowing to the surface through the surrounding strata have been estimated.

Abandoned Oil and Gas Wells

Oil and gas wells are required to be plugged with cement prior to abandonment to prevent both gas leakage from the well and migration of oil and gas to the surrounding strata. Despite the well abandonment regulations, wells exist that were not properly decommissioned. This occurs for several reasons, including abandonment prior to the enactment of regulations and bankruptcy of the well owner. While emissions arise from both plugged and unplugged wells, emissions from unplugged wells are significantly higher than from plugged wells. Table 3–9 presents emission estimates from abandoned oil and gas wells.

Table 3–9 **GHG Emissions from Abandoned Oil and Gas Wells**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
Abandoned Oil and Gas Wells	**190**	**370**	**550**	**550**	**540**	**500**	**510**	**510**
Abandoned Oil Wells[a]	80	130	180	180	180	180	180	180
Abandoned Gas Wells[b]	110	240	370	360	360	330	330	330

Notes:
Totals may not add up due to rounding.
a. Included in CRT category 1.B.2.a – Fugitive emissions from fuels – Oil and natural gas – Oil
b. Included in CRT category 1.B.2.b – Fugitive emissions from fuels – Oil and natural gas – Natural Gas

Oil Sands / Bitumen

This component includes emissions from open pit mining operations and heavy oil/bitumen upgrading to produce synthetic crude oil and other derived products for sale. Fugitive emissions are primarily from hydrogen production, flue gas desulphurization (FGD), venting and flaring activities, storage and handling losses, fugitive equipment leaks, and CH_4 from the open mine surfaces and from methanogenic bacteria in the mine tailings settling ponds.

Downstream Oil and Gas

Downstream oil and gas includes all fugitive emissions from petroleum refining and natural gas distribution to end consumers, including fugitive emissions at the point of consumption (post-meter fugitives). Reported emissions fall into the three major groups described below.

Petroleum Refining: Petroleum refining fugitive emissions consists of three main sources : intentional (process vents), unintentional, and flaring. Intentional fugitive sources include process vents such as the release of CO_2 during the production of hydrogen as well as process vents from other refining operations. Unintentional fugitive emissions result from equipment leaks, wastewater treatment, cooling towers, storage tanks, and loading operations. Flaring emissions result from the combustion of hazardous waste gas streams (such as acid gas and still gas) with natural gas. GHG emissions from fuel combustion are reported in the Energy Industries category.

Natural Gas Distribution: The natural gas distribution system receives high-pressure gas from the gate of the transmission system, reduces the pressure, and distributes the gas through underground gas mains and service lines to the end user. Emission sources include leaks from pipelines, metering and regulating stations, leaks from damaged lines, meters and short-term surface storage.

Post-Meter Fugitives: This segment includes fugitive emissions downstream of residential, commercial and industrial gas meters and from natural gas-fueled vehicles. Emission sources include leakage from internal piping and the end-of-pipe appliances (e.g., space heating, water heating, stoves, dryers, etc.). Emissions from start-stop-losses of appliances and combustion of gas are not included as they are part of fuel combustion estimates. Emissions for natural gas-fueled vehicles include releases during fueling, emptying of gas cylinders at high-pressure interim storage units for pressure tests, and leaks from vehicles' fuel tanks for pressure tests or decommissioning. Table 3–10 presents emission estimates from post-meter fugitives.

Table 3–10 **GHG Emissions from Post-Meter Fugitives**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
Post-Meter Fugitives[a]	**1 200**	**1 700**	**2 000**	**2 000**	**2 000**	**2 100**	**2 100**	**2 200**
Natural gas appliances in residential and commercial sectors	1 000	1 400	1 600	1 600	1 700	1 700	1 700	1 700
Natural gas fueled vehicles	0.04	0.01	0.02	0.02	0.03	0.03	0.03	0.03
Power plants and industrial facilities consuming natural gas	250	260	330	330	350	380	400	430

Notes:
Totals may not add up due to rounding.
a. Included in CRT category 1.B.2.b – Fugitive emissions from fuels – Oil and natural gas – Natural Gas

3.3.2.2. Methodological Issues

Fugitive emissions from Oil and Natural Gas systems are estimated using different methods depending on the emission source and data availability in the province or territory. Methodologies can generally be described as one of the following approaches:

Direct estimation / reported: where possible, facility reported volumetric data and detailed gas composition data are used to directly calculate emissions, or facility-reported emissions are aggregated and included in inventory estimates. This approach is applied in both the upstream and downstream oil and natural gas sectors to differing degrees.

Modelling: when facility reported data is not available, emissions are modelled using annual activity data and emission factors. Modelling is used for certain sources in the UOG sector, in addition to abandoned wells and post-meter fugitives.

Aerial measurements: source-resolved methane emission inventories derived from aerial measurements are used as the basis to estimate emissions from key sources in the UOG sector.

Interpolation/Extrapolation: detailed inventory studies provide the basis to interpolate or extrapolate emissions for years without detailed inventory data based on changes in various activity data. This approach is used for all sources, subsectors, provinces and territories where the three previous approaches are not applicable.

Upstream Oil and Gas

Direct estimation, modelling, aerial measurements, and interpolation/extrapolation are all employed to estimate emissions from the UOG sector.

Direct estimation: this method applies to reported venting and flaring emissions in Alberta, Saskatchewan, and British Columbia, as well as offshore flaring in Newfoundland and Labrador (see section A3.2.2.1.2).

Modelling: this approach is used to estimate emissions from pneumatic devices, compressor seals, and equipment leaks in British Columbia, Alberta, Saskatchewan and Manitoba. The modelling approach does not estimate fugitive emissions for individual UOG facilities, but for segments of the industry grouped by province and facility type. Emissions are modelled for specific facility types including batteries, compressor stations and gas plants. The facilities are further broken down by subtype (e.g., single-well battery, multi-well group battery, etc.) and product type (e.g., light/medium crude oil, heavy crude oil, natural gas, etc.). All active well sites are also included.

This approach facilitates continuous improvements via revisions to source data or model parameters, such as EFs for specific facility subtypes, product types or regions as new information becomes available. Given reliable data, changes to industry practices or government policy could also be reflected annually. Surface casing vent flow emissions in Alberta and British Columbia are also modelled using provincial data. For full descriptions of modelled UOG fugitive emissions, see sections A3.2.2.1.3 and A3.2.2.1.4.

Aerial measurements: source-resolved methane inventories are used to estimate emissions from storage tanks, compressor buildings, and unlit flares in British Columbia, Alberta and Saskatchewan, engine sheds in Alberta and Saskatchewan, and wellheads in Saskatchewan. The measurement-based methane estimates were developed by the Energy and Emissions Research Laboratory (EERL) at Carleton University using the results of aircraft-based measurement campaigns conducted during 2020 in Saskatchewan and 2021, 2023, and 2024 in all three western provinces (Conrad; 2023a, b; Johnson et al., 2023; EERL, 2025). For a full description of how aerial measurements are integrated into the inventory, see section A3.2.2.1.5.

Interpolation/Extrapolation: this applies to all other UOG fugitive emission sources and provinces and territories not mentioned above. Detailed UOG inventory studies for the years 2000, 2005, and 2011 provide the basis to interpolate or extrapolate emissions for all remaining years in the time series.

Interpolated or extrapolated fugitive emission estimates for the UOG industry use information in two separate studies that follow the same methodology. The Canadian Association of Petroleum Producers' (CAPP) study titled *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emissions by the Upstream Oil and Gas Industry* (CAPP, 2005) and referred to as the CAPP study, and an update of this inventory completed in 2014 for Environment Canada by Clearstone Engineering Ltd., referred to as the UOG study (EC, 2014).

The CAPP study provides a detailed emission inventory for the UOG industry for the year 2000. Similarly, the UOG study estimates emissions for the years 2005 and 2011. For both studies, the respective emission inventories used an IPCC Tier 3 bottom-up assessment, beginning at the individual facility and process unit level and aggregating the results to provide emission estimates by facility and geographic area. The Canadian UOG sector assets and operations are vast. The 2011 emissions inventory included over 300 000 capable oil and gas wells, 14 100 batteries producing gas into more than 5000 gathering systems delivering to almost 750 gas plants, and 24 000 oil batteries delivering to 150 tank terminals, all interconnected by tens of thousands of kilometres of pipeline carrying hydrocarbons from wells to batteries to plants and ultimately markets. The inventory includes emission estimates from flaring, venting, equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses, and accidental releases.

Both studies collected and used significant amounts of data, including the number and type of active facilities and facility-level activity data such as volumes of gas produced, vented and flared. An inventory of equipment was derived based on typical facility layouts and average number of pieces of equipment by facility type. Emission factors came from a variety of sources, including published reports, equipment manufacturers' data, observed industry values, measured vent rates, simulation programs and other industry studies. Volume 5 of the CAPP study (CAPP, 2005) and Volume 4 of the UOG study (EC 2014) lists data and emission factors.

The 1990–1999 fugitive emission estimates used annual industry activity data and the 2000 emission results. Volume 1 of the CAPP study presents the 1990–1999 estimates and method. The 2001–2004 fugitive emissions were estimated using the 2000 (CAPP, 2005) and 2005 (EC, 2014) emission results along with annual industry activity data and interpolation techniques. Similarly, the 2006–2010 emissions were estimated using the 2005 and 2011 (EC, 2014) emission results with annual industry activity data and interpolation techniques. From 2012 on, the 2011 (EC, 2014) emission results are used in conjunction with annual activity data to estimate emissions. Section A3.2.2.1.1 provides a more detailed description of the interpolation and extrapolation methodologies.

Abandoned Oil and Gas Wells

Emission estimates for abandoned wells are modelled using an IPCC Tier 2 approach. The CH_4 emission factors are derived entirely from measured emissions from Canadian wells. Province-specific emission factors are used for abandoned wells in British Columbia, Alberta, Saskatchewan, Ontario, and Québec (Klotz et al., 2025). In the remaining provinces and territories, generalized Canadian emission factors are also taken from the Klotz study (Klotz et al., 2025). Annual counts of abandoned wells are determined from provincial databases. See section A3.2.2.6, for more details.

Natural Gas Transmission and Storage

A combination of reported emissions and interpolation/extrapolation are used to estimate emissions from natural gas transmission and storage. Fugitive emissions from venting, flaring, and spills/pipeline ruptures in the natural gas transmission sector for 1990–1996 are taken from the study titled CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry (CAPP, 1999). This study follows a rigorous IPCC Tier 3 approach in estimating GHG emissions. Fugitive emission estimates for 1997–1999 were derived based on length of natural gas pipeline and emission rates developed using results from the original study. From the year 2000 onwards, emissions are based on data from the UOG study (EC, 2014), following an IPCC Tier 3 approach that rolled up the reported GHG emissions from individual natural gas companies. ORTECH Consulting Inc. (2013) compiled emissions data for the natural gas transmission and storage industry for the Canadian Energy Partnership for Environmental Innovation (CEPEI). CEPEI provided the data for the years 2000–2004, 2006–2010 and 2012–2024 following an IPCC Tier 3 approach.

Between 2004 and 2011 and from 2015 onwards, emissions from equipment leaks, compressor seals, and pneumatic devices are estimated following the methodology described in the preceding paragraph. For the period between 1990 and 2003, emissions are based on CAPP (1999) with revised equipment leak estimates for the year 1995, and a combination of interpolation and extrapolation approaches. Equipment leak, compressor seal, and pneumatics emissions are also interpolated in 2012–2014, which addresses specific methodological consistency issues in the CEPEI reported data. Section A3.2.2.2 details the complete methodology.

Oil Sands/Bitumen

Fugitive GHG emissions from oil sands mining, bitumen extraction and heavy oil/bitumen upgraders are developed based on two reports.

- *An Inventory of GHGs, CACs and H_2S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP, 2006), prepared by Clearstone Engineering Ltd. (referred to here as the bitumen study).
- *An Inventory of GHGs, CACs and Other Priority Emissions by the Canadian Oil Sands Industry: 2003 to 2015* (ECCC, 2017a), prepared by Clearstone Engineering Ltd. (referred to here as the oil sands study).

Each operator in the oil sands mining and upgrading industry used an IPCC Tier 3 approach to develop detailed emission estimates. A review of facility inventories ensured that all estimates were complete, accurate and transparent. The completed QA/QC and an uncertainty analysis followed IPCC Good Practice Guidance (IPCC, 2000).

The bitumen study (CAPP, 2006) is the basis for the 1990–2003 fugitive emission estimates, and the oil sands study (ECCC, 2017a) is the basis for the 2004–2024 fugitive emission estimates. An oil sands estimation model (referred to here as the oil sands model) allows annual updating of fugitive emissions from oil sands mining and bitumen/heavy oil upgrading activities from 2003 onwards. The oil sands model was developed using relevant parameters and results from the oil sands study, along with annual activity data. The activity data required by the model comes from the following sources: Alberta Mineable Oil Sands Plant Statistics by the Alberta Energy Regulator (AER, 1990–) and annual reports for the Lloydminster Upgrader (Cenovus, 2021–; Husky, 1998–2019). Section A3.2.2.5 also presents a summary of the estimation method of the oil sands model.

Emissions for oil sands facilities not included in the oil sands study, such as the Horizon Liquid Extraction Plant and the Fort Hills Mine, were estimated using emission factors from similar facilities or emission data reported to the GHGRP. See section A3.2.2.5 for more details.

The Scotford upgrader operated by Shell Canada Energy began capturing CO_2 emissions from its hydrogen production plant in 2015. The CO_2 venting emission for this facility exclude the captured CO_2 that is transported and injected into storage.

Downstream Oil and Gas Production

Petroleum Refining

Fugitive emissions from refineries are calculated using information contained in the Canadian Petroleum Products Institute (CPPI) study, *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI, 2004). Refer to the CPPI report for full details on the study. The Canadian Energy and Emissions Data Centre (CEEDC) and Canadian refineries provided historical fuel, energy and emission data, for the years 1990 and 1994–2002.

Process venting and unintentional fugitive emissions, for the years 1991–1993 and 2003 onward, were extrapolated using data in the CPPI report, and the petroleum refinery energy consumption and production data from the RESD. Section A3.2.2.3 provides a detailed description of the methodology used to estimate emissions from 1991 to 1993 and 2003 onward.

Facility reported data from Canada's GHGRP was integrated into inventory estimates to improve the quality of refinery flaring emissions and allow the inventory to better reflect operational changes over the last two decades (ECCC, 2024) while maintaining a consistent time series. Petroleum refining facilities have been reporting their flaring emissions to the GHGRP since 2004. In 2019, the GHGRP expanded its reporting requirements with specific estimation methods for flaring along with additional reporting elements such as fuel quantities, and carbon content assuring consistency across refineries while increasing transparency of reported information for analysis and QA/QC activities. For more details, refer to the GHGRP's *Schedule 7, Fuel Combustion and Flaring Reporting Requirement* of the reporting notice and Chapter 2 of the mandated quantification requirements (ECCC, 2023). The quantification requirements outlined estimation and sampling methods to improve the transparency of facility-reported data (FRD) to the GHGRP.

Facility data integration approach outlined in Volume 1, Chapter 2.3 of the 2019 IPCC Refinement was applied. FRD from the GHGRP was reviewed and any outliers were removed or corrected for use in updating flaring emissions and fuel volumes. Flared fuel volumes were then subtracted from refinery fuel combustion to avoid double counting. In addition, this approach captures relevant industrial changes along with facility closures and expansions over the time series.

Natural Gas Distribution

The emission estimates for the 1990–1999 period were derived from a study prepared for the Canadian Gas Association (CGA, 1997). The study estimated the emissions from the Canadian gas distribution pipeline industry, for the years 1990 and 1995, using an IPCC Tier 3 approach. Emissions in the study were calculated using emission factors from the U.S. EPA, other published sources and engineering estimates. The activity data in the study came from published sources and specialized surveys of gas distribution companies. The surveys obtained information on schedules of equipment, operation parameters of equipment, pipeline lengths used in the Canadian distribution system, etc. In the year 2000, the Gas Research Institute (GRI) reviewed and revised the 1997 CGA study, with more accurate and better-substantiated data for station vents (GRI, 2000). General emission factors were developed for the distribution system using the study data (CGA, 1997; GRI, 2000) and the gas distribution pipeline distances by province provided by StatCan.

For the year 2000 onwards, emission estimates use data from the UOG study (EC, 2014), following an IPCC Tier 3 approach that rolled-up the reported GHG emissions from individual natural gas companies. ORTECH Consulting Inc. (2013) compiled emissions data for the natural gas distribution industry for CEPEI. CEPEI provided emissions data for the years 2000–2004, 2006–2010 and 2012–2024 following an IPCC Tier 3 approach.

ECCC determined the equipment leak estimates in the CGA (1997) and GRI (2000) studies did not accurately represent Canada's natural gas distribution sector, since country-specific EFs had not yet been developed at the time of their publication. To provide representative estimates and a consistent time series, equipment leak emissions were backcasted for 1990–2004 from the 2005 estimates in the UOG study (EC, 2014) using pipeline length as activity data. Historical equipment leak emissions from cast-iron pipelines are also estimated using a generalized EF from CEPEI (2016) and are included for years prior to the phase out of cast-iron as a pipeline material in Canada. Similar to the gas transmission sector, equipment leaks for 2012–2014 were interpolated to address a known methodological discontinuity in the CEPEI reported emissions in 2015. Section A3.2.2.4 presents more details on the methodology used to estimate fugitive emissions from natural gas distribution systems.

Post-meter Fugitives

Emission estimates for post-meter fugitives from residential and commercial natural gas appliances, natural gas-fueled vehicles and industrial consumption of natural gas use an IPCC Tier 1 approach. IPCC Tier 1 emission factors were modified to reflect Canadian marketable natural gas compositions.

The number of residential natural gas appliances was taken from data published by NRCan (2025) for the years 2000–2022 by province/territory. Appliance counts for 1990–1999 and 2023–2024 were extrapolated based on the annual change in the number of residential natural gas customers by province. NRCan appliance count data was modified as necessary to reflect real-world conditions such as the lack of natural gas distribution systems in Prince Edward Island and Newfoundland and Labrador and unrealistic average appliance counts per customer in New Brunswick, Nova Scotia and Northwest Territories. The number of commercial natural gas appliances were estimated based on the annual number of commercial natural gas customers by province/territory and the national average number of residential appliances per customer.

ECCC internal vehicle fleet statistics provided the number of natural gas-fueled vehicles for each province and year.

Natural gas consumption data from the RESD was used to estimate post-meter fugitives from industrial consumption of natural gas. Since fugitive emissions at oil and gas facilities are already estimated using the methods discussed previously, any natural gas consumption occurring at oil and gas facilities was excluded from the post-meter fugitive emissions calculations.

See section A3.2.2.7 for more details.

3.3.2.3. Uncertainty Assessment and Time-Series Consistency

Upstream Oil and Gas

The overall uncertainty for the 2024 upstream oil and gas fugitive emissions is -4.5% to +5.8%. Table 3–11 lists the uncertainties for specific oil and gas categories. Accidents and equipment failures, post-meter fugitives, and abandoned oil and gas wells have the highest uncertainty, while oil production and transport have the lowest overall uncertainty.

The uncertainties were determined following an IPCC Tier 1 uncertainty approach which describes three sources of uncertainties: definitions, natural variability of the process that produces the emissions, and the assessment of the process or quantity. The analysis considered only the last two sources of uncertainty; uncertainties from the definitions are assumed negligible, as they were adequately controlled through QA/QC procedures.

Consistent methods and data sources were used throughout the time series to the extent possible. Details on UOG activity data sources and time-series considerations specific to each methodology can be found in section A3.2.2.1. Time-series consistency of aerial measurement-based estimates is discussed at length in section A3.2.2.1.5.

Table 3–11 **Uncertainty in Oil and Gas Fugitive Emissions (Excluding Petroleum Refining)**

Industry Segment	GHG Source Category Uncertainty (%)			
	Flaring	Fugitive	Venting	Total
Oil Production and Transport	-7.1 to +7.2	-4.3 to +4.8	-9.1 to +8.4	-6.8 to +6.3
Oil Sands Mining and Bitumen / Heavy Oil Upgrading	-23.3 to +23.4	-30.4 to +32.8	-29.0 to +29.7	-19.1 to +19.7
Gas Production / Processing	-2.9 to +3.3	-1.6 to +2.2	-9.4 to +16.4	-6.6 to +11.5
Gas Transmission, Storage and Distribution	-13.6 to +16.9	-17.9 to +19.0	± 11.8	-10.4 to +10.9
Accidents and Equipment Failures	—	-28.6 to +28.7	—	-28.6 to +28.7
Well Drilling, Servicing and Testing	-23.2 to +19.3	-24.7 to +28.2	-16.7 to +32.4	-19.4 to +16.7
Abandoned Oil and Gas Wells	—	-46.3 to +83.3	—	-46.3 to +83.3
Post-meter Fugitives	—	± 27.8	—	± 27.8

Note:
— = emissions from GHG source do not occur in this industry segment"

Oil Sands/Bitumen

The overall uncertainty for the 2024 oil sands/bitumen fugitive emissions is -19.1% to +19.7%. An IPCC Tier 1 uncertainty assessment was conducted for each oil sands mining and upgrading facility, with full details of the assessment contained in both the bitumen study (CAPP, 2006) and the oil sands study (ECCC, 2017a). Table 3–11 shows the aggregation of facility-level uncertainties by emission sources.

Downstream Oil and Gas

The CPPI (2004) study provides the data used in the inventory for fugitive emissions from refineries for 1990 and for 1994–2002. There is greater uncertainty for the 1991–1993 and 2003–2024 periods because of the available level of disaggregation of the activity data. For comparison purposes, a Tier 1 and Tier 2 uncertainty analysis provided overall CO_2 uncertainty values for the 2002 emission factors and activity data (CPPI, 2004).

For the Tier 1 analysis, the overall uncertainty was ±8.3%. The Tier 2 analysis determined that the overall uncertainty was ±14%. The difference between the Tier 1 and Tier 2 uncertainties may be due to the high level of variability in some of the emission factors. Table 3–12 presents these uncertainty results.

The overall uncertainty associated with Flaring ranges from ±5% to ±10%, since the volume of the quantity of fuel flared is known to an accuracy of about ±3% to ±10% while the uncertainty for the carbon content should not exceed ±5% as specified in the quantification requirements (ECCC, 2023).

Table 3–12 **Uncertainty in Oil Refining Fugitive Emissions**

	Uncertainty (%)			
	Overall	Excluding Refinery Fuel Gas	Excluding Flare Gas	Excluding Refinery Fuel and Flare Gas
Tier 1	± 8.3	± 4.3	± 8.3	± 8.3
Tier 2	± 14	± 5	± 14	± 14

3.3.2.4. QA/QC and Verification

General QA/QC and verification activities that occurred for the Oil and Natural Gas category are outlined in section 3.1.5.

To ensure that the results were correct, the CAPP and UOG studies (CAPP, 2005; EC, 2014) were subject to the following QA/QC procedures. First, all results were reviewed internally by senior personnel to ensure there were no errors, omissions or double counting. Then, individual companies reviewed and commented on the report. The project steering committee and nominated experts performed a second level of review. Where possible, results were compared with previous baseline data and other corporate, industrial and national inventories. Any anomalies were verified through examination of activity levels, changes in regulations, and voluntary industry initiatives.

The review of the methodology and parameters used to model fugitive emissions from pneumatic devices, compressor seals, and equipment leaks included several steps. It began with the completion of two third-party technical reviews of the updated modelling approach through contracts with Navius Research Inc. and Clearstone Engineering Ltd. Reviewers provided feedback on the underlying assumptions, parameters, and emission factors. The purpose of these expert reviews was not to receive validation of modelled estimates, but rather to assess the approach and to highlight areas for potential improvements. Then, in July 2021, provincial governments received a presentation of the updated methodology and comments were solicited. Within ECCC, internal reviews conducted in collaboration with the Oil, Gas and Alternative Energy Division of the Environmental Protection Branch, included QA/QC and verification of calculated model parameters and emission factors.

Methane emission estimates derived from aerial measurements for Canada's main oil and gas producing provinces of Alberta, British Columbia and Saskatchewan (Conrad et al., 2023a, b; Johnson et al., 2023; EERL, 2025) were compared against inventory estimates to verify emission levels and recent trends. The results of this comparison are presented in section 2.3.1.3. Separately, independent tower-based methane measurements (Chan et al., 2024) have been compared to inventory estimates for further verification of overall emissions levels and trends, as detailed in section A3.2.2.1.5.

3.3.2.5. Recalculations

Fugitive emissions from oil and natural gas were revised for the 1990–2023 period because of changes to activity data and methodologies. See Table 3–2 for a summary of the impact of the recalculations.

CH_4 emissions from UOG sources estimated using aerial measurements (compressor buildings, engine sheds, storage tanks, unlit flares, and wellheads) were recalculated for all years. In addition to new source-resolved aerial measurement inventories for 2024, ECCC received updated CH_4 data from EERL for 2020 (for Saskatchewan only), 2021 (for Saskatchewan and British Columbia), and 2023 (for Alberta, Saskatchewan, and British Columbia). The revised EERL inventory estimates (EERL, 2025) incorporated more precise meteorological data and improved facility classifications. As a result, CH_4 estimates for the EERL inventory years were recalculated, as were backcasted estimates for British Columbia (1990–2020) and Saskatchewan (1990–2019). For a full description of the methodology and how aerial measurements have been incorporated for the UOG sector, see section A3.2.2.1.5.

Further methodological improvements resulted in recalculations with various impacts for the UOG sector. Fugitive equipment leak estimates were revised for Alberta, Saskatchewan, and Manitoba, as model parameters were updated and extrapolated emissions were adjusted to better reflect leak detection and repair requirements in these provinces, leading to downward revisions from 2020 to 2023. Thermal heavy oil production emissions in Saskatchewan were updated to use facility-level estimates for reported venting and flaring. Other extrapolated emissions estimates for cold heavy oil production and thermal heavy oil production in Saskatchewan were updated to reflect the different production trends in these two subsectors, and additional updates were made to refine historical estimates for thermal heavy oil production in Alberta. Improvements to natural gas composition data for British Columbia resulted in revised estimates for multiple UOG emission sources in the province: flaring, reported venting, formation CO_2, pneumatics, fugitive equipment leaks, compressor seal CO_2, and surface casing vent flow.

Natural gas transmission and storage estimates were revised downwards for 2023 following the incorporation of the latest emissions data from CEPEI. New CEPEI data similarly resulted in downward revisions to natural gas distribution emissions for 2023.

Refinery flaring estimates were revised by integrating facility-reported data to better reflect operational changes over time. To avoid double counting, volumes of fuel flared were reallocated from fuel combustion to fugitive flaring.

Abandoned oil and gas well emissions were also recalculated for 1990–2023 following the adoption of new CH_4 emission factors, which were developed using a combination of new and previously published measurement data gathered from field campaigns across Canada (Klotz et al, 2025).

The combined impact of recalculations on each fugitive category under oil and natural gas are as follows.

- **Oil**: recalculations resulted in upward revisions from 1990 to 2016, ranging from +10 kt (+0.1%) in 2016 to +179 kt (+2.6%) in 2002, and downward revisions from 2017 to 2023. Minor revisions (< ±1.0%) in 2017 to 2019 were followed by significant downward revisions ranging from -1.9 Mt (-25.0%) in 2020 to -2.1 Mt (-26.1%) in 2023, which were driven by updates to modelled fugitive equipment leak emissions in Alberta.
- **Natural Gas**: recalculations cumulatively resulted in minor downward revisions in 1990, 2020, and a maximum of -70 kt (-0.9%) in 2023 for the natural gas category. Upward revisions occurred in all remaining years, ranging from +4 kt (+0.04%) in 1991 to +219 kt (+1.8%) in 2008.
- **Venting**: cumulatively, recalculations due to revised aerial CH_4 emissions data and methodological updates resulted in upward revisions to venting emissions for 1990 to 2021, with changes ranging from +200 kt (+0.5%) in 1990 to +1.5 Mt (+2.2%) in 2005. Downward revisions of -609 kt (-1.3%) and -1.0 Mt (-2.4%) occurred in 2022 and 2023, respectively, mainly due to revised aerial measurement data.
- **Flaring**: recalculations due to methodological changes and updated activity data resulted in revisions in all years. The most significant changes were due to methodological updates to flaring in the Petroleum Refining sector, which resulted in upward revisions that were partially offset by downward revisions to UOG flaring in British Columbia. Revisions were minor (< ±1.0%) from 1990 to 2003. Upward revisions occurred from 2004 to 2023, with a maximum overall revision of +710 kt (+10.2%) in 2021.

3.3.2.6. Planned Improvements

Upstream Oil and Gas

Various items have been identified to improve the accuracy of fugitive oil and gas emission estimates.

- Additional source-level estimates derived from atmospheric measurements of CH_4 in Alberta, British Columbia, and Saskatchewan may be incorporated to further refine emission estimates. Similar methodological updates may be implemented for other jurisdictions, after results from aerial surveys become available.
- Researchers at Natural Resources Canada are exploring how raw gas composition data collected by provincial regulators in British Columbia, Alberta, and Saskatchewan could be incorporated into a unified dataset (Naseri and Vena, 2025). This work may enable modelled and direct estimates to utilize natural gas composition profiles developed using a single consistent approach for Western Canada.
- Data reported to British Columbia's industrial GHG reporting program and Alberta's OneStop reporting system will be analyzed to potentially further improve emission estimates from equipment leaks, enabling modelled estimates to continue tracking the impact of Leak Detection and Repair (LDAR) programs.
- A liquefied natural gas (LNG) export terminal operated by LNG Canada in Kitimat, British Columbia came online in 2025. Fugitive emission estimates from this facility will be developed using data reported to Canada's GHGRP combined with Petrinex volumetric activity data.

Downstream Oil and Gas

Work is underway to evaluate data collected under ECCC's expanded GHG Reporting Program for the purpose of improving the quality of petroleum refining process venting and other unintentional leak emissions.

3.4. CO_2 Transport and Storage (CRT Category 1.C)

This section presents information on existing commercial operations involved in carbon capture, transport, use, and storage (CCTUS) and their associated CO_2 emissions. Currently, CCTUS includes the capture of anthropogenic CO_2 from industrial processes or combustion sources and its transport to a long-term storage (LTS) facility or enhanced oil recovery (EOR) operation. Table 3–13 summarizes existing sources of CO_2 captured and transported in Canada, including: CO_2 imported from the Dakota Gasification Company in North Dakota, United States; domestically captured CO_2 from SaskPower's Boundary Dam power station located in Saskatchewan; and domestically captured CO_2 from Shell's Scotford upgrader, Agrium's fertilizer plant, and North-West Redwater Partnership's Sturgeon refinery, all located in Alberta. Table 3–13 also summarizes the annual, and cumulative, final disposition of CO_2 imported to, or captured in, Canada: whether used for EOR or injected into long-term storage.

Table 3–13 **Quantity of CO_2 Import, Capture, Use and Store**

	CO_2 Quantity (kt of CO_2)							
	1990	2000	2005	2020	2021	2022	2023	2024
Captured CO_2 Source								
Imported	**NO**	**1 800**	**2 010**	**1 590**	**1 670**	**1 610**	**1 080**	**870**
Domestic Capture TOTAL	**NO**	**NO**	**NO**	**2 870**	**2 830**	**2 890**	**3 390**	**3 450**
Energy Industries (1.A.1)	NO	NO	NO	730	440	750	790	840
Oil, Natural Gas (1.B.2)	NO	NO	NO	1 950	2 230	1 930	2 330	2 300
Ammonia Production (2.B.1)	NO	NO	NO	190	160	200	280	320
Captured CO_2 Use and Storage								
Enhanced Oil Recovery	**NO**	**1 800**	**2 010**	**3 440**	**3 400**	**3 420**	**3 380**	**3 270**
Cumulative EOR[a]	NO	1 800	10 900	44 800	48 200	51 600	55 000	58 300
Long-term Geologic Storage	**NO**	**NO**	**NO**	**1 020**	**1 100**	**1 070**	**1 090**	**1 050**
Cumulative LTS[b]	NO	NO	NO	6 090	7 190	8 260	9 360	10 400

Notes:
Total quantities for capture source, and use and storage, may not be equal due to rounding.
NO = Not occurring
a. Cumulative EOR = On December 31st of the year, the total historic volume used for enhanced oil recovery (EOR).
b. Cumulative LTS = On December 31st of the year, the total historic volume injected into long-term storage (LTS).

Table 3–14 **CO_2 Transport, Use and Storage GHG Contribution**

GHG Source Category	CO_2 Emissions (kt of CO_2)							
	1990	2000	2005	2020	2021	2022	2023	2024
CO_2 Transport and Storage TOTAL (1.C)	**NO**	**0.09**	**0.09**	**0.49**	**0.65**	**0.64**	**0.65**	**0.65**
Transport of CO_2 (1.C.1)	NO	0.09	0.09	0.46	0.60	0.60	0.60	0.60
Injection and Storage (1.C.2)	NO	NO	NO	0.02	0.04	0.04	0.04	0.04

Note:
NO = Not occurring

In 2024, fugitive CO_2 emissions from the four active pipelines and four capture sites were approximately 0.65 kt, as shown in Table 3–14. Of the four pipelines in Canada, three currently transport only CO_2 used for EOR. Any fugitive emissions from projects that use CO_2 injection to enhance oil production appear in subcategories 1.B.2.a.2 oil – production, 1.B.2.c.1.i venting – oil and 1.B.2.c.2.i flaring – oil in the reporting tables.

The net impacts of GHG emissions from all capture activities are included as part of the Energy Industries (1.A.1), Oil and natural gas and other emissions from energy production (1.B.2), CO_2 Transport and Storage (1.C), and Ammonia Production (2.B.1) categories.

3.4.1. Captured CO_2 Usage

Currently, commercial use of the captured CO_2 presented in this category includes only EOR or direct injection into LTS. In the future, captured CO_2 may be used, and permanently stored, in a much wider range of approved sites and products, such as cement and agriculture, and these volumes will be presented in category 1.C at that time.

3.4.1.1. Captured CO_2 Usage – Enhanced Oil Recovery

In Canada, imported CO_2 and CO_2 captured at a coal-fired power plant in Saskatchewan, and from fertilizer and refinery production in Alberta, are used as an EOR flooding agent to increase crude oil production at three oil reservoirs. This CO_2 acts as a solvent and increases reservoir pressure, loosening and moving trapped hydrocarbons to production wells. The high-pressure flooding process also traps CO_2 in the voids previously occupied by hydrocarbon molecules. In the future, when oil production stops, the reservoirs will provide long-term geological storage of CO_2.

In Saskatchewan, CO_2 flooding started in 2000 at the Weyburn site, currently operated by Whitecap Resources Inc, and in 2005 at the nearby Midale site, currently operated by Cardinal Energy Ltd, with the goal of extending reservoir life by 30 years. CO_2 purchased from the Dakota Gasification Company located in North Dakota and SaskPower's Boundary Dam coal-fired power station, arrives via pipeline. In 2024, the Boundary Dam facility captured approximately 840 kt of CO_2 for shipment to the Weyburn site (SaskPower, 2025). While total annual injection volumes at this reservoir include the fresh supply of CO_2 and the recovered CO_2 from the reservoir, Canada only reports the yearly fresh supply. From 2000 to 2024 over 58.3 Mt of purchased CO_2 was injected for EOR.

In addition to being an EOR operation, Weyburn was the site of a full-scale geological CO_2 storage research program led by the International Energy Agency's Greenhouse Gas Research and Development Programme (IEAGHG) with the support of various industries, research organizations and governments. The IEA Weyburn-Midale research project focused on developing a best practice manual for future geological CO_2 storage projects.

Modelling and simulation results from the first phase (2000 to 2004) of the IEAGHG's CO_2 monitoring and storage project, managed by the Petroleum Technology Research Centre (PTRC), indicate that, after EOR operations are completed, over 98% of CO_2 will remain trapped in the Weyburn reservoir after 5000 years, with only 0.14% of the remainder released to the atmosphere (PTRC, 2004; Mourits, 2008). Soil gas sampling campaigns were conducted yearly between 2000 and 2006, and again in 2011. This protracted monitoring of soil gas geochemistry at the Weyburn oil field found no evidence of leakage of the injected CO_2 to the surface (Lawton, et al., 2021). Additional details on the findings of the research project are available from PTRC.

Whitecap Resources Inc. has an ongoing Measurement, Monitoring and Verification (MMV) program at the Weyburn EOR site. While looking at a broad range of potential emission sources, the program specifically looks for any leakage from the site using methods, such as shallow aquifer regional fluid characterization that employs isotope and chemical water tests to confirm that injected CO_2 is not appearing in surface water, and 4D Seismic testing to evaluate CO_2 in-zone conformance and verify no vertical migration to the surface (Whitecap Resources, 2018).

Cardinal Energy Ltd. has an ongoing MMV program at the Midale EOR site. In 2022, Cardinal Energy had their previously sequestered CO_2 volumes verified by an independent third party (Cardinal Energy, 2023).

Enhance Energy Inc. operates the Clive Leduc Field EOR site in central Alberta and has a monitoring program mandated by the Alberta government's Ministry of Environment and Parks that is described in available quantification documents (AEP, 2022). This comprehensive monitoring plan involves testing in the hydrosphere, biosphere and atmosphere with the goal of assuring that CO_2 is contained within the working formation (Enhance Energy, 2019). The plan includes seismic testing, monitoring wells in the production and overlying formations, soil gas surveys, water well surveys, injection well pressure monitoring and CO_2 isotope measurements. The unique isotope composition of the injected CO_2, and H_2S present in the working formation, will make any leakage from the formation readily observable. In addition, the presence of many coal bed methane (CBM) wells in the area provides an additional opportunity to test for the presence of the unique isotope profiles in the injected CO_2 outside of the working formation.

As of 2024, ongoing monitoring, measurement and verification programs show no evidence that CO_2 from any of the current EOR sites has leaked to nearby formations or the atmosphere.

3.4.1.2. Captured CO_2 Usage – Long-term Storage Injection

Canada has two operational long-term storage (LTS) sites, the Quest CCS facility operated by Shell Canada and the Aquistore Deep Saline CO_2 Storage Project operated by PTRC near Estevan, Saskatchewan. LTS of CO_2 started in 2015 and by the end of 2024, over 10.4 Mt was stored at these two sites.

The Alberta government's Ministry of Environment and Parks has extensive quantification and MMV requirements related to carbon sequestration (AEP, 2023). The Quest CCS facility has a monitoring plan that tests the hydrosphere, biosphere and atmosphere with the goal of assuring that CO_2 is contained within the working formation. As per, *Quest Carbon Capture and Storage Project Annual Summary Report - Alberta Department of Energy: 2022 MMV, "activities are focused on operational monitoring and optimization and MMV data indicate that no CO_2 has migrated outside of the Basal Cambrian Sands (BCS) injection reservoir to date"* (Shell Canada Energy, 2023).

The Aquistore storage site has a range of technologies installed on the surface, shallow subsurface and deep subsurface, along with seismic monitoring and isotope measurements (Aquistore, 2015). The MMV process includes groundwater and soil-gas monitoring, ongoing seismic measurements and down-hole monitoring of a temperature, pressure and fluid composition. Any changes to monitored characteristics would indicate possible leakage from the storage formation.

As of 2024, ongoing monitoring, measurement and verification programs show no evidence that CO_2 from any of the current long-term sites has leaked to nearby formations or the atmosphere.

3.4.2. CO_2 Transport and Storage (CRT Category 1.C)

Two CO_2 pipelines transport captured CO_2 from the Dakota Gasification Company's Great Plains Synfuels Plant in North Dakota (CO_2 import began 2000) and SaskPower's Boundary Dam Power Station near Estevan (CO_2 capture began November 2014) to the Weyburn and Midale EOR sites near Weyburn, Saskatchewan.

A pipeline associated with Shell Canada's Quest CCS project moves captured CO_2 from the Scotford upgrader, near Edmonton, Alberta, to Quest's LTS site north-east of the city.

The Alberta Carbon Trunk Line (ACTL) became active in 2020, and transports CO_2 captured at the Agrium fertilizer plant and Sturgeon refinery, near Edmonton, Alberta, to the Clive Leduc EOR site, operated by Enhance Energy Inc., in central Alberta.

Overall fugitive emissions from CO_2 Transport and Storage were 0.65 kt in 2024 with about 0.6 kt from pipelines and 0.04 kt from injection activities at LTS and EOR sites (Table 3–14).

3.4.2.1. Category Description

The source is fugitive emissions from pipeline systems used to transport CO_2 to injection sites and from its injection at LTS and EOR sites.

3.4.2.2. Methodological Issues

The 2006 IPCC Guidelines provide a Tier 1 methodology for emissions from pipeline transport of CO_2. Pipeline lengths from both the Canada/United States border to the EOR facilities at Weyburn and from Boundary Dam to Weyburn are both approximately 60 km. The pipeline length between the Scotford refinery and the associated long-term geological storage site is about 80 km. The pipeline length between the Agrium and Sturgeon facilities, and the associated EOR site, is approximately 240 km. Emission calculations use the IPCC default medium emission factor of 0.0014 kt CO_2/km pipeline length/year.

Fugitive emissions from LTS and EOR injection operations follow the 2019 IPCC Refinement approach as outlined in Volume 1, Chapter 2.3 for the integration of FRD. FRD from the GHGRP prescribes methods for quantifying emissions as outlined in Chapter 1 of the GHGRP Quantification Requirements (ECCC, 2023).

3.4.2.3. Uncertainty Assessment and Time-Series Consistency

Uncertainty estimates for emissions from CO_2 pipelines use 2006 IPCC Tier 1 defaults of +200% to -50% (± a factor of 2). For emission estimates based on facility reported volumes, it is expected that the overall uncertainty of CO_2 volumes at the gate is within +/- 3% due to metering standards.

Uncertainty estimate of emissions from the use of captured CO_2 at LTS and EOR sites are expected to range from ±3%, as the CO_2 volumes at the gate must follow metering standards for the purchase and sale of goods.

3.4.2.4. QA/QC and Verification

General QA/QC and verification activities that occurred for the CO_2 Transport and Storage category are outlined in section 3.1.5.

3.4.2.5. Recalculations

Due to reporting errors, FRD CO_2 emissions for 2019 were recalculated for CO_2 injection sites (1.C.2) while allocation and calculation errors resulted in a recalculation of pipeline emissions (1.C.1) for 2020 to 2023. These corrections resulted in a more consistent time series for the CO_2 Transport and Storage category as shown in Table 3-13.

3.4.2.6. Planned Improvements

Future emission estimates will include additional CO_2 capture facilities and pipelines, currently planned or under construction, as they come on-line and report their data to Canada's GHGRP. Inclusion of new facility-reported data will require an assessment for compliance with quality (such as completeness, transparency, etc.) and methodology standards, as prescribed in Canada's Greenhouse Gas Quantification Requirements (ECCC, 2023).

3.5. Memo Items (CRT Category 1.D)

3.5.1. International Bunker Fuels (CRT Category 1.D.1)

3.5.1.1. Category Description

Following the 2006 IPCC Guidelines and modalities, procedures and guidelines for the transparency framework for action and support referred to in paragraph 53, Article 13 of the Paris Agreement (MPGs), International Aviation and International Navigation emissions are reported as two separate entries and do not contribute to the national total. Table 3–15 summaries the GHG emissions occurring from these categories and Table 3–16 presents the relative distribution between domestic and international emissions by each subcategory.

Table 3–15 **GHG Emissions from International Aviation and Navigation**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
International Aviation	5 800	10 100	15 200	6 580	6 610	11 400	13 600	14 500
International Navigation	5 370	6 580	4 500	4 020	3 720	3 760	3 580	3 360
Total	**11 200**	**16 700**	**19 700**	**10 600**	**10 300**	**15 200**	**17 100**	**17 800**

Note: Totals may not add up due to rounding.

Table 3–16 **Distribution of Emissions from Aviation and Navigation**

GHG Source Category	Distribution (per cent)							
	1990	2005	2019	2020	2021	2022	2023	2024
Aviation								
Domestic	56%	43%	36%	42%	46%	40%	38%	36%
International	44%	57%	64%	58%	54%	60%	62%	64%
Navigation								
Domestic	37%	38%	47%	48%	44%	47%	48%	50%
International	63%	62%	53%	52%	56%	53%	52%	50%

3.5.1.2. Methodological Issues

Refer to sections A3.1.4.2.2 and A3.1.4.2.3 for the methodologies for aviation and navigation respectively.

Careful consideration should be taken when comparing fuel consumption (in energy terms) from the Navigation subcategory to those of the RESD and IEA. The method employed in the national inventory uses detailed domestic and international movements based on a vessel's port of origin and destination. The fuel consumption values reported to the IEA by Canada are based on vessel flag (domestic or foreign). Furthermore, due to design and operating procedures of marine vessels, it is common for vessels to store significant amounts of fuel onboard. This means that it is possible for vessels to navigate in Canadian waters without purchasing fuel from a Canadian supplier. Since the RESD contains only domestic fuel transactions, it is possible to have more fuel consumed in the marine sector than the amounts reported for Canada.

3.5.1.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty was not quantified for these categories. The uncertainty associated with International Aviation and Navigation were estimated to be ±6.6% and ±2.5%, respectively.

Consistent method and data sources were used throughout the time series, thus, ensuring the time-series consistency.

3.5.1.4. QA/QC and Verification

General QA/QC and verification activities that occurred for International Aviation and Navigation are outlined in section 3.1.5.

3.5.1.5. Recalculations

No recalculations occurred for the International Aviation subcategory for the current inventory edition.

Recalculations for the International Navigation subcategory are discussed in section 3.2.3.5.

3.5.1.6. Planned Improvements

Planned improvements for the International Navigation subcategory are discussed in section 3.2.3.6.

3.5.2. CO_2 Emissions from Biomass (1.D.3)

3.5.2.1. Category Description

As per the MPGs, a memo item reports CO_2 from sustainably produced biomass fuels combusted to produce energy. The Energy sector totals exclude these CO_2 emissions. The LULUCF sector tracks the CO_2 as a loss of biomass (forest) stocks. The energy sector reports the CH_4 and N_2O emissions from biomass fuels in the appropriate categories. Table 3–17 summaries the CO_2 emissions excluded from the national total and Table 3–18 summarizes the quantities of biomass fuels consumed.

3.5.2.2. Methodological Issues

Refer to section A3.1.4 for additional details on the methodologies for biomass fuels combusted in stationary and mobile sources.

The fuel values for motor gasoline and diesel fuel oil published in the RESD data represent fuels blended with biofuels such as ethanol, biodiesel, and renewable diesel. Therefore, biofuels are introduced and modelled as if it were mixed into the total gasoline and diesel for the region(s).

Table 3–17 **CO_2 Emission from Biomass Combustion**

GHG Source Category	CO_2 Emissions (kt)							
	1990	2005	2019	2020	2021	2022	2023	2024
Fuel Combustion Activities (1.A)	**45 500**	**65 700**	**59 800**	**53 600**	**55 800**	**56 600**	**55 400**	**54 000**
Energy Industries (1.A.1)	340	5 580	3 750	2 490	1 870	2 510	1 660	1 000
Manufacturing Industries and Construction (1.A.2)	34 000	51 000	40 300	36 800	39 800	38 700	36 800	35 800
Transport (1.A.3)	42	310	5 420	5 120	5 530	6 400	8 190	8 790
Other Sectors (1.A.4)	11 100	8 800	10 300	9 200	8 600	9 000	8 800	8 400
Other (Not Specified Elsewhere) (1.A.5)	NO	0.001	0.39	0.49	1.7	1.2	2.3	2.8
Memo Items (1.D)	**NO**	**0.07**	**11**	**26**	**30**	**26**	**49**	**28**

Notes:
NO = Not occurring
Totals may not add up due to rounding.

Table 3–18 **Biomass Consumption**

GHG Source Category & Fuel Type	1990	2005	2019	2020	2021	2022	2023	2024
Fuel Combustion Activities (1.A)								
Ethanol (ML)	30	220	3 000	2 700	2 900	3 400	3 900	4 200
Biodiesel (ML)	NO	2.1	360	350	440	460	530	450
Renewable Diesel (ML)	NO	NO	430	540	530	550	1 200	1 500
Residential Firewood (kt)	8 900	6 700	7 200	6 200	5 600	6 000	5 500	5 200
Solid Wood Waste and Spent Pulping Liquor (kt)	25 400	39 200	30 500	27 100	28 600	28 100	25 900	24 700
Mixed Waste (TJ)	NO	290	980	2 100	1 300	1 500	1 800	2 400
Municipal Waste (kt)	800	550	490	460	460	460	450	440
Biogas (kt)	80	220	360	360	360	360	350	350
Memo Items (1.D)								
Ethanol (ML)	NO	0.01	1.5	2.2	2.3	2.6	2.8	3.0
Biodiesel (ML)	NO	0.02	1.3	2.6	3.9	2.5	2.5	2.1
Renewable Diesel (ML)	NO	NO	2.3	6.5	6.9	6.6	15	7.5

Note:
NO = Not occurring

Analysis of the chemical properties of ethanol resulted in a higher heating value (HHV)[6] of 29.67 kJ/g, a carbon content of 52.14% and a density of 789.3 kg/m^3 (ECCC, 2017b). A study conducted between 2004 and 2005 (BioMer, 2005) provided the properties used for biodiesel. Those properties include an HHV of 35.18 TJ/ML, with a carbon content of 76.5% and a density of 882 kg/m^3. A country-specific analysis for renewable diesel has not been incorporated into the model therefore all bio-based diesel is modelled as biodiesel.

3.5.2.3. Uncertainty Assessment and Time-Series Consistency

The uncertainties associated with the CH_4 and N_2O emissions from biomass fuel combustion are integrated into each sector in which they are consumed.

Consistent method and data sources were used throughout the time series, thus, ensuring the time-series consistency.

3.5.2.4. QA/QC and Verification

General QA/QC and verification activities that occurred for biofuel combustion are outlined in section 3.1.5.

3.5.2.5. Recalculations

Stationary Biofuels: Revisions are due to updated activity data for digester gas, landfill gas, municipal waste, mixed waste fuel, residential firewood, sludge gas, solid wood waste, and spent pulping liquor from 1990 to 2023 (emission changes ranged from -0.33 Mt in 2023 to +0.02 Mt in 2006).

Mobile Biofuels: Revision are due to a new data source of renewable fuels that are applicable to all Transport and Off-Road subcategories that consume motor gasoline and/or diesel fuel oil. The new data source provides additional biofuel use details such as differentiating biofuel types and provincial disposition. In addition, the Rail Association of Canada started collecting biofuel consumption from locomotives which was incorporated in the railway model. As a result, this improved the accuracy of emissions associated with biofuels.

3.5.2.6. Planned Improvements

Work is underway to improve tracking and allocation of emissions associated with low-carbon fuel (e.g., bio-ethanol, biodiesel, renewable natural gas, etc.) combustion.

Additional work is underway to continue to evaluate and update average renewable fuel content values used as input in several mobile emissions models, for the entire time series.

6 Higher heating value and lower heating value are technical terms identifying the energy content of a specific fuel and differ depending on whether the water in the combustion products is in the liquid or gaseous phase respectively. Synonyms for higher heating value include gross heating value or gross calorific value while synonyms for lower heating value include net heating value or net calorific value.

CHAPTER 4

INDUSTRIAL PROCESSES AND PRODUCT USE (CRT SECTOR 2)

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4.1. Overview

This chapter covers greenhouse gas (GHG) emissions produced by various industrial processes that chemically or physically transform materials. These processes include the production and use of mineral products, metal production, chemical production, consumption of sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3), halocarbon production and use as substitutes to ozone-depleting substances (ODS), and non-energy products from fuels and solvent use. GHG emissions from fuel combustion supplying energy to industrial activities are reported in the Energy sector (Chapter 3). In some cases, it is difficult to differentiate between emissions associated with energy and those produced by industrial process use of fuel. In such cases, and where industrial process use of fuel is predominant, the emissions are allocated to the Industrial Processes and Product Use (IPPU) sector. However, when data is available, emissions from specific fuels will be reallocated to the specific IPPU category, as required by the 2006 IPCC Guidelines. Emissions from the use of natural gas for hydrogen production in the upstream and downstream oil industries are accounted for in the Energy sector.

Greenhouse gas emissions from the IPPU sector contributed 53.3 Mt CO_2 eq to the 2024 national GHG inventory (Table 4–1), compared with 56.8 Mt CO_2 eq in 2005. IPPU emissions represented 7.8% of total Canadian GHG emissions in 2024.

In line with the principle of continuous improvement and in response to comments made by the technical expert review teams (TERTs) on previous submissions, this submission has incorporated improvements/revisions to activity data, emission factors, and/or methods. Tier 1 emission estimates for iron ore pellet production (CRT 2.C.1.e) and rare earths production (CRT 2.C.7.a) were added for this submission. Detailed explanations for the changes in estimates as a result of these improvements/revisions are described in the “Recalculations” sections of this chapter and impacts are summarized in Table 4–2.

The IPPU key categories are presented in Table 4–3. Additional information is found in Annex 1.

Table 4–1 **Overview of GHG Emissions from the Industrial Processes and Product Use Sector, Selected Years**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
INDUSTRIAL PROCESSES AND PRODUCT USE TOTAL	**55 744**	**56 808**	**54 462**	**52 149**	**53 886**	**53 231**	**54 750**	**53 284**
Mineral Products (CRT 2.A)	**8 489**	**10 275**	**8 852**	**8 263**	**9 017**	**8 411**	**8 850**	**8 472**
Cement Production (CRT 2.A.1)	5 823	7 614	7 195	6 759	7 385	6 752	7 300	6 895
Lime Production (CRT 2.A.2)	1 864	1 834	1 339	1 187	1 314	1 338	1 245	1 282
Mineral Product Use (CRT 2.A.3 and 2.A.4)	802	827	317	318	318	322	305	295
Chemical Industry (CRT 2.B, except 2.B.9)	**16 291**	**9 972**	**6 200**	**5 929**	**5 716**	**5 738**	**5 597**	**5 590**
Ammonia Production (CRT 2.B.1)	2 739	2 705	2 501	2 294	2 538	2 590	2 414	2 291
Nitric Acid Production (CRT 2.B.2)	865	1 070	225	168	192	128	133	129
Adipic Acid Production (CRT 2.B.3)	9 162	2 264	-	-	-	-	-	-
Petrochemical and Carbon Black Production (CRT 2.B.5, 2.B.8 and 2.B.10)	3 525	3 933	3 474	3 467	2 986	3 020	3 050	3 170
Metal Production (CRT 2.C)	**23 899**	**21 304**	**15 726**	**14 699**	**16 063**	**15 544**	**16 668**	**16 499**
Iron and Steel Production (CRT 2.C.1 and 2.C.2)	11 154	11 583	10 185	8 688	10 045	9 551	10 076	10 241
Aluminium Production (CRT 2.C.3)	9 564	8 297	5 249	5 836	5 774	5 655	6 090	5 960
Magnesium and Other Metal Production (CRT 2.C.4 and 2.C.7)	3 181	1 424	292	176	244	337	502	297
Production and Consumption of Halocarbons, SF_6 and NF_3 (CRT 2.B.9, 2.E and 2.F)	**818**	**4 823**	**11 581**	**11 297**	**10 739**	**10 582**	**10 244**	**9 725**
Non-Energy Products from Fuels and Solvent Use (CRT 2.D)	**5 886**	**9 927**	**11 488**	**11 302**	**11 687**	**12 348**	**12 745**	**12 315**
Other Product Manufacture and Use (CRT 2.G)	**361**	**507**	**616**	**659**	**663**	**608**	**645**	**684**

Note: Totals may not add up due to rounding.

The IPPU key categories that have the strongest influence based on the level assessment (with LULUCF) for the latest data year are:

1. Non-energy Products from Fuels and Solvent Use (CRT category 2.D)
2. Iron and Steel Production (CRT category 2.C.1)
3. Cement Production (CRT category 2.A.1)

For the trends assessment, the IPPU categories with the strongest influence (with LULUCF) for the latest data year are:

1. Refrigeration and Air conditioning (CRT category 2.F.1)
2. Aluminium Production (CRT category 2.C.3)
3. Non-energy Products from Fuels and Solvent Use (CRT category 2.D)

The contributing factors of the long-term and short-term trends in this sector include a decrease in the Chemical industry due to the closure of adipic acid production in 2009, and a decrease in emissions from the Metal Industry due to the closure of outdated facilities. Additional specific information on the trends observed are discussed in Chapter 2.

Table 4–4 summarizes the methodological tiers used in the IPPU sector.

General quality control (QC) procedures applied to categories in the IPPU sector include systematic Tier 1 QC checks for key categories and informal checks throughout the compilation process on all categories in a manner consistent with Volume 1, section 6.6 of the 2006 IPCC Guidelines (IPCC, 2006). Checks include a review of activity data, emission factors and implied emission factors, time-series consistency and trends, transcription accuracy, national and provincial/territorial emission estimates, unit conversions, and documentation of recalculations. The QC procedures, activity data, methodologies and changes to methodologies for each category are documented and archived.

Table 4–2 **Summary of Recalculations for the Industrial Processes and Product Use Sector, Selected Years**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
INDUSTRIAL PROCESSES AND PRODUCT USE								
Previous Submission (2025 NIR)	55 096	56 032	54 719	53 737	51 414	53 217	52 522	53 530
Current Submission (2026 NIR)	55 744	56 808	55 856	54 462	52 149	53 886	53 231	54 750
Change in Emissions	+648	+776	+1137	+725	+734	+668	+710	+1220
	1%	1%	2%	1%	1%	1%	1%	2%
Mineral Products (CRT 2.A)								
Previous Submission (2025 NIR)	8 489	10 275	8 679	8 852	8 214	9 011	8 408	8 846
Current Submission (2026 NIR)	8 489	10 275	9 003	8 852	8 263	9 017	8 411	8 850
Change in Emissions	+0	+0	+324	-	+49	+6	+4	+5
	0%	0%	4%	-	1%	0%	0%	0%
Chemical Industry (CRT 2.B, except 2.B.9)								
Previous Submission (2025 NIR)	16 291	9 972	6 353	6 198	5 927	5 715	5 741	5 596
Current Submission (2026 NIR)	16 291	9 972	6 355	6 200	5 929	5 716	5 738	5 597
Change in Emissions	+0	+0	+2	+2	+2	+1	-3	+1
	0%	0%	0%	0%	0%	0%	0%	0%
Metal Production (CRT 2.C)								
Previous Submission (2025 NIR)	23 236	20 517	16 054	15 135	14 082	15 406	14 820	15 848
Current Submission (2026 NIR)	23 899	21 304	16 649	15 726	14 699	16 063	15 544	16 668
Change in Emissions	+662	+787	+596	+591	+617	+657	+724	+820
	3%	4%	4%	4%	4%	4%	5%	5%
Production and Consumption of Halocarbons, SF_6 and NF_3 (CRT 2.B.9, 2.E and 2.F)								
Previous Submission (2025 NIR)	818	4 823	11 487	11 427	11 221	10 726	10 591	10 289
Current Submission (2026 NIR)	818	4 823	11 716	11 581	11 297	10 739	10 582	10 244
Change in Emissions	-	-	+229	+154	+76	+13	-9	-45
	-	-	2%	1%	1%	0%	0%	0%
Non-Energy Products from Fuels and Solvent Use (CRT 2.D)								
Previous Submission (2025 NIR)	5 900	9 938	11 501	11 509	11 312	11 696	12 354	12 306
Current Submission (2026 NIR)	5 886	9 927	11 487	11 488	11 302	11 687	12 348	12 745
Change in Emissions	-14	-11	-14	-21	-10	-8	-6	+439
	0%	0%	0%	0%	0%	0%	0%	4%
Other Product Manufacture and Use (CRT 2.G)								
Previous Submission (2025 NIR)	361	507	645	616	659	663	608	645
Current Submission (2026 NIR)	361	507	645	616	659	663	608	645
Change in Emissions	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-

Notes:
Totals may not add up due to rounding.
"-" in the "Change in Emissions" data indicates that there were no recalculations.

Table 4–3 **Summary of Key Categories for the Industrial Processes and Product Use Sector for 2024**

CRT Code	IPCC Category	Gas	2024	
			With LULUCF	without LULUCF
2.A.1	Cement Production	CO_2	Level	Level
2.C.1	Iron and Steel Production	CO_2	Level	Level, Trend
2.C.3	Aluminium Production	CO_2	Level, Trend	Level, Trend
2.C.3	Aluminium Production	PFCs	Trend	Trend
2.C.4	Magnesium Production	SF_6	Trend	Trend
2.D	Non-energy Products from Fuels and Solvent Use	CO_2	Level, Trend	Level, Trend
2.F.1	Refrigeration and Air conditioning	Aggregated F-gases	Level, Trend	Level, Trend
2.F.2	Foam Blowing Agents	Aggregated F-gases	Trend	Trend

Table 4–4 **Summary of Methodological Tiers by Category**

IPPU GHG Source Category	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3
MINERAL INDUSTRY (CRT 2.A)							
Cement Production (CRT 2.A.1)	T2, T3	-	-	-	-	-	-
Lime Production (CRT 2.A.2)	T2, T3	-	-	-	-	-	-
Glass Production (CRT 2.A.3)	T1	-	-	-	-	-	-
Other Process Uses of Carbonates (CRT 2.A.4)	T1, T2, T3	-	-	-	-	-	-
CHEMICAL INDUSTRY (CRT 2.B)							
Ammonia Production (CRT 2.B.1)	T2, T3	-	-	-	-	-	-
Nitric Acid Production (CRT 2.B.2)	-	-	T1, T2, T3	-	-	-	-
Adipic Acid Production (CRT 2.B.3)	-	-	T1, T2, T3	-	-	-	-
Carbide Production (CRT 2.B.5)	IE	T1	-	-	-	-	-
Titanium Dioxide Production (CRT 2.B.6)	IE	-	-	-	-	-	-
Soda Ash Production (CRT 2.B.7)	T1	-	-	-	-	-	-
Petrochemical and Carbon Black Production (CRT 2.B.8)	T1,T2	T1, T2,T3	-	-	-	-	-
Fluorochemical Production (CRT 2.B.9)	-	-	-	T1	-	-	-
Other (CRT 2.B.10)	T1	-	T2	-	-	-	-
METAL INDUSTRY (CRT 2.C)							
Iron and Steel Production (CRT 2.C.1)	T1, T2, T3	T1	-	-	-	-	-
Ferroalloys Production (CRT 2.C.2)	IE	IE	-	-	-	-	-
Aluminium Production (CRT 2.C.3)	T2, T3	-	-	-	T2, T3	T3	-
Magnesium Production (CRT 2.C.4)	T1	-	-	-	-	T2	-
Lead Production (CRT 2.C.5)	IE	-	-	-	-	-	-
Zinc Production (CRT 2.C.6)	IE	-	-	-	-	-	-
Other (CRT 2.C.7)	T1	-	-	-	T1	-	-
NON-ENERGY PRODUCTS FROM FUELS AND SOLVENT USE (CRT 2.D)							
Lubricant Use (CRT 2.D.1)	T1	-	-	-	-	-	-
Paraffin Wax Use (CRT 2.D.2)	IE	-	-	-	-	-	-
Other (CRT 2.D.3)	T1, T2	-	-	-	-	-	-
ELECTRONICS INDUSTRY (CRT 2.E)							
Integrated Circuit or Semiconductor (CRT 2.E.1)	-	-	-	-	T2	T2	T2
Other (CRT 2.E.5)	-	-	-	-	T1	-	-
PRODUCT USES AS SUBSTITUTES FOR ODS (CRT 2.F)							
Refrigeration and Air-Conditioning (CRT 2.F.1)	-	-	-	T2	T2	-	-
Foam Blowing Agents (CRT 2.F.2)	-	-	-	T1	T2	-	-
Fire Protection (CRT 2.F.3)	-	-	-	T1	-	-	-
Aerosols (CRT 2.F.4)	-	-	-	T1	-	-	-
Solvents (CRT 2.F.5)	-	-	-	T1	T1	-	-
Other Applications (CRT 2.F.6)	-	-	-	T1	-	-	-
OTHER PRODUCT MANUFACTURE AND USE (CRT 2.G)							
Electrical Equipment (CRT 2.G.1)	-	-	-	-	-	T3	-
SF_6 and PFCs from Other Product Use (CRT 2.G.2)	-	-	-	-	NE	NE	-
N_2O from Product Uses (CRT 2.G.3)	-	-	OTH	-	-	-	-
PFCs from Other Contained Product Uses (CRT 2.G.4)	-	-	-	-	T1	-	-

Notes:
T1 = Tier 1
T2 = Tier 2
T3 = Tier 3
OTH = Other (not a tiered methodology)
NE = Not estimated
IE = Included elsewhere (within another GHG source category)
"-" = Not Applicable

4.2. Mineral Products (CRT Category 2.A)

4.2.1. Cement Production (CRT Category 2.A.1)

4.2.1.1. Category Description

Portland cement accounts for more than 90% of all cement produced in Canada, while the rest is masonry and other cement (Statistics Canada, n.d.[b]). The Cement Production category considers carbon dioxide (CO_2) emissions associated with the production of clinker, the precursor of Portland cement, and excludes other cement production (IPCC, 2006). There are 15 separate facilities that produce clinker in Canada, all of which use dry kilns. These facilities are in Nova Scotia, Quebec, Ontario, Alberta and British Columbia.[1] Total clinker production capacity in Canada is approximately 18 Mt/year.

The Cement Production category accounted for 6895 kt (or 1.0%) of Canada's total emissions in 2024, a 9% decrease from 2005, and represents a key category in the inventory. The downwards trend of emissions can be attributed largely to variations in annual clinker production, as is described in Chapter 2, section 2.3.2.1.

Emissions that result from the combustion of fossil fuels to generate heat to drive the reaction in the kiln fall under the Energy sector and are not considered in this category.

4.2.1.2. Methodological Issues

CO_2 emissions from Cement Production were estimated for 1990–2016 using a modified Tier 2 method (Equation 4–1) that incorporates country-specific emission factors and emissions from carbon-bearing non-fuel materials (IPCC, 2006). For 2017 onwards, CO_2 emission estimates came directly from the data reported by Canadian cement production facilities to the Greenhouse Gas Reporting Program (GHGRP) (ECCC, 2025a). The CO_2 emissions reported by cement production facilities to the GHGRP were calculated using Equation 4–2, a modified Tier 3 method (IPCC, 2006).

Equation 4–1

$$CO_2\ emissions = EF_{cl} \times M_{cl} \times CF_{ckd} + EF_{toc} \times M_{cl}$$

EF_{cl}	=	annual calcination emission factor based on clinker production, kt CO_2/kt clinker
M_{cl}	=	clinker production data, kt of clinker
CF_{ckd}	=	correction factor for the loss of cement kiln dust and by-pass dust, fraction
EF_{toc}	=	annual emission factor for CO_2 emissions from total organic carbon in the raw feed, kt CO_2/kt clinker

Equation 4–2

$$E_{CO_2} = \sum_m^{12}[Q_{CLI_m} \times EF_{CLI_m}] + \sum_q^4[Q_{CKD_q} \times EF_{CKD_q}] + [TOC_{RM} \times RM \times 3.664]$$

E_{CO_2}	=	the total annual quantity of CO_2 emissions from cement production (tonnes)
$Q_{CLI\ m}$	=	the total quantity of clinker in month "m" (tonnes)
$EF_{CLI\ m}$	=	the plant-specific emission factor of clinker in month "m" (tonnes CO_2/tonnes clinker)
$Q_{CKD\ q}$	=	the total quantity of cement kiln dust not recycled back to the kiln in quarter "q" (tonnes)
$EF_{CKD\ q}$	=	the plant-specific emission factor of cement kiln dust not recycled back to the kiln in quarter "q" (tonnes CO_2/tonnes cement kiln dust), using Equation 4–3
TOC_{RM}	=	the measured annual organic carbon content in raw material, or using a default value of 0.002 (0.2%)
RM	=	the total annual quantity of raw material consumption (tonnes)
3.664	=	ratio of molecular weights of CO_2 to C

Disaggregated data on the composition of raw materials and clinker, the calcination degree of cement kiln dust (CKD), and the amount of bypass dust and CKD are not publicly available for 1990–2016. However, national aggregated data expressed as an annual calcination emission factor (EF_{cl}) and annual amounts of bypass dust and CKD are available from the Cement Association of Canada (CAC) for 1990, 2000 and 2002–2014 (CAC, 2014) and from the GHGRP for 2017 onwards (ECCC, 2025a). These same quantities have been estimated for the remaining reporting years (1991–1999, 2001, 2015–2016). The CAC receives plant-based data from its member companies in accordance with the quantification method published under the umbrella of the Cement Sustainability Initiative of the World Business Council for Sustainable Development (WBCSD), CO_2 Emissions Inventory Protocol, Version 3.0. The protocol provides for two pathways for estimating process-related CO_2 emissions from the calcination of raw materials. The first is based on the amount and chemical composition of the products

1 Natural Resources Canada, Personal communication on Canada's Minerals subsector.

(clinker plus dust leaving the kiln system). The second is based on the amount and composition of the raw materials entering the kiln. Canadian cement production facilities report plant-based data to the GHGRP in accordance with section 4 of Canada's Greenhouse Gas Quantification Requirements (ECCC, 2023).

Equation 4–2 sums CO_2 emissions from clinker production, CO_2 emissions from cement kiln dust, and CO_2 emissions from organic carbon oxidation in raw materials. CO_2 emissions from cement kiln dust are calculated using plant-specific emission factors of CKD not recycled back to the kiln, which are calculated using Equation 4–3. In contrast to the 2006 IPCC Tier 3 method, this modified Tier 3 method does not require the subtraction of CO_2 emissions from uncalcined carbonate in CKD not recycled to the kiln, as this is accounted for using the plant-specific emission factors of CKD.

Equation 4–3

$$EF_{CKD_q} = [CaO_{CKD_q} - fCaO_q] \times 0.785 + [MgO_{CKD_q} - fMgO_q] \times 1.092$$

EF_{CKD_q}	=	the plant-specific emission factor of CKD not recycled back to the kiln in quarter "q" (tonnes CO_2 / tonnes CKD)
CaO_{CKD_q}	=	the total calcium (expressed as CaO) content of CKD not recycled back to the kiln in quarter "q" (tonnes CaO / tonnes CKD)
$fCaO_q$	=	the non-calcined calcium oxide (CaO) content of CKD not recycled back to the kiln in quarter "q" (tonne CaO / tonne CKD)
MgO_{CKD_q}	=	the total magnesium (expressed as MgO) content of CKD not recycled back to the kiln in quarter "q" (tonne MgO / tonne CKD)
$fMgO_q$	=	the non-calcined magnesium oxide (MgO) content of CKD not recycled back to the kiln in quarter "q" (tonne MgO / tonne CKD)
0.785	=	ratio of molecular weights of CO_2 to CaO
1.092	=	ratio of molecular weights of CO_2 to MgO

The CO_2 calcination emission factor, organic carbon emission factor, and CKD/bypass dust correction factor vary from year to year and are based on the available data from the CAC for 1990, 2000 and 2002–2014 and from the GHGRP facility-reported data for 2017 onwards. For the unknown data years (1991–1999, 2001, 2015–2016), an average is taken from the years before and after the unknown data point.

Clinker production data for 1990–1996 was obtained from the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC, 2010). Clinker production data for 1997–2016 was obtained from Statistics Canada (Statistics Canada, 1990–2004, n.d.[a]).

Provincial/territorial emission estimates are apportioned from national emission estimates based on the clinker production capacity of each province/territory for 1990–2016. The source of 1990–2006 data was the *Canadian Minerals Yearbook* (NRCan, 1990–2006). For 2007–2013, Natural Resources Canada provided capacity information directly via personal communication.[2] For 2014–2016, the Mining and Processing Division of ECCC provided clinker production capacity via personal communication.[3] For 2017 onwards, provincial/territorial emission estimates are based on the emissions reported to the GHGRP by cement production facilities in each province/territory.

4.2.1.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty estimate has been developed based on the default uncertainty values set out in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) for the parameters in the modified Tier 2 method and modified Tier 3 method. The error associated with the non-response rate of the Statistics Canada survey for clinker production data has also been considered in the uncertainty estimate. The Tier 1 uncertainty associated with the CO_2 emission estimates for clinker production has been calculated to be ±13.8% for 1990–2016 and ±8.5% for 2017 onwards. Equation 3.1 from Volume 1, Chapter 3 (IPCC, 2006) has been applied over the time series. The activity data sources have changed over the time series from CIEEDAC publications to data collected by Statistics Canada, as described in section 4.2.1.2.

To address time-series consistency between the Tier 2 method applied for 1990–2016 and modified Tier 3 method applied for 2017 onwards, splicing techniques were assessed from Volume 1, Chapter 5, section 5.3.3 (IPCC, 2006) and a modified average splicing technique was chosen as being the most suitable. With this approach, the annual EF_{cl}, EF_{toc}, and CF_{ckd} for 2015–2016 were averages calculated based on the 2014 values provided by the CAC and the 2017 values calculated from the GHGRP facility-reported data. This modified average splicing technique was chosen because the country-specific EF_{cl}, EF_{toc}, and CF_{ckd} were last updated in 2014 by the CAC and the EF_{cl}, EF_{toc}, and CF_{ckd} calculated from the 2017 GHGRP facility-reported data were comparable with the EF_{cl}, EF_{toc}, and CF_{ckd} updated by the CAC in 2014. A similar approach was applied for 1990–2014 to ensure time-series consistency for the EF_{cl}, EF_{toc}, and CF_{ckd}. The CAC provided national cement production data for the calculation of EF_{cl}, EF_{toc}, and CF_{ckd} for years 1990, 2000 and 2002–2014 (CAC, 2014). The EF_{cl}, EF_{toc}, and CF_{ckd} for 1991–1999 were taken to be an average of the 1990 and 2000 EF_{cl}, EF_{toc}, and CF_{ckd}, while the EF_{cl}, EF_{toc}, and CF_{ckd} for 2002 was taken to be an average of the 2000 and 2002 EF_{cl}, EF_{toc}, and CF_{ckd}.

2 Panagapko D. 2008–2014. Personal communications (emails from Panagapko D to EC, last email dated September 16, 2014). Natural Resources Canada.

3 Sunstrum J. 2020. Personal communications (emails Sunstrum J to ECCC, last email dated July 9, 2020). Mining and Processing Division, Environment and Climate Change Canada.

4.2.1.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for this category.

4.2.1.5. Recalculations

CO_2 emissions for this category were recalculated due to updates to facility reports to the GHGRP for 2018 and 2020, which resulted in increases of 323 kt CO_2 and 46 kt CO_2, respectively. The recalculation for 2018 addressed a data outlier which previously impacted the implied emission factor (IEF) for that year and was identified by the TERT in 2023.

4.2.1.6. Planned Improvements

No improvements are currently planned for this category.

4.2.2. Lime Production (CRT Category 2.A.2)

4.2.2.1. Category Description

Dolomitic lime and high-calcium lime are both produced in Canada, and emissions from their production are accounted for in this inventory submission. Table 4–5 indicates the proportion of dolomitic and high-calcium lime in Canada. Information on hydraulic lime production in Canada is unavailable, and as a result its proportion of total lime production is assumed to be zero. There are 11 separate lime production facilities in Canada. These facilities are in New Brunswick, Quebec, Ontario, Manitoba, Alberta and British Columbia. Total lime calcining capacity in Canada is approximately 3.1 Mt/year.

The Lime Production category contributed 1282 kt (0.2%) to Canada's total emissions in 2024, a 30% decrease from 2005. Fluctuations in emissions over the time series are largely due to variations in lime production quantities.

Emissions from the regeneration of lime from spent pulping liquors at pulp mills are not accounted for in the IPPU sector. CO_2 emissions that are associated with the use of natural limestone for lime production in the pulp and paper industry are accounted for in the Other Limestone and Dolomite Use category (section 4.2.3).

4.2.2.2. Methodological Issues

A Tier 2 methodology (Equation 4–4) was used to estimate the CO_2 emissions from Lime Production for 1990–2016, where country-specific emission factors were applied to national activity data (IPCC, 2006). The country-specific emission factors for dolomitic lime and high-calcium lime were developed using information on Canadian lime compositions collected from the Canadian Lime Institute[4] and from annual averages of all lime production facilities in Canada that reported to the GHGRP for 2017–2023, and are provided in Annex 6. Data on total national lime production, hydrated lime production and lime plant calcining capacities were obtained from the *Canadian Minerals Yearbook* (NRCan, 1990–2006)[5] for the period up to and including 2006. In subsequent years, information was provided directly by Natural Resources Canada via personal communication.[6]

For 2017 onwards, lime production activity data came directly from data reported by facilities in Canada to the GHGRP (ECCC, 2025a). The CO_2 emissions were calculated based on facility-reported data, using a modified Tier 3 method in accordance with section 3 of Canada's Greenhouse Gas Quantification Requirements (ECCC, 2023).

Equation 4–4

$$E_{CO2} = \sum_i (Q_i \times EF_i) \times CF_{LKD} \times CF_{hydrated}$$

where

Q_i = production data of lime i, kt of lime i

EF_i = emission factor for lime type i produced in Canada, kt CO_2/kt of lime i

CF_{LKD} = correction factor that corrects for the loss of lime kiln dust and production of byproducts and wastes, fraction

$CF_{hydrated}$ = correction factor that corrects for hydrated lime, fraction

4 Kenefick W. 2008. Personal communication (email from Kenefick W to Shen A, Environment Canada, dated October 7, 2008). Canadian Lime Institute.

5 [NRCan] Natural Resources Canada. 1990–2006. *Canadian Minerals Yearbook. Minerals and Metals Sector* (Annual). Natural Resources Canada (discontinued).

6 [NRCan] Natural Resources Canada. 2007–2018. Canada, Production of Limestone – Stone. Unpublished data. Natural Resources Canada, Mineral & Mining Statistics Division.

Canadian lime plants are classified into three types based on their final products: dolomitic lime only, high-calcium lime only, and both dolomitic and high-calcium lime. Information on lime type(s) produced at each facility was sourced from the *Canadian Minerals Yearbook* for data years 1990-2006 (NRCan, 1990-2006), and from detailed facility-level data reported to Canada's GHGRP for 2017 onwards. When facility-level information was available on major product(s) and/or the ratio of dolomitic to high-calcium lime for facilities producing both lime types, this was applied to the facility's capacity for 1990-2016. In the absence of facility-level information on the breakdown of lime types, for 1990–2016, a 15/85 ratio for dolomitic lime/high-calcium lime was assumed for lime plants that produced both types of lime. Table 4–5 provides the breakdown between dolomitic lime and high-calcium lime production in Canada for 1990-2016. National CO_2 emissions for 1990–2016 were calculated by applying the Canadian emission factors to the estimated annual national lime production data, by lime type.

The water content of Canadian hydrated lime is estimated to be 28.25%.[7] The water content of hydrated lime is deducted from national lime production to calculate the amount of "dry" lime production, which is broken down into dolomitic lime and high-calcium lime. Corresponding emission factors are subsequently applied.

The lime kiln dust (LKD) correction factor was developed from annual averages of emissions from all byproducts and wastes, including LKD, from all lime production facilities in Canada, as reported to the GHGRP for 2017–2023. This correction factor was applied to national emission estimates from lime production for 1990–2016.

Provincial CO_2 emission estimates are apportioned from national emission estimates based on the total calcining capacity of each province/territory for 1990–2016. The *Canadian Minerals Yearbook* (NRCan, 1990–2006) provided data on calcining capacity for 1990–2006. For 2007–2013, Natural Resources Canada provided capacity information directly via personal communication.[8] For 2014–2016, the Mining and Processing Division of ECCC provided calcining capacity via personal communication.[9] For 2017 onwards, provincial/territorial emission estimates are based on facility-reported data reported to the GHGRP by lime production facilities in each province/territory.

The variation in the percent split of dolomitic and high-calcium lime over the time series can be attributed to changes in production and capacities at facilities across Canada, as well as facility closures. For instance, the slight decrease in the share of dolomitic lime in 2008–2009 is attributed to the closure of the Timminco Limited plant in Haley Station, Ontario that produced only dolomitic lime.

Canada's average annual proportion of dolomitic lime over the time series (19%) was greater than the default value (15%) outlined in the 2006 IPCC Guidelines (IPCC, 2006). Along with the inclusion of emissions from byproducts and wastes other than LKD, this resulted in the Implied Emission Factors being closer to the high end of the range of default emission factors associated with Lime Production, as presented in the 2006 IPCC Guidelines.

Table 4–5 **Split between Dolomitic and High-Calcium Lime Production in Canada (1990–2016)**

Year	% Split	
	Dolomitic Lime	High-Calcium Lime
1990–1992	17%	83%
1993–1994	19%	81%
1995–1997	20%	80%
1998–1999	19%	81%
2000–2006	20%	80%
2007–2008	17%	83%
2009–2014	16%	84%
2015–2016	18%	82%

7 Kenefick W. 2008. Personal communication (email from Kenefick W to Shen A, Environment Canada, dated October 22, 2008). Canadian Lime Institute.

8 Panagapko D. 2013. Personal communication (email from Panagapko D to Edalatmanesh M, Environment Canada, dated November 6, 2013). Natural Resources Canada.

9 Sunstrum J. 2020. Personal communications (emails from Sunstrum J to ECCC, last email dated July 9, 2020). Mining and Processing Division, Environment and Climate Change Canada.

4.2.2.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty estimate has been developed based on the default uncertainty values set out in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) for the parameters in the modified Tier 2 method and modified Tier 3 method. The Tier 1 uncertainty associated with the CO_2 emission estimates for Lime Production has been calculated to be ±33.2% for 1990–2016 and ±6.7% for 2017–2024. Equation 3.1 from Volume 1, Chapter 3 (IPCC, 2006) has been applied over the time series.

To address time-series consistency between the Tier 2 method applied for 1990–2016 and Tier 3 method applied for 2017 onwards, splicing techniques were assessed from Volume 1, Chapter 5, section 5.3.3 (IPCC, 2006) and a modified average splicing technique was chosen as being the most suitable. With this approach, the annual EF for dolomitic lime production (EF_{dol}) and the annual EF for high-calcium lime production ($EF_{h\text{-}c}$) for 2009–2016 are averages calculated based on the 2008 values provided by the Canadian Lime Institute and the 2017–2023 values calculated from the GHGRP facility-reported data. The LKD correction factor applied for 1990–2016 was calculated based on GHGRP facility-reported data for 2017–2023. This modified average splicing technique was chosen because the country-specific EF_{dol} and $EF_{h\text{-}c}$ were last provided in 2008 by the Canadian Lime Institute, and the EF_{dol} and $EF_{h\text{-}c}$ calculated from the 2017–2023 GHGRP facility-reported data were comparable with the EF_{dol} and $EF_{h\text{-}c}$ provided by the Canadian Lime Institute in 2008. The 1990–2007 EF_{dol} and $EF_{h\text{-}c}$ were assumed to be the same as the 2008 EF_{dol} and $EF_{h\text{-}c}$ provided from the Canadian Lime Institute because no other national EFs were available from Canadian Lime Institute and were considered the most representative EFs for that time period. The source of activity data has changed over the time series from the Canadian Lime Institute to Natural Resources Canada and Canada's GHGRP, as described in section 4.2.2.2.

4.2.2.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for this category.

4.2.2.5. Recalculations

Recalculations for this category occurred due to updated facility-reported data to the GHGRP, resulting in updates to the split of high-calcium and dolomitic lime for 1990-2016 and corrections to activity data for the years 2018 and 2020-2022. The magnitude of the recalculations ranged from -4 kt CO_2 in 2022 to +2 kt in 2021.

4.2.2.6. Planned Improvements

No improvements are currently planned for this category.

4.2.3. Mineral Product Use (CRT Categories 2.A.3 and 2.A.4)

4.2.3.1. Category Description

The categories discussed in this section, under the aggregate title of "Mineral Product Use", include Glass Production (CRT category 2.A.3), Ceramics Production (CRT category 2.A.4.a), Other Uses of Soda Ash (CRT category 2.A.4.b), Non-Metallurgical Magnesia Production (i.e., magnesite use) (CRT category 2.A.4.c) and Other Limestone and Dolomite Use (CRT category 2.A.4.d).

In 2024, the aggregate category accounted for 295 kt (or 0.04%) of Canada's total GHG emissions, with a decrease of approximately 64% in total emissions since 2005. Non-metallurgical Magnesia Production accounted for 39% of Mineral Product Use emissions, whereas Other Limestone and Dolomite Use, Other Uses of Soda Ash, and Glass Production contributed 37%, 13% and 11% of emissions, respectively.

Glass Production (CRT Category 2.A.3)

CO_2 emissions associated with soda ash and limestone consumed in Canadian glass production are included in this category. Soda ash has been the predominant source of CO_2 emissions from Glass Production throughout the entire time series.

Ceramics Production (CRT Category 2.A.4.a)

The production of bricks, roof tiles, vitrified clay pipes, refractory products, expanded clay products, wall and floor tiles, table and ornamental ware, sanitary ware, technical ceramics, and inorganic bonded abrasives are included in the Ceramics Production category. Calcination of carbonates in the clay results in process emissions of CO_2.

Other Uses of Soda Ash (CRT Category 2.A.4.b)

Soda ash is used in the production of chemicals, soaps and detergents, pulp and paper, flue gas desulphurization (FGD), and water treatment.

Non-Metallurgical Magnesia Production (Magnesite Use) (CRT Category 2.A.4.c)

Magnesite ore is processed to produce magnesia (MgO) at one facility in Canada, which has been operational throughout the entire time series. Emissions associated with the use of magnesite and other carbonates in metallurgical magnesium production are reported under CRT category 2.C.4.

Other Limestone and Dolomite Use (CRT Category 2.A.4.d)

Limestone and dolomite are used in several industrial applications in Canada, including the production of cement, lime, glass, and iron and steel. The emissions associated with these industrial applications are reported within their respective categories.

The emissions included in the Other Limestone and Dolomite Use category are associated with other applications, such as its use in pulp and paper mills as makeup lime, and other chemical uses, including FGD and wastewater treatment.

4.2.3.2. Methodological Issues

Glass Production (CRT Category 2.A.3)

National CO_2 emissions from Glass Production are calculated using a Tier 1 method that applies the stoichiometric carbon emission factors to the estimated quantities of soda ash and limestone consumed in the production of glass.

The fraction of total soda ash use that goes to glass production in the United States is applied to the total Canadian soda ash consumption to obtain the quantity of soda ash used for glass production in Canada. The quantity of limestone consumed in glass production is based on limestone production statistics collected by Natural Resources Canada.[10]

Ceramics Production (CRT Category 2.A.4.a)

To assess the significance of CO_2 emissions from Ceramics Production, a Tier 1 method was used to estimate emissions for 2005 to 2007 and for 2011 to 2024. For 2005 to 2007, national total annual amounts of clay used for ceramics were obtained from the *Canadian Minerals Yearbook* (NRCan, 1990–2008). A default carbon content of 10% was applied to the annual amount of clay used to determine the mass of carbonate consumed (M_c). The M_c for each year from 2005 to 2007 was then multiplied by 85% of the default emission factor for limestone calcination and by 15% of the default emission factor for dolomite calcination to estimate the CO_2 emissions per year. For 2011 to 2024, industrial process emission estimates were obtained from major Canadian manufacturers of structural clay products via the Greenhouse Gas Reporting Program. The emission estimates for 2005 to 2007 ranged from 45 kt CO_2 in 2006 to 54 kt CO_2 in 2007 and for 2011 to 2024 ranged from 23 kt CO_2 in 2014 to 52 kt CO_2 in 2017, which were below 0.05% of Canada's national total GHG emissions and did not exceed 500 kt CO_2 eq. Subsequently, CO_2 emissions from Ceramic Production are considered "insignificant" under paragraph 32 of the Modalities, procedures, and guidelines (MPGs) for the Enhanced Transparency Framework of the Paris Agreement.

Other Uses of Soda Ash (CRT Category 2.A.4.b)

National CO_2 emissions are calculated using a Tier 1 method that applies the stoichiometry-based emission factor of 415 g CO_2/kg soda ash to the national consumption data, assuming 100% purity of soda ash used in Canada.

Soda ash consumption data has been estimated based on soda ash production, import and export data.

Import and export data have been obtained from Statistics Canada's Canadian International Merchandise Trade Web Application (Statistics Canada, n.d.[f]). The total quantities of soda ash used have been distributed by application type, based on the U.S. pattern of soda ash consumption: glass, chemical, soaps and detergents, pulp and paper, FGD and other. Likewise, provincial emissions have been estimated by apportioning the national emissions according to the respective provincial gross output values of the same sectors.

Non-Metallurgical Magnesia Production (Magnesite Use) (CRT Category 2.A.4.c)

A Tier 1 method is used to estimate CO_2 process emissions from the use of magnesite in magnesia production. The method applies an emission factor of 522 g CO_2/kg magnesite, on the basis of the stoichiometric quantity of carbon available in the magnesite and assumes the purity of magnesite to be 97% (AMEC, 2006). The emission factor is multiplied by facility-specific activity data to estimate CO_2 emissions at provincial and national levels.

10 Data for 1990–2006 is available in the *Canadian Minerals Yearbook* (NRCan, 1990–2006). Subsequent data has been provided by Natural Resources Canada via personal communication.

The only magnesia production plant has been operational for the full reporting period (1990–2024) and its annual activity data is sourced from British Columbia's Ministry of Energy and Mines (British Columbia Geological Survey, 2025).

Other Limestone and Dolomite Use (CRT Category 2.A.4.d)

Different Tier methodologies are used for different years and applications of limestone and dolomite across the time series, based on available activity data. IPCC Tier 2 and 3 methods are used across the time series to estimate CO_2 emissions from limestone and dolomite separately and by application, using respective consumption data (Table 4–6) and emission factors, as described below.

Limestone and Dolomite as Flux in Iron and Steel Production

Emissions from limestone and dolomite used as flux in iron and steel production are reported under CRT category 2.C.1.f.

For the years 1990–2016, a Tier 2 methodology was used to estimate emissions from limestone and dolomite in iron and steel production, multiplying quantities of stone consumed (Table 4–6) by the corresponding emission factors, which vary depending on the year. Data on raw stone used as flux in iron and steel furnaces was gathered from the *Canadian Minerals Yearbook* (NRCan, 1990–2006) and directly from Natural Resources Canada via personal communication (2007–2016). The raw stone data was disaggregated between limestone and dolomite based on the average split of reported quantities of limestone and dolomite to Canada's Greenhouse Gas Reporting Program (GHGRP) for 2017–2023.

For 1990–2006, the emission factor used for Canadian limestone use is derived from the process stoichiometric ratio of 440 g of CO_2/kg of limestone used and is adjusted to consider a purity fraction of 95% (Derry Michener Booth and Wahl and Ontario Geological Survey, 1989). The Canadian emission factor is therefore 418 g CO_2/kg of limestone used (AMEC, 2006). An overall emission factor of 468 g CO_2/kg of dolomite used was derived based on the emission factors for pure limestone (440 kg CO_2/tonne) and magnesite (522 kg CO_2/tonne) and on the assumption that dolomite is composed of approximately 58% $CaCO_3$ and 41% $MgCO_3$ (AMEC, 2006).

For 2007–2016, emission factors for each stone were derived by taking the average of the emission factors for limestone and dolomite, described above, with the average emission factors for each stone for 2017–2024, calculated from the facility-reported data to the GHGRP.

A Tier 3 methodology was used to estimate emissions from limestone and dolomite used in iron and steel furnaces for years 2017 onwards. Quantities of limestone and dolomite reported by iron and steel facilities to the GHGRP were used as activity data (ECCC, 2025a). Reported carbon contents of limestone and dolomite from each facility were used respectively to calculate emissions, according to Equation 4–5, and summed to estimate national CO_2 emissions.

Equation 4–5

$$E_{CO_2,carbonate} = [(Q_L \times CC_L) + (Q_D \times CC_D)] \times 44/12$$

$E_{CO_2,\ carbonate}$	=	CO_2 emissions from carbonate (i.e., limestone, dolomite) used as flux in iron and steel production, kt CO_2
Q_x	=	Quantity of carbonate x (limestone or dolomite) consumed in iron and steel production, kt
CC_x	=	Carbon content of carbonate x (limestone or dolomite), kt C/kt carbonate
$44/12$	=	Multiplication factor for the mass of CO_2 emitted from each mass unit of total carbon used, kt CO_2/kt C

Limestone in Pulp and Paper Mills

For the years 1990–2017, an IPCC Tier 2 methodology was used to estimate emissions from limestone used in pulp and paper mills, by multiplying quantities of limestone consumed (Table 4–6) by the Canadian limestone emission factor. Data on raw limestone was gathered from the *Canadian Minerals Yearbook* (NRCan, 1990–2006) and directly from Natural Resources Canada via personal communication (2007–2017). The emission factor applied, 418 g CO_2/kg of limestone, is the Canadian limestone emission factor (AMEC, 2006), derived as described above.

An IPCC Tier 3 methodology was used to estimate CO_2 emissions from limestone used in pulp and paper mills for the years 2018 onwards. Emissions were calculated according to Equation 2.16 in Volume 3, Chapter 2 of the 2006 IPCC Guidelines, using the default fraction of calcination of 1.00 (IPCC, 2006). Quantities of limestone used, reported by pulp and paper facilities to the GHGRP, were used as activity data and the emission factor was derived from the default emission factor for limestone (0.43791 tonnes CO_2/tonne limestone) with a default 95% purity fraction.

Limestone in Non-Ferrous Smelters, Glass Factories, Other Chemical Uses

An IPCC Tier 2 methodology is used to estimate CO_2 emissions from limestone use in non-ferrous smelters, glass factories, and other chemical uses for the entire time series (1990–2024).

For the years 1990 through 2006, data on raw stone use in each application was gathered from the *Canadian Minerals Yearbook* (NRCan, 1990–2006). For subsequent years, information has been provided directly by Natural Resources Canada via personal communication. National CO_2 emissions are estimated by multiplying the quantities of limestone consumed (Table 4–6) by the Canadian limestone emission factor, 418 g CO_2/kg of limestone (AMEC, 2006), derived as described above. The emissions are subsequently allocated to the respective reporting categories of Glass Production (CRT category 2.A.3) and Other Limestone and Dolomite Use (CRT category 2.A.4.d).

The source of activity data does not provide a comprehensive breakdown of "other chemical uses." Therefore, this subcategory has been assumed to be 100% emissive and 100% composed of limestone and has been duly accounted for. Dolomite is usually less appropriate than limestone for most industrial applications, and most dolomite that is mined is crushed and sieved to be utilized as aggregate in concrete or asphalt (Bliss et al., 2008). Other markets of dolomite, such as glassmaking and agricultural use, are excluded from Canada's "other chemical uses" subcategory.

According to Canadian information,[11] only limestone is used for FGD processes in Canadian coal power plants.

Table 4–6 **High Calcium Limestone and Dolomite Consumption in Canada**

Year	2.C.1 Iron and Steel			2.A.3 Glass Production		2.A.4.d Other Process Uses of Carbonates					
	High-Calcium Limestone (kt)	Dolomite (kt)	IPCC Tier	High-Calcium Limestone (kt)	IPCC Tier	Pulp and Paper Mills		Non-Ferrous Smelters		Other Chemical Uses	
						High-Calcium Limestone (kt)	IPCC Tier	High-Calcium Limestone (kt)	IPCC Tier	High-Calcium Limestone (kt)	IPCC Tier
1990	384	272	T2	171	T2	214	T2	16	T2	846	T2
1991	288	203	T2	169	T2	220	T2	162	T2	964	T2
1992	329	233	T2	154	T2	231	T2	167	T2	264	T2
1993	116	82	T2	161	T2	224	T2	176	T2	244	T2
1994	111	79	T2	146	T2	234	T2	154	T2	587	T2
1995	180	127	T2	146	T2	130	T2	181	T2	436	T2
1996	174	123	T2	146	T2	134	T2	164	T2	711	T2
1997	194	138	T2	181	T2	117	T2	158	T2	915	T2
1998	230	162	T2	158	T2	89	T2	129	T2	857	T2
1999	230	162	T2	137	T2	96	T2	101	T2	522	T2
2000	398	282	T2	51	T2	118	T2	39	T2	928	T2
2001	279	198	T2	44	T2	69	T2	94	T2	680	T2
2002	151	107	T2	46	T2	57	T2	55	T2	927	T2
2003	165	117	T2	18	T2	62	T2	46	T2	939	T2
2004	122	87	T2	18	T2	75	T2	51	T2	1 109	T2
2005	127	89	T2	18	T2	80	T2	47	T2	1 175	T2
2006	117	83	T2	18	T2	173	T2	57	T2	1 057	T2
2007	58	41	T2	32	T2	41	T2	64	T2	1 178	T2
2008	186	132	T2	12	T2	15	T2	65	T2	1 182	T2
2009	152	108	T2	0	T2	36	T2	74	T2	923	T2
2010	183	130	T2	0	T2	41	T2	65	T2	423	T2
2011	293	207	T2	0	T2	40	T2	52	T2	508	T2
2012	445	315	T2	0	T2	31	T2	34	T2	521	T2
2013	366	259	T2	0	T2	30	T2	46	T2	342	T2
2014	593	420	T2	0	T2	40	T2	32	T2	364	T2
2015	725	512	T2	0	T2	37	T2	32	T2	356	T2
2016	662	468	T2	0	T2	36	T2	28	T2	350	T2
2017	324		T3	0	T2	45	T2	28	T2	196	T2
2018	425		T3	0	T2	44	T3	28	T2	201	T2
2019	222		T3	0	T2	32	T3	26	T2	189	T2
2020	179		T3	0	T2	42	T3	22	T2	204	T2
2021	248		T3	0	T2	39	T3	21	T2	207	T2
2022	174		T3	0	T2	36	T3	19	T2	210	T2
2023	181		T3	0	T2	36	T3	17	T2	203	T2
2024	272		T3	0	T2	37	T3	16	T2	205	T2

Note: Quantities of limestone and dolomite for 2017–2024 are aggregated to protect confidentiality.

11 Cook S. 2013. Personal communication (email from Cook S to Edalatmanesh M, Environment Canada dated November 18, 2013). Canadian Electricity Association.

Provincial emission estimates have been obtained by apportioning the national emissions according to the sum of the provincial gross output values for the major sectors in which limestone and dolomite have been used (i.e., pulp and paper, non-ferrous metal, glass, and chemical sectors) for the applications and years where a Tier 2 methodology is applied. For applications and years where a Tier 3 methodology is applied, provincial emission estimates are based on facility-reported data to the GHGRP.

4.2.3.3. Uncertainty Assessment and Time-series Consistency

Tier 1 uncertainty assessments were performed for the categories of Glass Production, Other Uses of Soda Ash, Non-Metallurgical Magnesia Production, and Other Limestone and Dolomite Use. The uncertainty assessments considered uncertainties associated with consumption data, production data, import and export data, emission factors, and assumptions, where applicable. Uncertainties associated with each category are outlined in Table 4–7. No uncertainty assessment was performed for the category of Ceramics Production because this category was determined insignificant under paragraph 32 of the MPGs, as described in section 4.2.3.2.

To retain time series consistency in the categories of Glass Production, Other Uses of Soda Ash, and Non-Metallurgical Magnesia Production, the same emission factors have been consistently applied over the time series for each respective category. The respective activity data sources and emission factors are described in section 4.2.3.2.

To address time-series consistency between the Tier 2 method applied for 1990–2016 and Tier 3 method applied for 2017 onwards for limestone and dolomite used as flux in iron and steel production, splicing techniques were assessed from Volume 1, Chapter 5, section 5.3.3 (IPCC, 2006) and a modified average splicing technique was chosen as being the most suitable. Emission factors for 1990–2006 were applied based on a study completed in 2006 (AMEC, 2006), and emission factors for 2007–2016 were an average of the values established in 2006 and the emission factors calculated from facility-reported data to the GHGRP for 2017–2024. Activity data sources and emission factors are described in section 4.2.3.2.

For limestone used in pulp and paper mills, the Tier 2 method applied for 1990–2017 and the Tier 3 method applied for 2018 onwards retain time-series consistency. The emission factor used for the Tier 2 method, calculated for Canadian limestone (AMEC, 2006), is equivalent to the emission factor calculated using the method outlined in the 2006 IPCC Guidelines (IPCC, 2006) that is applied for the Tier 3 method. Activity data sources are provided in section 4.2.3.2.

The same emission factor has been consistently applied over the time series for all other applications of limestone use. The activity data source is provided in section 4.2.3.2.

Table 4–7 **Summary of Uncertainty Assessments for Mineral Product Use Categories**

Category	CRT Category	Uncertainty Assessment Tier level	Gas	Uncertainty Range	Year Range
Glass Production	2.A.3	Tier 1	CO_2	±7.2% to ±10.2%	1990–2024
Ceramics Production	2.A.4.a	NA	NA	NA	NA
Other Uses of Soda Ash	2.A.4.b	Tier 1	CO_2	±5.9% to ±7.5%	1990–2024
Non-Metallurgical Magnesia Production (Magnesite Use)	2.A.4.c	Tier 1	CO_2	±8.1%	1990–2024
Other Limestone and Dolomite Use	2.A.4.d	Tier 1	CO_2	±15.4% to ±38.0%	1990–2024

Note:
NA = Not applicable, category was not assessed for uncertainty as emissions from this category were determined insignificant.

4.2.3.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for this category.

4.2.3.5. Recalculations

For the Other Uses of Soda Ash category, updates to the activity data resulted in an increase of less than 1 kt CO_2 for the 2022 data year.

For the Other Limestone and Dolomite Use category, recalculations for 2020-2023 were a result of updated facility reports to the GHGRP and updated proxy data, and ranged from +4 kt CO_2 in 2021 to +7 kt CO_2 in 2022.

4.2.3.6. Planned Improvements

No improvements are currently planned for this category.

4.3. Chemical Industry (CRT Category 2.B)

4.3.1. Ammonia Production (CRT Category 2.B.1)

4.3.1.1. Category Description

Ammonia Production (CRT category 2.B.1) accounted for 2291 kt (0.3%) of Canada's emissions in 2024. This category accounts for CO_2 emissions from feedstock use (typically natural gas) in the steam methane reformation (SMR) process, CO_2 emissions recovered for urea production, and CO_2 emissions recovered for carbon capture and storage (CCS) activities. SMR may use natural gas as energy to drive the process of generating hydrogen, an essential feedstock for the Haber-Bosch process in the production of ammonia. Natural gas can also be used as feedstock for the SMR process to provide a source of hydrogen. In both uses, most of the carbon in natural gas ends up as CO_2 emissions. GHG emissions (CO_2, nitrous oxide [N_2O], and methane [CH_4]) from the energy use of natural gas in SMR process and GHG emissions from fuels used in non-SMR ammonia production processes are accounted for in the Energy sector.

There are currently nine ammonia production plants operating in Canada, located in Alberta, Saskatchewan, Manitoba and Ontario (Fertilizer Canada, 2023). One plant uses by-product hydrogen (purchased from a neighbouring chemical plant) to feed into the Haber-Bosch reaction and is therefore assumed to have negligible process-related CO_2 emissions. Eight plants use steam-methane reformers to produce ammonia, of which most recover CO_2 emissions to produce urea. Two of the eight SMR plants conduct carbon capture and storage (CCS) activities.

Urea production is a downstream process associated with ammonia production plants. The process recovers and uses the by-product CO_2 stream from the ammonia synthesis process. To avoid overestimation of CO_2 emissions, the use of recovered CO_2 in urea production is accounted for as part of estimations for this category (see Equation 4–6). The use of urea as a fertilizer and its associated emissions are reported in the AFOLU sector, as per Box 3.2 of 2006 IPCC Guidelines, Volume 3, Chapter 3. Emissions from use of urea-based additives in catalytic converters are discussed in section 4.5 and reported in CRT category 2.D.3. Other uses of urea (e.g., its use as an ingredient in manufacturing of resins, plastics or coatings) are reported in CRT category 2.B.10.

Two SMR facilities recover CO_2 emissions for enhanced oil recovery (EOR). Recovered emissions from CCS activities are deducted from gross ammonia production emissions in the calculation of net ammonia production emissions (see Equation 4–6), as per Box 3 of Figure 3.1 in the 2006 IPCC Guidelines, Volume 3, Chapter 3.

4.3.1.2. Methodological Issues

To calculate the net national emissions from ammonia production, Equation 4–6 is used.

Equation 4–6 **CO_2 Emissions from Ammonia Production**

$$E_{CO2} = \sum_i \frac{44}{12} \times NG_i \times CC_i \times COF - E_{CO2Urea\,i} - E_{CCS\,i}$$

E_{CO2}	=	national emissions of CO_2, kt
NG_i	=	natural gas used as feed of facility i, m^3
CC_i	=	carbon content factor of facility i, kt carbon/m^3 of natural gas
$44/12$	=	ratio of molecular weights, CO_2 to carbon
COF	=	carbon oxidation factor = 1 (unitless)
$E_{CO2Urea\,i}$	=	CO_2 recovered for urea production of facility i, kt
$E_{CCS\,i}$	=	carbon capture and storage for facility, i, kt

For 1990 to 2017

For 1990 to 2017, a Tier 2 country-specific method is applied. The feedstock use of natural gas is determined by multiplying the annual ammonia production by the calculated ammonia-to-feed fuel conversion factor that is specific to each facility. The data sources for annual ammonia production and other activity data for 1990 to 2017 are summarized in Table 4–8. The ammonia-to-feed fuel conversion factors were developed from the facility-level data collected between 2005 and 2009 as part of the voluntary data submission. For the 2005–2009 period, there were nine plants in operation (two others stopped operating in 2005). Seven of the nine plants (two of which have 2 SMR units each) provided ammonia-to-feed fuel factors. These facility-specific ammonia-to-feed fuel factors are considered confidential and are therefore not published. Based on the data collected, the average ammonia-to-feed fuel factor was calculated to be 671 m^3 of natural gas/tonne of NH_3 produced, and was used to estimate emissions for one SMR facility that did not participate in the voluntary data collection. The remaining facility does not use the SMR process. At the plant level, the variability of the ammonia-to-feed fuel conversion factor is very steady, varying by less than 0.001% from year to year over the five years. Similarly, the average value varied by less than 0.001% from year to year over the five years.

Table 4–8 **Description of Activity Data Sources used in Ammonia Production Emission Estimation (1990–2017)**

Facility ID	Ammonia Production	Summary of Natural Gas Carbon Content	Urea Production[c]
A	1990–2004: Cheminfo Services (2006) 2005–2009: Voluntary Data collection 2010–2017: ICSR[a]	Facility confirmed the use of the average of 2018–2020 carbon contents reported to the GHGRP to be suitable.	1990–2007: Derived from facility values 2008–2017: ICSR
B	1990–2004: Cheminfo Services (2006) and derived based on known facility capacity and utilization 2005–2009: Voluntary Data collection 2010–2017: ICSR	Facility provided facility-specific average carbon content value (based on 1998–2017 values).	1990–2007: Derived from facility values 2008–2017: ICSR
C	1990–2004: Cheminfo Services (2006) and derived based on known facility capacity and utilization 2005–2009: Voluntary Data collection 2010–2017: ICSR	Facility provided facility-specific average carbon content value (based on 2003–2017 values).	1990–2007: Derived from facility values 2008–2017: ICSR
D	1990–2004: Cheminfo Services (2006) and derived based on known facility capacity and utilization 2005–2009: Voluntary Data collection 2010–2017: ICSR	Facility provided facility-specific average carbon content value (based on 2004–2017 values).	1990–2007: Derived from facility values 2008–2017: ICSR
E	1990–2004: Cheminfo Services (2006) and derived based on known facility capacity and utilization 2005–2009: Voluntary Data collection 2010–2017: ICSR	For 1990-2009, facility confirmed the use of the average of 2018–2020 carbon contents reported to the GHGRP to be suitable. For subsequent years, year-specific carbon content values were provided.[b]	1990–2007: Derived from facility values 2008–2017: ICSR
F	1990–2004: Cheminfo Services (2006) 2005–2009: Voluntary Data collection 2010–2017: ICSR	For 1990-2007, facility provided facility-specific average carbon content value (based on 2008–2012 values). For subsequent years, year-specific carbon content values were provided.	1990–2007: Derived from facility values 2008–2017: ICSR
G	1990-2004: Cheminfo Services (2006) 2005–2009: Voluntary Data collection 2010–2017: ICSR	Facility confirmed the use of the average of 2018–2020 carbon contents reported to the GHGRP to be suitable.	1990–2007: Derived from facility values 2008–2017: ICSR
H	1990–2012: Derived based on known facility capacity and utilization 2013–2017: ICSR	Facility suggested the use of annual provincial carbon content values. Internally developed annual and province-specific carbon content values found in Table A6.1–1 were used.	1990–2007: Derived from facility values 2008–2017: ICSR

Notes:
a. Statistics Canada's Industrial Chemicals and Synthetic Resins Survey (ICSR) (Statistics Canada, n.d.[c])
b. Facility E provided carbon content values in KgC/KgFeedstock from 2010 to 2017. These values were converted to KgC/KlFeedstock based on the average of 2018–2020 reference temperature, the average of 2018–2020 pressure reported to the GHGRP and facility-specific molecular mass of natural gas provided by the facility from 2010 to 2017. The use of 2018–2020 average temperature and pressure have been confirmed to be suitable by the facility.
c. Urea production from 1990 to 2007 derived from actual ammonia production and the respective average ratio of ammonia-to-urea production for each plant taken over data years 2008–2013.

All eight active SMR facilities have voluntarily confirmed or provided the natural gas carbon content values used for estimating emissions for 1990 to 2017, as summarized in Table 4–8. In general, natural gas carbon contents do not vary significantly from year to year and from facility to facility. The range of facility-confirmed natural gas content values is 0.49 to 0.54 kgC/kl feedstock, which is comparable to the values obtained through the GHGRP.

For 1990 to 2017, the amount of CO_2 consumed in the production of urea is quantified using a stoichiometric quantity of 0.733 kg CO_2/kg urea. Sources of plant-specific urea production used from 1990 to 2017 are summarized in Table 4–8.

For 2018 and after

For the years 2018 and after, a Tier 3 method is applied in accordance with the 2006 IPCC Guidelines (IPCC, 2006). More specifically, facility-level data (including natural gas used as feedstock, natural gas carbon content, CO_2 recovered and used for urea production) from the federal Greenhouse Gas Reporting Program (GHGRP) were used.

Carbon capture and storage

Two of the eight SMR facilities conduct CCS activities, and emissions recovered for CCS activities are estimated since 1990. Facilities were identified as being involved in CCS activities through the reporting of emissions under "Other Recovered CO_2" in the GHGRP and additional communication to confirm the activities/uses of the recovered emissions. Both facilities engage in CO_2 recovery through EOR. Table 4–9 summarizes the CCS and other carbon recovery activities for each facility using SMR. The facilities were contacted again in 2025 and confirmed that there have been no changes in their CCS activities.

Finally, the quantity of natural gas used to produce hydrogen for ammonia production was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double counting, the natural gas amounts allocated by Statistics Canada for hydrogen production are systematically removed from the non-energy use of natural gas reported under the Non-Energy Products from Fuels and Solvent Use category (refer to section A3.3.2, Non-energy Products from Fuels and Solvent Use). Since disaggregated activity data (i.e., natural gas used as feedstock and for energy purposes) are available, GHG emissions (CO_2, nitrous oxide [N_2O], and methane [CH_4]) resulting from the energy use of natural gas are accounted for in the Energy sector.

Table 4–9 **Summary of Carbon Capture and Storage and CO_2 Recovery Activities**

Facility ID	CCS or CO_2 Recovery Summary
A	No past, current or planned CCS activities. Facility recovers CO_2 and sends it off-site to a nearby greenhouse. Activity does not qualify as CCS, as the emissions recovered do not go to a long-term storage. Furthermore, the recovered CO_2 sent to greenhouse is not expected to be accounted for elsewhere in the NIR. Therefore, it is not subtracted from the ammonia emission estimate.[a]
B	Facility has been exporting carbon dioxide to the Alberta Carbon Trunkline since 2019 and this CO_2 is used in enhanced oil recovery. It is expected that the CO_2 stays underground upon its use; therefore, it is subtracted from the ammonia emission estimate.
C	No past, current or planned CCS activities.
D	No past, current or planned CCS activities.
E	Facility sends recovered CO_2 to third party company over the past 30-40 years. The company uses approximately 20% of the recovered CO_2 in enhanced oil recovery. It is expected that the CO_2 stays underground upon its use; therefore, the portion allocated to CCS is subtracted from the ammonia emission estimate.
F	No past, current or planned CCS activities.
G	No past, current or planned CCS activities.
H	No past, current or planned CCS activities. Facility recovers CO_2 and sends off-site for use in third party industry to which facility has no control over. Because there is no clear indication that the recovered CO_2 gets sent to a long-term storage, it is not subtracted from the ammonia emission estimate.[b]

Notes:
a. Volume 3, section 1.2.2 of the 2006 IPCC Guidelines explains that "quantities of CO_2 for later use and short-term storage should not be deducted from CO_2 emissions, except when the CO_2 emissions are accounted for elsewhere in the inventory."
b. Ibid

4.3.1.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for the category of Ammonia Production. The assessment considers the uncertainties associated with the ammonia and urea production, ammonia-to-feed fuel conversion factor, feedstock volumes, and carbon content of natural gas. The uncertainty values associated with CO_2 emissions from the category vary over the time series from 6.2% to 8.8%.

To ensure time-series consistency, operating facilities were contacted and requested to confirm on a voluntary basis the suitability of the use of 2018 to 2020 facility-specific natural gas carbon content values for emission estimations of 1990 to 2017. As a result of this communication, either confirmation or year- and facility-specific values were obtained. Further details are provided in section 4.3.1.2.

4.3.1.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for this category. In addition, category-specific checks were done to confirm CO_2 recovery activities at facilities and ensure that only CSS-related emissions were deducted when quantifying ammonia production emissions.

4.3.1.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

4.3.1.6. Planned Improvements

No improvements are currently planned for this category.

4.3.2. Nitric Acid Production (CRT Category 2.B.2)

4.3.2.1. Category Description

Nitric acid is a chemical intermediate that is commonly used to produce ammonium nitrate fertilizers or explosives. As shown in Table 4–10, 14 nitric acid production lines (plants) at 9 facilities have operated during the time series (Cheminfo Services, 2006). Since 2005, national nitric acid production has decreased by 23%, mainly due to the closure of all plants at the Dyno Nobel Nitrogen Inc. facility in Maitland, ON in 2010. In 2024, 8 plants were operational at 5 facilities.

The Nitric Acid Production category accounted for 129 kt CO_2 eq of Canada's emissions in 2024, an 88% decrease from 2005. This decrease is driven by the installation of secondary and tertiary nitrous oxide (N_2O) abatement technologies at the Orica Canada Inc. Carseland Works facility. All operational plants in Canada currently have N_2O abatement systems installed.

Nitric acid is produced in two stages. In the first stage, ammonia is catalytically oxidized on a platinum-rhodium gauze, which produces nitrogen oxides, notably, nitrogen dioxide. In the second stage, the nitrogen dioxide is then absorbed into water in an absorption tower to produce nitric acid. During the oxidation of ammonia, some N_2O is produced as a by-product.

There are two nitric acid production process types used in Canada: high pressure and dual pressure. The high-pressure design, commonly used in North America, applies a single pressure throughout the oxidation and absorption stages (Cheminfo Services, 2006). Dual pressure plants use a lower pressure for the reaction stage and higher pressure for the absorption stage (Cheminfo Services, 2006). To increase the efficiency of the absorption stage, plants can 'extend' the absorption tower by adding more trays. In Table 4–10, this is referred to as 'Extended Absorption Type 1' (Cheminfo Services, 2006). Plants can also have a second tower in place to allow for 'double absorption'. This is referred to as 'Extended Absorption Type 2' in Table 4–10 (Cheminfo Services, 2006).

The most commonly used N_2O abatement technology type at Canadian plants are non-selective catalytic reduction systems. The emission abatement systems are classified as 'non-selective' when a reductant such as natural gas or ammonia purge gas is used to reduce nitrogen oxides (NO_x) and nitrous oxide (N_2O). In contrast, a selective catalytic reduction system uses ammonia and reacts with N_2O only (Perez-Ramirez et al., 2003). Catalytic reduction systems are installed downstream of the absorption tower tail-gases. They are a considered a tertiary abatement measure when they are installed between the absorption column and the tail-gas expansion turbine, and a quaternary or end-of-pipe solution when installed downstream of the tail-gas expansion turbine prior to the stack (IPCC, 2006). 6 of the 8 active plants have employed non-selective catalytic reduction systems since 1990 or since their startup (Cheminfo Services, 2006). In 2021, a tertiary selective catalytic reduction system was retroactively installed at plant 1 at the Orica Canada Inc. Carseland Works site.[12] This installation is the main driver for an emission decrease of 33% in this category between 2021 and 2022.

Process-gas catalytic decomposition systems are also employed in some Canadian nitric acid production plants. These systems are a secondary abatement measure that consist of catalysts installed underneath the ammonia burner that catalyze the N_2O formed during the ammonia oxidation reaction. These systems were installed retroactively in the two plants at Orica Canada Inc.'s Carseland Works in 2008 and 2012 (Orica Canada Inc., 2014, 2016). These installations are responsible for most of the emission decrease observed since 2005 in this category. Figure 4–1 shows the production and emission trends for the category.

4.3.2.2. Methodological Issues

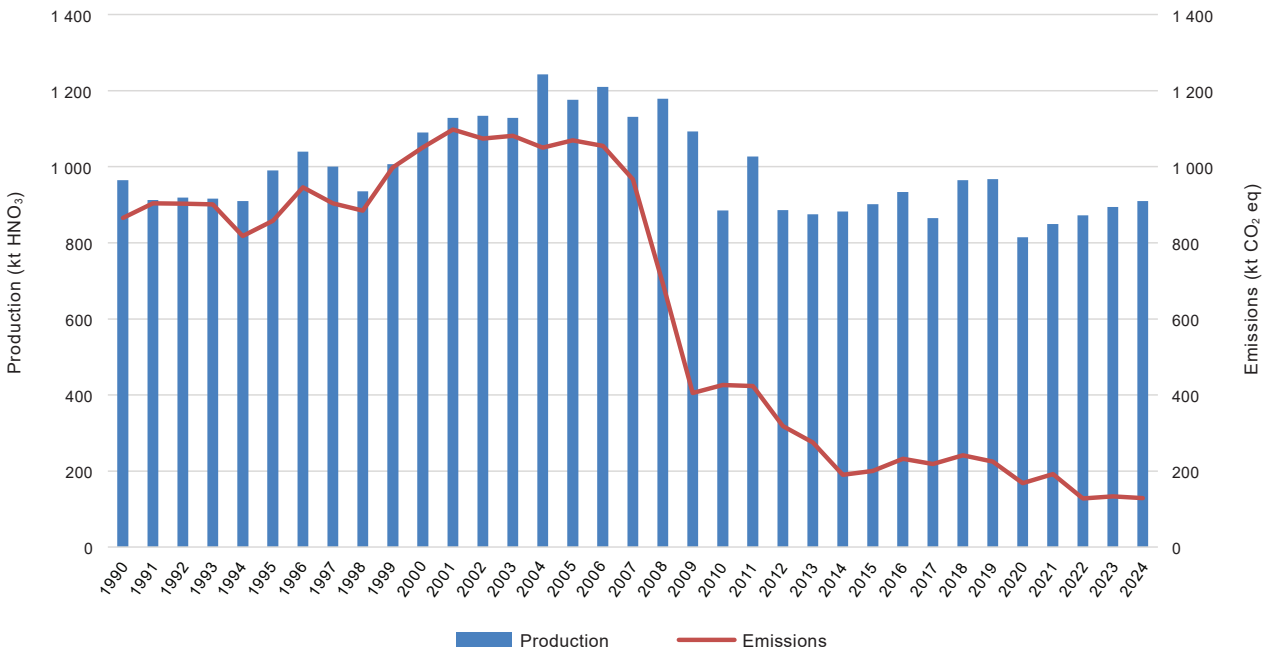
A mix of Tier 3, Tier 2, and Tier 1 methods were used in the estimation of N_2O from Nitric Acid Production. Higher tiers were used when possible, depending on the availability of data:

1. Tier 3 method: use of plant-specific production data and plant-specific emission factors or continuous emission monitoring system (CEMS) data when these were available from companies.
2. Tier 2 method: use of facility-specific (combined from multiple nitric acid plants at the same facility) or plant-specific production data and technology-specific emission factors that are provided by plant technology vendors or national technology-specific average values.
3. Tier 1 method: use of estimated production data and either plant-specific or technology-specific emission factors.

Table 4–10 describes the nitric acid industry in Canada and the methods used in compiling the estimates on a facility-specific basis.

12 Orica Canada Inc. 2024. Personal communication (email from Orica Canada Inc. to Greenhouse Gas Reporting Program dated September 10, 2024). Orica Canada Inc.

Figure 4–1 **Nitric Acid Production and N_2O Process Emission Trends**



For 1990–2004, plant activity data were from the 2006 Cheminfo study (Cheminfo Services, 2006) when they were possible to collect. To fill in missing activity data gaps, plant capacities from the Cheminfo study and national production quantities from Statistics Canada's Industrial Chemicals and Synthetic Resins (ICSR) survey were used to estimate production as shown in Equation 4–7 (Cheminfo Services, 2006):

Equation 4–7

$$\textit{Estimated Production, plant } i = \left(\textit{National production} - \sum \textit{reported plant data}\right) \times \frac{\textit{Production capacity of plant } i}{\sum \textit{Production capacities for nonreporting plants}}$$

For 2005–2009, activity data was reported by companies to ECCC on a voluntary basis. Missing data from the voluntary survey was filled in using facility-level ICSR survey data when available. Rarely, when plant or facility-level data was unavailable from voluntary surveys and the ICSR, Equation 4–7 was used to estimate production.

For 2010 onwards, facility-level production data was primarily obtained from the ICSR survey. In certain cases, plant-level production data from the Greenhouse Gas Reporting Program (GHGRP) or separate company data requests were used when facility-reported ICSR data did not pass quality control checks. This included instances when companies did not report on a calendar year basis, or when companies reported outlier production values that exceeded their production capacity.

Tier 3 plant-specific emission factors or CEMS data were used to estimate emissions from five plants when available and applicable to the specific years of activity data. Those for years prior to 2005 were collected from facilities during the 2006 Cheminfo study (Cheminfo Services, 2006). CEMS systems were installed during the installation of process-gas catalytic decomposition emission control systems at the Orica Canada Inc. Carseland Works site in 2008 and 2012. Facility-provided CEMS data was collected in conjunction with the GHGRP and has been used to estimate emissions for all years since installation. For years where a Tier 3 method could not be applied due to lack of emission factor data, a Tier 2 method was used, using technology-specific emission factors provided by plant equipment vendors or the Canadian Fertilizers Institute. To ensure that confidential plant- or facility-specific production data is fully protected, it is not possible to specifically associate emission factors with the plants. A weighted average emission factor for 2024 is available in Table A6.2–3.

Table 4–10 **Nitric Acid Production Facilities in Canada**

Company	Location	Production Lines	Years in Operation during Time-Series	Process Type[a]	N_2O Emission Controls[b]	Production Data		Emission Factors		Emission Estimate Quality
						Estimated (allocation of national production)	Facility data	Country-specific (CS) or technology-specific	Facility data	IPCC Tier
Cominco Inc.	Calgary, AB	1	1990–1994	DP (M/H), EA2	None	1990–1994	N/A	1990	N/A	T1 (1990–1994)
Cyanamid Canada	Niagara Falls, ON	1	1990	HP	NSCR	1990	N/A	1990–1994	N/A	T1 (1990)
Dyno Nobel Nitrogen Inc.	Maitland, ON	3	1990–2010	HP	NSCR	N/A	1990–2010	1990–2010	N/A	T2 (1990–2010)
Koch Fertilizer Canada, ULC	Brandon, MB	3	Plant 1: 1990–present Plant 2: 1994–present Plant 3: 1997–present	HP	NSCR	1991–1999, 2007	1990, 2000–2006, 2008–present	1990–present	N/A	T1 (1991–1999, 2007) T2 (1990, 2000–2006, 2008–present)
Nutrien (Canada) Holdings ULC.	Redwater, AB	1	1990–present	HP	NSCR	1991–1999	1990, 2000–present	2005–present	1990–2004	T1 (1991–1999) T2 (2005–present) T3 (1990, 2000–2004)
Orica Canada Inc.	Carseland, AB	2	Plant 1: 1990–present Plant 2: 1999–present	Plant 1: DP (M/H), EA1 Plant 2: HP	Plant 1: None (1990–2008), PGCD (2008–2021), PGCD & SCR (2021–present) Plant 2: None (1999–2012), PGCD (2012–present)	N/A	1990–present	Plant 1: 1990–2008 Plant 2: 1999–2012	Plant 1: 2008–present Plant 2: 2012–present	Plant 1: T2 (1990–2008), T3 (2008–present) Plant 2: T2 (1999–2012), T3 (2012–present)
Orica Canada Inc.	Beloeil, QC	1	1990–1999	HP, EA2	NSCR	1990–1999	N/A	1990–1999	N/A	T1 (1990–1999)
Terra International (Canada) Inc.	Courtright, ON	1	1990–present	HP	NSCR	N/A	1990–present	2005–present	1990–2004	T2 (2005–present) T3 (1990–2004)
Yara Belle Plaine Inc.	Belle Plaine, SK	1	2004–present	HP	NSCR	N/A	2004–present	2005–present	2004	T2 (2005–present) T3 (2004)

Notes:

a. Process types use the definitons in the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019), and were determined from facility information collected during the Cheminfo Services (2006) study.

b. N_2O emission controls are aligned with the definitions in the 2006 IPCC Guidelines (IPCC, 2006). Information on emission controls employed at facilities were collected during the Cheminfo Services (2006) study and from offset project verification reports (Orica Canada Inc., 2014, 2016). Information on the 2021 SCR installation at plant 1 of the Carseland, AB site was verified by Orica Canada Inc. in 2024.

HP = Single high-pressure of 6.5–13 bar, held constant through oxidation and absorption stages (IPCC, 2019).

DP (M/H) = Dual-pressure, with a medium applied pressure of 1.7 - 6.5 bar in the oxidation stage and a high applied pressure of 6.5 - 13 bar in the absorption stage (IPCC, 2019).

EA1 = Extended absorption by adding more trays in the absorption tower (Cheminfo Services, 2006).

EA2 = Extended absoprtion through the use of two absoprtion towers (Cheminfo Services, 2006).

N/A = Not applicable

NSCR = Non-selective catalytic reduction system located downstream of the absorption stage (reducing both NO_X and N_2O emissions) (IPCC, 2006).

PGCD = Process-gas catalytic decomposition (located beneath the ammonia burner used for the oxidation stage) (IPCC, 2006).

SCR = Selective catalytic reduction system located downstream of the absorption stage (reducing N_2O emissions only) (Perez-Ramirez et al., 2003)

4.3.2.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for the category of Nitric Acid Production. It considers the uncertainties associated with the national, facility, and plant-specific nitric acid production data, the production allocation process (when applicable) and emission factors. The uncertainty values associated with N_2O emissions range from ±3% to 10% and generally decrease across the time-series with the availability of detailed production and emissions data.

All activity data is derived from facility-reported production data. When individual facility-level data is unavailable, production data is estimated using national total production data, which is compiled from facility-level data reporting to the ICSR.

When plant- and year-specific Tier 3 emission factors are unavailable, plant equipment vendor or technology-specific emission factors (Tier 2) are used for estimating facility emissions. In general, the plant- and year-specific emission factors fluctuate upwards and downwards from the technology-specific emission factors, confirming the validity of the Tier 2 emission factors as an appropriate average. Input from facilities indicates that it is inappropriate to use plant- and year-specific emission factors for other years in the time-series, since plant emission factors can fluctuate over time depending on the age of abatement catalysts and other factors. Therefore, the Tier 2 emission factors serve as an average and are used in the absence of year-specific emission factors.

4.3.2.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for this category. In addition, the following category-specific checks were done:

- Ensure that activity data are for 100% nitric acid product and are reported on a calendar year basis.
- Check new or revised activity data and CEMS-implied emission factors for unexplained inter-year differences that are greater than 10%, and contacting data sources for verification and explanation as required.
- Check that the sum of allocated activity data and the sum of facility-reported activity data sums to the published national activity data total (when applicable).
- Check plant-specific emission factors, CEMS-implied emission factors, and technology-specific emission factors against those reported for similar plants and circumstances in other national inventories and the IPCC Emission Factor Database.

4.3.2.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

4.3.2.6. Planned Improvements

N_2O emissions for most facilities from 2005 onwards are calculated using technology-specific (Tier 2) emission factors (IPCC, 2006). ECCC is working with nitric acid producers to receive high-quality up-to-date N_2O emission factors for use in Tier 3 calculations.

ECCC is also working with nitric acid producers to receive information on CO_2 and CH_4 process emissions from the use of reducing agents in catalytic reduction systems.

4.3.3. Adipic Acid Production (CRT Category 2.B.3)

4.3.3.1. Category Description

Invista Canada, formerly Dupont Canada, located in Maitland, Ontario, operated the only adipic acid production facility in Canada. A catalytic N_2O abatement system with an emission monitoring system was started up in 1997. However, the plant has not produced adipic acid since the spring of 2009; hence for years after 2009, both N_2O and CO_2 are indicated as “NO” in the CRT.

4.3.3.2. Methodological Issues

Emission estimates for adipic acid production were provided by the facility. For the 1990–1996 period, when no emission controls were in place, the reported emission estimates were calculated by multiplying the annual adipic acid production by the IPCC default generation factor of 0.3 kg N_2O/kg adipic acid.

Since 1997, the total emissions for the category are the sum of two modes of operation, either with or without an abator, as shown in Equation 4–8. The estimated emissions that occur when the abator is operating (Equation 4–9) are calculated separately from emissions that occur when the abator is not operating (Equation 4–10) due to maintenance or technical problems.

Equation 4–8

$$\textit{Total Emissions (t)} = \textit{N}_2\textit{O Emissions (t) with abator} + \textit{N}_2\textit{O Emissions (t) without abator}$$

N_2O Emissions with Abator:

Equation 4–9

$$\boldsymbol{N_2O\ Emissions\ (t)\ with\ Abator} = \left(\boldsymbol{Production(t)}\right) \times \left(\frac{\boldsymbol{0.3t\ N_2O}}{\boldsymbol{t\ adipic\ acid}}\right) \times \left(\boldsymbol{1 - Destruction\ Efficiency}\right) \times \left(\boldsymbol{Abatement\ Utilization\ Ratio}\right)$$

$\boldsymbol{Destruction\ Efficiency}$ = determined on the basis of the difference between the amount of N_2O entering the abatement unit and that leaving the unit—it is a monthly average calculated using values recorded by analyzers located at the inlet and outlet of the abator—the targeted instantaneous destruction efficiency is 97%

$\boldsymbol{Abatement\ Utilization\ Ratio}$ = number of hours during which N_2O goes through the abator divided by the total operating time

N_2O Emissions without Abator:

Equation 4–10

$$\boldsymbol{N_2O\ Emissions\ (t)\ without\ Abator} = \left(\boldsymbol{Production(t)}\right) \times \left(\frac{\boldsymbol{0.3t\ N_2O}}{\boldsymbol{t\ adipic\ acid}}\right) \times \left(\boldsymbol{1 - Abatement\ Utilization\ Ratio}\right)$$

$\boldsymbol{Abatement\ Utilization\ Ratio}$ = number of hours during which N_2O goes through the abator divided by the total operating time

It is important to note that the in-line continuous emission monitor has never been used to directly monitor net N_2O emissions. This is because the analyzer is limited to accurately measuring relatively low concentrations of N_2O only when the reactor is online and abating N_2O gas. The analyzer cannot measure the full range of N_2O concentrations that could potentially exist in the stack. The N_2O concentration can vary from a low nominal level of 0.3% when the stream leaves the abator to a high nominal level of 35% to 39% N_2O in the unabated stream. When the abatement reactor is bypassed, there is no N_2O abatement occurring and the analyzer will not record N_2O stack emissions (Cheminfo Services, 2006).

The calculation technique used to estimate emissions for the 1990–1997 period is in accordance with the Tier 1 method of the 2006 IPCC Guidelines (IPCC, 2006). For the period between 1998 and 2009, the estimation methods used for emissions with and without the abator aligned with a Tier 3 method when data was provided directly by the facility, otherwise a Tier 2 method was implemented (IPCC, 2006).

4.3.3.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for the category of Adipic Acid Production. It considers the uncertainties associated with the adipic acid production data, the emission factor, the destruction efficiency and the abatement utilization factor. The uncertainty associated with the category is evaluated at ±11%, with the emission factor being the largest contributor. The uncertainty value is applicable to all years of the time series.

As explained in section 4.3.3.2, two methods are applied in the time series: one for the period during which the plant operated **with** the emission abatement system and another for the period during which the plant operated **without** the emission abatement system.

4.3.3.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for this category.

4.3.3.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

4.3.3.6. Planned Improvements

No improvements are currently planned for this category.

4.3.4. Petrochemical and Carbon Black Production (CRT Categories 2.B.8 and 2.B.10)

4.3.4.1. Category Description

The categories under Petrochemical and Carbon Black Production (CRT Categories 2.B.8 and 2.B.10) include Methanol Production (CRT category 2.B.8.a and CRT category 2.B.10), Ethylene Production (CRT category 2.B.8.b and CRT category 2.B.10), Ethylene Dichloride Production (CRT category 2.B.8.c), Ethylene Oxide Production (CRT category 2.B.8.d), Carbon Black Production (CRT category 2.B.8.f and CRT category 2.B.10), and Styrene Production (CRT category 2.B.8.g).

In 2024, Petrochemical and Carbon Black Production accounted for 3170 kt CO_2 eq (0.5%) of Canada's emissions, a decrease of 19% in emissions since 2005.

Methanol Production (CRT Category 2.B.8.a and CRT Category 2.B.10)

There were three methanol production facilities operating in Canada between 1990 and 2006. One was closed in 2001, another in 2005 and the last in 2006. Methanol production in Canada ceased in 2006 but resumed in 2011 at one location.

Process GHG (CO_2, methane [CH_4] and N_2O) emissions result from process off-gas that is separated from methanol and combusted on-site for energy recovery. The process off-gas contains excess CO, CO_2 and light hydrocarbons. Additional CH_4 emissions can occur in venting of process gases from the methanol distillation train and methanol storage tanks and from fugitive emissions from equipment leaks (Cheminfo Services 2010). N_2O emissions are reported in CRT category 2.B.10 Other (Methanol Production – N_2O Emissions).

Ethylene Production (CRT Category 2.B.8.b and CRT Category 2.B.10)

There were five ethylene facilities in operation in Canada between 1990 and 2024, one of which began operating in 1994 and another of which shut down in 2008. The facilities consume fuels such as ethane and propane in the production of ethylene through steam cracking. Process CO_2 and CH_4 emissions are reported in CRT category 2.B.8.b and N_2O emissions are reported in CRT category 2.B.10 Other (Ethylene Production – N_2O Emission).

Ethylene Dichloride Production (CRT Category 2.B.8.c)

Three ethylene dichloride production (EDC) facilities operated in Canada for different periods between 1990 and 2006; all plants are currently closed, with the last one closing in 2006.

Two processes had been used to produce EDC in Canada. The first is the direct chlorination of ethylene in a vapour or liquid phase reaction using ethylene dibromide as catalyst. The second process is called oxychlorination.

In terms of emissions, the process off-gas that contains the chlorinated hydrocarbons is combusted within the plant prior to release, so any carbon in this off-gas is converted to CO_2. The process CO_2 emissions from EDC production come from the side reaction of feedstock oxidation. The process CH_4 emissions would most likely come from light hydrocarbons from distillation operations that are not captured by a flare gas recovery system. These emissions are vented to the atmosphere (Cheminfo Services, 2010).

Ethylene Oxide Production (CRT Category 2.B.8.d)

Ethylene Oxide is a chemical intermediate that is used in the manufacture of glycols, including monoethylene glycol. Table 4–11 presents an overview of Canadian ethylene oxide production during the time-series.

CO_2 emissions are produced as a by-product of the direct oxidation of ethylene feedstock and are dependent on the selectivity of the process (IPCC, 2006). CH_4 is used to carry all reaction gases through the process (IPCC, 2006). It can be emitted through the ethylene oxide process vent, the purification process exhaust gas stream, and as fugitive (IPCC, 2006).

Table 4–11 **Ethylene Oxide Production Facilities in Canada**

Company	Location	Production Lines	Years in Operation during Time-Series	Process Type
MEGlobal Canada ULC	Fort Saskatchewan, AB	1	1990–present	Oxygen
MEGlobal Canada ULC	Prentiss, AB	2	Plant 1: 1990–present Plant 2: 1994–present	Oxygen
Shell Chemicals Canada	Scotford, AB	1	2000–present	Oxygen
Union Carbide Canada	Montréal-Est, QC	1	1990–1993	Oxygen

Note: Adapted from Cheminfo, 2010.

Carbon Black Production (CRT Category 2.B.8.f and CRT Category 2.B.10)

Four facilities produced carbon black in Canada between 1990 and 2024, three of which are currently operating. CO_2, CH_4 and N_2O emissions can arise from carbon black production. N_2O emissions are reported in CRT category 2.B.10 Other (Carbon Black Production – N_2O Emissions), while CO_2 emissions are included in CRT category 2.D (Non-Energy Products from Fuels and Solvent Use). CO_2 emissions from carbon black production are reported as "IE" ("included elsewhere") in the CRT Reporter because CRT category 2.D cannot be disaggregated.

Styrene Production (CRT Category 2.B.8.g)

During styrene production, process CO_2 emissions can come from the combustion of the process off-gas (fuel gas) as fuel or from flaring of over-pressured process streams. CH_4 could be present along with the process reactants ethylene and benzene and would be emitted if there is any venting of these process or recycle streams. Fugitive emissions from these streams would also contain methane (Cheminfo Services, 2010).

Three styrene facilities produced styrene in Canada since 1990, one of which ceased production in 1998 and another in 2024. CO_2 and CH_4 emissions can arise from styrene production. CO_2 emissions are included in CRT category 2.D (Non-Energy Products from Fuels and Solvent Use). CO_2 emissions from styrene production are reported as "IE" in the CRT Reporter because CRT category 2.D cannot be disaggregated.

4.3.4.2. Methodological Issues

Methanol Production (CRT Category 2.B.8.a and CRT Category 2.B.10)

When available, facility-reported CO_2, CH_4 and N_2O emissions data was included in this submission. The remaining emissions were estimated using a Tier 2 approach where reported facility production data and emissions were used to derive a country-specific emission factor for CO_2, CH_4 and N_2O. National methanol production values are taken from Camford's CPI Product Profile for 1990–1999 and estimated on the basis of assumed capacity utilization for 2000–2006 (Cheminfo Services 2010).

Methanol production restarted in Canada in 2011 in a facility that had previously been included in the inventory. The country-specific emission factors were updated in 2023 to consider the single facility's emissions reported to the GHGRP. For 2012 onwards, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

Ethylene Production (CRT Category 2.B.8.b and CRT Category 2.B.10)

Two consulting studies were commissioned to evaluate CO_2, CH_4 and N_2O emission sources in Canadian petrochemical production as well as the quantity of fuels consumed as feedstocks. The latter was required to differentiate the emissions associated with petrochemical production (CRT category 2.B.8) from the emissions associated with non-energy uses of fuels (CRT category 2.D).

As part of the first study (Cheminfo Services 2010), a questionnaire was sent on behalf of Environment Canada to the four companies that have had ethylene production operations in Canada. Three of the four operating plants responded to the voluntary questionnaire request, representing 90% of Canadian ethylene production capacity in 2009. The data provided included emissions and production values for the years 2007 to 2009 and was used to develop the facility-level N_2O emission factors. The second study (Cheminfo Services 2015) examined the fuels consumed by Canadian ethylene producers over the 1990–2014 period and derived facility-level emission factors for CO_2 and CH_4 on a year-by-year basis. The two emission factors change over time in step with changes to the feedstocks consumed in Canadian ethylene production. In 2021, an in-house analysis of feedstock used by facilities was completed and showed that in 2016, two companies had changed the type of fuel used in their production. The emission factors for those facilities were updated according to the new feedstock using the Cheminfo Service, 2015 methodology.

National ethylene production data is taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. For 2008 onwards, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. The facility-specific emission factors applied are treated as confidential since they are derived from business-sensitive data. However, average industry-wide emission factors are recorded in Annex 6.

When process GHGs were reported directly by a facility, the reported data was used in the inventory. When reported emission data is not available, estimated emissions are calculated using the estimated ethylene production (allocated to each non-reporting facility by share of capacity) and the corresponding plant-specific emission factors. CO_2 and CH_4 emissions for the entire time series were reported under Category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) due to the confidentiality of ethylene oxide production data. N_2O emissions are reported under Category 2.B.10 Other (Ethylene production– N_2O Emissions).

Ethylene Dichloride Production (CRT Category 2.B.8.c)

CH_4 emissions from ethylene dichloride (EDC) production for 1990–2006 were developed through a consulting study. Since all EDC plants are currently closed and no survey response could be provided for historical data, a Tier 1 calculation approach (i.e., annual production multiplied by the Tier 1 IPCC default emission factor) was taken to develop 1990–2006 process CH_4 emission estimates. The annual EDC production data comes from the Canadian C2+ Petrochemical Report, which was prepared and published by an independent consultant who supplies market intelligence to the Canadian chemical industry. It provides balances of ethylene and its derivatives using total production, dispositions and Canadian trade statistics. The default process CH_4 emission factor for EDC was derived from the integrated EDC/VCM factor in Table 3–19 of the 2006 IPCC Guidelines, using the EDC/VCM process Tier 1 feedstock consumption factor for a balanced process. For the purpose of emission estimation at the provincial level, the annual EDC production was allocated by Cheminfo Services to each plant on the basis of the capacity share (calculated from production capacity data reported by companies during the Cheminfo Services [2010] study).

Ethylene Oxide Production (CRT Category 2.B.8.d)

CO_2 and CH_4 emissions from the production of Ethylene Oxide were estimated using a 2006 IPCC Tier 1 method, which involved multiplication of annual plant-specific production quantities by emission factors. Tier 1 CO_2 and CH_4 emission factors used were selected from tables 3.20 and 3.21 of the 2006 IPCC Guidelines based on consultant knowledge of the industry (Cheminfo, 2010). The sources of activity data and emission factors, in addition to all data disaggregation methodologies, assumptions, and missing data imputation techniques are described in Table 4–12.

No more than 2 companies producing ethylene oxide were operational in any year (Table 4–11). To protect confidential ethylene oxide production and catalyst selectivity data, all data is aggregated in Category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) in CRT reporting for the entire time series.

Table 4–12 **Data Sources and Methodologies Used in the Ethylene Oxide Estimate**

Variable	Years	Data Source and Methodology
Activity Data	1990–2009	National production from the Canadian C2+ Petrochemical Report was disaggregated to individual plants based on their capacity share (Cheminfo, 2010).
	2010–2015	Interpolated at the plant-level using 2009 and 2016 data.
	2016	All plants: Plant-level data reported to Statistics Canada's Industrial Chemicals and Synthetic Resins (ICSR) survey.
	2017–2018	2 plants: Plant-level data reported the ICSR. 2 plants: Aggregated company-level data reported to the ICSR, disaggregated using 2016 plant-level production ratios.
	2019–present	2 plants: Plant-level data reported the ICSR. 2 plants: Missing company-level data was imputed by Statistics Canada by deflating monetary shipment data from the Annual Survey of Manufacturing and Logging or the Monthly Survey of Manufacturing to calculate growth or decline from 2018 production levels. This aggregated company-level imputed data was then disaggregated using 2016 plant-level production ratios.
CO_2 Emission Factors	All years	3 plants: The consultant had knowledge of plant catalyst selectivities and industrial process CO_2 rates; Tier 1 CO_2 emission factors were selected or calculated using Table 3.20 of 2006 IPCC Guidelines (Cheminfo, 2010). 2 plants: The consultant did not have knowledge of plant catalyst selectivities; the default Tier 1 CO_2 emission factor for the oxygen process in Table 3.20 was selected (Cheminfo, 2010).
CH_4 Emission Factors	All years	All plants: No information on thermal treatment was available; the default Tier 1 CH_4 emission factor was selected from Table 3.21 of the 2006 IPCC Guidelines, Volume 3 (Cheminfo, 2010).

Carbon Black Production (CRT Category 2.B.8.f and CRT Category 2.B.10)

CH_4 and N_2O emissions from carbon black production were estimated in 2010 through a consulting study. A survey requesting 1990–2009 data on carbon black capacity and production and on process GHG emissions was sent to the three operating carbon black facilities. All three facilities reported 1990–2009 data for carbon black capacity, but not all facilities reported process emissions.

From the received responses, two facility-level Tier 3 emission factors for CH_4 were derived as weighted averages of the reported 2007–2009 data. Two sector-wide process emission factors, one for each CH_4 and N_2O, were also calculated as weighted averages using the same set of data reported by the two facilities (1.3 kg CH_4/t product and 0.032 kg N_2O/t product).

The sector-wide CH_4 EF value is lower than the IPCC default value of 11 kg CH_4/t product. It is suspected that the IPCC default EF, which is based on only one study, has included CH_4 from the combustion of fuel as well. The Canadian EF only includes the CH_4 that originates directly from the feed.

Sector-wide emission factors are applied when facility-level emission factors cannot be used. When process emissions are reported directly by a facility, the reported data are used in the inventory. However, when reported emission data are not available, emissions were estimated by multiplying (reported or estimated) carbon black production by facility-level or sector-wide emission factor. The estimated carbon black production is calculated from total national carbon black

production less the sum of all reported carbon black production; it is then distributed to each non-reporting facility based on its share of production capacity. National carbon black production data are taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. Interpolations were made for years in between (i.e., 1996–2006) on the basis of a sector average growth rate for 1990–1994. The total sector production for each year from 1996 to 2006 is calculated by multiplying the sector average growth rate by the total sector production of the preceding year (starting from 1995). Production data for years 2010 onwards are obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

Styrene Production (CRT Category 2.B.8.g)

In the absence of data from operating facilities, a Tier 1 approach was taken to develop process CH_4 emission estimates. Annual styrene production data were retrieved from the Canadian C2+ Petrochemical Report. To estimate emissions at the provincial level, the annual styrene production is allocated to each plant on the basis of capacity share for years 1990–2009. Since 2010 and 2011 production data are available, these data years are assumed to be equal to 2009 production. For years 2012 onwards, production data are retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

The default process CH_4 emission factor for styrene (4 kg/t) comes from Table 2–10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997). As the 2006 IPCC Guidelines do not cover styrene production under its petrochemicals section, a more recent emission factor cannot be found.

CH_4 emissions are reported under 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) for the entire time series to protect confidential styrene activity data.

Activity data from the ethylene oxide production category contains confidential data that needs to be protected for the entire time series. Table 4–13 summarizes the categories that need to have their associated GHG emission estimates aggregated in the CRT reporting. CO_2 emissions and CH_4 emissions are aggregated under category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions). N_2O emissions do not require aggregation to protect confidentiality.

Table 4–13 **Categories Included in Confidential CRT Node**

Category	1990–present
Ethylene	CO_2, CH_4
Ethylene oxide	CO_2, CH_4
Styrene	CH_4

4.3.4.3. Uncertainty Assessment and Time-series Consistency

The uncertainty assessments for Petrochemical and Carbon Black Production were based on the Cheminfo Services (2010) study. As part of the Cheminfo (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided uncertainty estimates for their data. As a result, uncertainties based on expert knowledge of the industry were used in the analysis. Table 4–14 summarizes the Tier level and uncertainty ranges estimated for each subcategory.

Table 4–14 **Summary of Uncertainty Assessments for Petrochemicals and Carbon Black**

Category	CRT Category	Uncertainty Assessment Tier level	Gas	Uncertainty Range	Year Range
Methanol Production	2.B.8.a, 2.B.10	Tier 1	CH_4	±8% to ±15%	1990–present
			N_2O	±11% to ±30%	
			CO_2	±4% to ±11 %	
Ethylene Production	2.B.8.b, 2.B.10	Tier 1	CH_4	±7% to 12%	1990–present
			N_2O	±12% to ±21%	
			CO_2	±4% to ±7%	
Ethylene Dichloride Production	2.8.8.c	Tier 1	CH_4	±9% to ±11%	1990–2006
Ethylene Oxide	2.B.8.d	Tier 2	CH_4	±30% to ±38%	1990–present
			CO_2	±5% & ±9%	
Carbon Black Production	2.B.8.f, 2.B.10	Tier 1	CH_4	±6% to ± 11%	1990–present
			N_2O	±11% to ±13%	
			CO_2	±2 to ±7	
Styrene Production	2.B.8.g	Tier 1	CH_4	±20% to ±23%	1990–present

4.3.4.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for the Petrochemical and Carbon Black Production categories.

In addition, the following informal checks are conducted for Ethylene Oxide Production:

- Check to ensure that activity data are reported on a calendar year basis and that missing data are imputed by Statistics Canada using surrogate data consistent with methods in the 2006 IPCC Guidelines, Volume 1, Chapter 5.
- Check new or revised activity data for unexplained inter-year differences that are greater than 10% and contacting data sources for verification and explanation as required.

4.3.4.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

4.3.4.6. Planned Improvements

Ethylene Oxide Production (CRT Category 2.B.8.d)

ECCC is working with ethylene oxide producers to obtain data to develop a Tier 2 mass balance CO_2 estimate and account for permanent carbon capture and storage.

4.3.5. Carbide Production, Titanium Dioxide Production, Soda Ash Production, Fluorochemical Production and Other Uses of Urea (CRT Categories 2.B.5, 2.B.6, 2.B.7, 2.B.9.a, and 2.B.10.b)

4.3.5.1. Category Description

Carbide Production (CRT Category 2.B.5)

Two kinds of carbide are considered in this section: silicon carbide (SiC) and calcium carbide (CaC_2). SiC and CaC_2 are no longer produced in Canada; the last of two SiC plants closed in 2002 and the only CaC_2 plant closed in 1992.

Titanium Dioxide Production (CRT Category 2.B.6)

Titanium dioxide (TiO_2) is one of the most commonly used white pigments (IPCC, 2006). Its main use is in paint manufacture followed by paper, plastics, rubber production and other miscellaneous uses (IPCC, 2006).

There are three industrial processes related to TiO_2 production that can lead to significant greenhouse gas emissions: titanium slag production, synthetic rutile production, and rutile TiO_2 production using the chloride process (IPCC, 2006). Another TiO_2 production route, anatase TiO_2 production using the sulphate process, does not produce any significant process emissions (IPCC, 2006).

In Canada, there are two facilities involved in the types of TiO_2 production that give rise to process GHG emissions: Rio Tinto Fer et Titane and Kronos Canada. Rio Tinto Fer et Titane in Sorel-Tracy, Quebec, produces titanium slag by smelting ilmenite in an electric arc furnace using anthracite coal as a reductant (Weidenhammer, 2021). The titanium slag products are shipped as process inputs for producing TiO_2 using the sulphate process and the chloride process. Kronos Canada in Varennes, Quebec produces TiO_2 using the chloride process using petroleum coke as a carbothermal reducing agent (Cheminfo, 2010).

Kronos Canada also operates a sulphate process line, which digests titanium slag using sulphuric acid (Cheminfo, 2010). Tioxide Canada, which was located directly opposite from Rio Tinto Fer et Titane, also produced TiO_2 using the sulphate process until 1993 (Environment Canada, 1996).

Soda Ash Production (CRT Category 2.B.7)

Soda ash can be produced in the Solvay process in which sodium chloride brine, limestone, metallurgical coke and ammonia are used as the raw materials in a series of reactions. Although CO_2 is generated as a by-product during some of these reactions, it is recovered and recycled for use in the carbonation stage, i.e., CO_2 generation equals uptake (IPCC, 2006). Canada had a single operational Solvay soda ash production facility between 1990 and 2001. There has been no production in Canada since 2001.

Fluorochemical Production (By-product Emissions, CRT Category 2.B.9.a)

During the manufacture of chlorodifluoromethane (HCFC-22), trifluoromethane (HFC-23 or CHF_3) is generated as a by-product (IPCC, 2006). Two HCFC-22 producers (Dupont Canada and Allied-Signal) operated in Canada in the 1980s and early 1990s, but production ended in 1992. In Canada, there has been no manufacturing or import of equipment containing HCFC-22 as of January 1, 2010 (HRAI, 2008). HFC-23 releases as a by-product of HCFC-22 production were 810 kt, 890 kt and 700 kt (in 1990, 1991 and 1992, respectively). There has been no known production of sulphur hexafluoride (SF_6) or perfluorocarbons (PFCs) in Canada throughout the time series.

Other Uses of Urea (CRT Category 2.B.10.b Other [Other uses of Urea – CO_2 Emissions])

The Other Uses of Urea category accounts for potential emissions from urea used as an ingredient in the manufacturing of resins, plastics, and coatings products. To determine the amount of Other Uses of Urea, the total quantity of urea produced at ammonia plants is balanced with the urea that is imported to and exported from Canada, the quantity used for agriculture, and the estimated amount of urea-based additives required in catalytic converters for vehicles.

4.3.5.2. Methodological Issues

Carbide Production (CRT Category 2.B.5)

Tier 1 IPCC default emission factors were applied to estimate CH_4 emissions from carbide production. A study was commissioned to identify and establish the production capacities of the three carbide production facilities in Canada. A time series of process CH_4 emissions was estimated for the two silicon carbide facilities from 1990 to 2001 and for one calcium carbide facility from 1990 to 1991 based on assumed capacity utilization and CH_4 emission factors. Only production capacity data (SiC and CaC_2) over the time series was identified in the study. The following Equation 4–11 was used to estimate total CH_4 emissions from carbide production:

Equation 4–11

$$\textit{Total } CH_4 \textit{ emissions (t)} = \sum^{y} [(\textit{SiC capacity} \times \textit{capacity utilization} \times \textit{Emission Factor_SiC}) + (CaC_2 \textit{ capacity} \times \textit{capacity utilization} \times \textit{Emission Factor_}CaC_2)]$$

y	=	companies
$\textit{SiC or } CaC_2 \textit{ capacity}$	=	data collected from the industry, kt
$\textit{Capacity utilization}$	=	based on Cheminfo Services' knowledge of the industry, %
$\textit{Emission Factor_SiC}$	=	see Annex 6
$\textit{Emission Factor_}CaC_2$	=	see Annex 6

Titanium Dioxide Production (CRT Category 2.B.6)

Generally, the titanium dioxide facilities have reported their process inputs to the Report on Energy Supply and Demand (RESD) feeder surveys as energy inputs rather than process inputs. Therefore, process emissions are mainly included in the Energy sector estimates (Table 4–15). To reflect this situation, CO_2 emissions from the Titanium Dioxide Production category are reported as "Included Elsewhere" (notation key "IE") in the CRT.

Table 4–15 **Titanium Dioxide Production in Canada, and Location of Process Emissions in the CRT**

Company	Location	Product[a]	Primary Process Input[a]	Years	Location of Process Emissions in the CRT[b]
Rio Tinto Fer et Titane	Sorel-Tracy, QC	Titanium Slag	Anthracite Coal	1990–present	1.A.2.b – Non-Ferrous Metals
Kronos Canada	Varennes, QC	TiO_2 – Chloride Route	Petroleum Coke	1990–2020	1.A.2.c – Chemicals
				2021–present	2.C.1.a – Steel, 2.C.3 – Aluminium, and 2.D.3.d – Non-energy products from fuels and solvent use – Other and Undifferentiated

Notes:
a. Product types use the definitions from the 2006 IPCC Guidelines (IPCC, 2006), and product types and primary process inputs were determined from *Developments in Canadian Hydrometallurgy Since 1950* (Weidenhammer, 2021) and from a contracted Cheminfo study (Cheminfo, 2010).
b. From 2021 onwards, the use of petroleum coke in titanium dioxide production was reported in the RESD with all other non-energy uses of petroleum coke. To avoid double-counting, quantities of petroleum coke estimated to be used in steel and aluminium production are subtracted from all other non-energy uses of petroleum coke. The remaining petroleum coke (if any) is used to estimate emissions in CRT category 2.D.3.d.

Soda Ash Production (CRT Category 2.B.7)

A Tier 1 method has been applied to estimate the CO_2 emissions potentially generated from the ash production process for the applicable reporting years (1990–2001). However, the net CO_2 emissions are considered negligible because the CO_2 resulting from the Solvay process was recovered for re-use and has been recorded as such in CRT category 2.B.7 (AMEC, 2006).

Fluorochemical Production (By-product Emissions, CRT Category 2.B.9.a)

To estimate HFC-23 emissions from HCFC-22 production, the total HCFC-22 production was multiplied by the IPCC Tier 1 default emission factor of 0.04 t HFC-23/t HCFC-22 produced (IPCC, 2006). It was assumed that destruction (through thermal oxidation) or transformation of HFC-23 was not practised in Canada. The 1990–1992 production data were collected by Environment Canada from HCFC producers.[13]

Other Uses of Urea (CRT Category 2.B.10.b Other [Other uses of Urea – CO_2 Emissions])

There is no available methodology in the IPCC 2006 Guidelines for the estimation of emissions coming from other uses of urea. Because it is believed that the Canadian context would be similar to that of the United States for this category, the Canadian methodology in Equation 4–12 was derived from that described in the U.S. National GHG Inventory (U.S. EPA, 2018).

Equation 4–12

$$\textit{Total } CO_2 \textit{ emissions (t)} =$$

$$[U_{production} - U_{fertilizer} + U_{imports} - U_{exports} - (U_{UAN\ fertilizer} - U_{UAN\ imports}) - U_{UAN\ exports} - U_{SCR}] \times EF$$

$U_{production}$	=	Urea produced in Canada (t)
$U_{fertilizer}$, $U_{UAN\ fertilizer}$	=	Urea applied as fertilizer (t) from urea and urea-ammonium-nitrate (UAN)
$U_{imports}$, $U_{UAN\ imports}$	=	Urea imported to Canada (t) as urea or urea-ammonium-nitrate (UAN)
$U_{exports}$, $U_{UAN\ exports}$	=	Urea exported from Canada (t) as urea or urea-ammonium-nitrate (UAN)
U_{SCR}	=	Urea used as an additive in catalytic converters (t)
EF	=	0.733 t CO_2 emitted per t urea

The collection of urea production data is described in section 4.3.1.

Import and export data for urea and urea-ammonium-nitrate from 1990–present were obtained from Statistics Canada's Canadian International Merchandise Trade Web Application (Statistics Canada, n.d.[f]).

Provincial-level data for quantities of urea and urea-ammonium-nitrate used as fertilizer were obtained from the AFOLU sector and summed to determine the national total. Lastly, national totals for urea used as an additive in catalytic converters were calculated, as discussed in section 4.5 and reported in CRT category 2.D.3.d.

It is assumed that any urea that is not used as a fertilizer, as an additive for selective catalytic converters, or that is not exported in the same year is used as an ingredient in manufacturing of resins, plastics or coatings. It is also assumed that all the carbon contained in the urea used for other uses is released in the same year as its production or import.

To estimate the CO_2 emitted from Other Uses of Urea, an emission factor of 0.733 kg CO_2 emitted/kg of urea used is applied. This factor is the stoichiometric quantity of CO_2 required to produce urea, assuming the complete conversion of ammonia and CO_2 to urea (IPCC, 2006). The same factor is used as the emission factor based on the assumption that all CO_2 contained in the manufactured urea is emitted upon use.

Provincial CO_2 estimates are allocated from the national CO_2 estimate using ECCC economic data on industries likely to use urea shown in Table 4–16 (ECCC, 2025b).

Table 4–16 **Industries used for the Provincial Allocation of Other Uses of Urea Emissions**

North American Industry Classification System Codes	Description
313 & 314	Textile and textile product mills
315 & 316	Clothing and leather and allied product manufacturing
32513	Synthetic dye and pigment manufacturing
3252, 3255–3259	Other Chemicals
326	Plastics and Rubber Products Manufacturing
339	Miscellaneous Manufacturing
481	Air Transportation

13 Bovet Y and Guilbault Y. 2004–2006. Personal communications (emails from Bovet Y and Guilbault Y to Au A, Environment Canada dated 2004–2006). UPCIS.

4.3.5.3. Uncertainty Assessment and Time-series Consistency

The uncertainty assessment for Carbide Production was based on the Cheminfo Services (2010) study. As part of the Cheminfo (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided uncertainty estimates for their data. As a result, uncertainties based on expert knowledge of the industry were used in the analysis. For Soda Ash Production, the method, emission factor and activity data are consistent across the time series. The assessment for Fluorochemical production and Other Uses of Urea follow the 2006 IPCC Guidelines. Table 4–17 summarizes the Tier level and uncertainty ranges estimated for each category.

Table 4–17 **Summary of Uncertainty Assessments**

Category	CRT Category	Uncertainty Assessment Tier level	Gas	Uncertainty Range	Year Range
Carbide Production	2.B.5	Tier 1	CO_2	±16% to ±27%	1990–2001
Soda Ash Production	2.B.7	Tier 1	CO_2	±14%	1990–2001
Fluorochemical Production[a]	2.B.9.a	Tier 1	HFC-23	±50%	1990–1992
Other Uses of Urea[b]	2.B.10.b	Tier 1	CO_2	±7% to ±10%	1990–present

Notes:

a. Uncertainty in the HFC-23 emission estimates has not been assessed. However, it is believed that the production data reported by HCFC-22 producers was reasonably accurate. A significant source of uncertainty could be attributed to the Tier 1 default emission factor, which does not reflect facility-specific conditions, as the correlation between the quantity of HFC-23 emitted and the HCFC-22 production rate can vary with plant infrastructure and operating conditions (IPCC, 2006). The IPCC 2006 Guidelines state that a 50% uncertainty factor for a Tier 1 HFC production estimate may be appropriate.

b. The assessment considered the uncertainties associated with urea production data, import and export data, urea used in agriculture data, urea used in catalytic converters, and the urea-to-CO_2 conversion factor. In addition, it was assumed that the uncertainty associated with the calculated value of urea available in one year for other uses was high due to the assumption that all the urea is converted to CO_2, regardless of the type of final product.

4.3.5.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for the Carbide Production, Soda Ash Production, Fluorochemical Production and Other Uses of Urea categories.

The following informal check is also done for Other Uses of Urea:

- Compare the sum of facility-reported urea production received through the Greenhouse Gas Reporting Program (ECCC, 2025a) to the published national production totals from Statistic Canada's Industrial Chemicals and Synthetic Resins survey to ensure that activity data is complete.

4.3.5.5. Recalculations

Other Uses of Urea (CRT Category 2.B.10 Other [Other Uses of Urea – CO_2 Emissions])

The Other Uses of Urea CO_2 emission estimate was recalculated for all years using revisions to 1990 to 2020 and 2022 fertilizer use data, 2009 to 2022 SCR vehicles data, and 2022 to 2023 urea import data. The recalculations ranged from -3 kt CO_2 eq in 2022 to +3 kt CO_2 eq in 2011. Provincial estimates were also recalculated using revised economic data.

4.3.5.6. Planned Improvements

Titanium Dioxide Production (CRT Category 2.B.6)

As noted in section 4.3.5.2, industrial process emissions from CRT category 2.B.6 are currently reported in other Energy and IPPU sector categories (Table 4–15). As such, the notation key "IE" is used in the CRT for this category. To ensure proper emission reallocation back to the category for which the order of magnitude is expected to be potentially greater than 500 kt CO_2 eq, various data sources are being explored. Efforts will also be made to ensure that process input quantities are reconciled with other inventory categories to avoid double-counting.

4.4. Metal Production (CRT Category 2.C)

4.4.1. Iron and Steel Production (CRT Category 2.C.1)

4.4.1.1. Category Description

The Iron and Steel Production is a key category that contributed 10 241 kt (1.5%) to Canada's total emissions in 2024, a 12% decrease from 2005.

There are four integrated iron and steel mills in Canada, all located in Ontario. One of the mills uses the electric arc furnace (EAF) process to produce a portion of its steel. In 2013, one of the integrated iron and steel mills closed its iron and steel producing facilities, while maintaining their coke oven battery for coke production. Annex 3.3 provides additional detail on the technologies employed in Canada to produce iron and steel.

In the production of pig iron, carbon plays the dual role of fuel and reductant. Emissions from the combustion of fuels such as coke oven gas are not reported in this category, but rather under the appropriate industrial category in the Energy sector.

Total emissions in the Iron and Steel Production category are the sum of emissions from the following sources:

- CO_2 emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron
- CO_2 emissions during steel production, which occur to a much lesser extent (these come from the oxidation of carbon in crude iron and electrode consumption)
- CO_2 emissions given off by limestone flux in the blast furnace
- CO_2 emissions from the use of carbonates in the production or iron ore pellets
- CH_4 emissions from metallurgical coke and natural gas use (as a reductant)

4.4.1.2. Methodological Issues

An IPCC Tier 2 methodology is used to estimate most emissions from Iron and Steel Production (IPCC, 2006), however, iron ore pellet production is estimated using a Tier 1 methodology. The method reflects the operation of Canadian facilities with country-specific emission factors for coke (EF_{met_coke}), natural gas (EF_{NG}) and carbon content of pig iron. For more specific information on the Canadian Iron and Steel sector, refer to section A3.3.

Pig Iron Production (CRT Category 2.C.1.b)

CO_2 emissions from the production of pig iron in blast furnaces are reported under the CRT category 2.C.1.b Pig Iron. In 2024, a change in methodology was implemented to the emission estimate of pig iron production. This involved the inclusion of natural gas used as a reductant, in addition to metallurgical coke, in the blast furnace. A voluntary survey was sent to facilities producing pig iron to obtain the volumes of natural gas used from 1990 to 2017. Two of the three blast furnace operators responded to the survey. The collected data, along with GHGRP data from 2018 to present were incorporated into the time series. Previously, all the natural gas used in the iron and steel sector was reported under CRT category 1.A.2.a. A reconciliation with the energy category was completed to eliminate double counting. These emissions were estimated using the following Equation 4–13:

Equation 4–13

$$E_{CO2_PI} = (EF_{met_coke} \times M_{met_coke} + EF_{NG} \times V_{NG}) - (P_{PI} \times CC_{PI}) \times (44/12)$$

E_{CO2_PI}	=	process emissions from pig iron production, kt
EF_{met_coke}	=	year-specific emission factors (t CO_2 / t metallurgical coke used)
M_{met_coke}	=	mass of metallurgical coke, ore, kt
EF_{NG}	=	year-specific emission factor (g CO_2 / m^3 of natural gas used)
V_{NG}	=	volume of natural gas (m^3)
CC_{PI}	=	carbon content of metallurgical coke, pig iron, %
P_{PI}	=	production of pig iron, kt
$44/12$	=	ratio of the molecular weight of CO_2 to the molecular weight of carbon

Table 4–18 summarizes the different sources of activity data and other variables used in the calculation of Equation 4–13.

Table 4–18 **Sources of Iron Production Activity Data and Other Variables Used in Equation 4–13**

Variable	Year	Source
M_{met_coke} – metallurgical coke used	1990–present	RESD (Statistics Canada, No date (e))
P_{PI} – Pig Iron production	1990–2003	Statistics Canada (Cat. No. 41-001)
	2004–2012	Statistics Canada (Cat. No. 41-019)
	2013–2016	Canadian Steel Producers Association (CSPA, 2019)
	2017–present	GHGRP (ECCC, 2025a)
EF_{met_coke} – metallurgical coke emission factor	1990–2009	Cheminfo (2010)
	2010–2016	constant – average of 2009 (Cheminfo, 2010) and yearly national average of GHGRP data for the years 2017–2019 (ECCC, 2025a)
	2017–present	GHGRP (ECCC, 2025a)
V_{NG} – volume of natural gas used	1990–2017	Voluntary facility survey responses
	2018–present	GHGRP (ECCC, 2025a)
EF_{NG} – natural gas emission factor	1990–present	Annex 6, Table A6.1–1 Emissions Factors for Marketable Natural Gas
CC_{PI} – carbon content of pig iron	1990–2012	Canadian Steel Producers Association (Chan, 2009)
	2013–2016	constant – average of CSPA value and the national average of GHGRP data for 2017 (ECCC, 2025a)
	2017–present	GHGRP (ECCC, 2025a)

The emission factors for coke use (EF_{met_coke}) were obtained from the Cheminfo Services (2010) study, where the four integrated steel mills in Canada were surveyed for their coke consumption and emission estimates for the years 1990 to 2009. The emission factors for natural gas (EF_{NG}) were obtained from Annex 6, Table A6.1–1 CO_2 Emissions Factors for Marketable Natural Gas.

Facility-level data began being collected through the Greenhouse Gas Reporting Program in 2017 and year-specific national averages of facility provided data are used in the calculation of emissions from Pig Iron as indicated in Table 4–18.

CH_4 emissions were estimated by multiplying the mass of metallurgical coke (Statistics Canada 1990–2023) and the volume of natural gas used by their respective emission factor. The emission factor value for CH_4 emissions from coke use in the iron and steel industry is not presented in this report to protect the confidentiality of the data.

A range of emission factors used for iron ore reduction with coke and carbon contents of pig iron are included in Annex 6.

Direct Reduced Iron (CRT Category 2.C.1.c)

In Canada, there is currently only one facility that produces sponge iron through the Direct Reduced Iron (DRI) process, and these emissions are reported under category 1.A.2.a due to confidentiality concerns, as well as difficulty in disaggregating the use of natural gas.

Sinter (CRT Category 2.C.1.d)

Sinter production is occurring at the integrated mills; however, the emissions of coke oven and blast furnace gases are reported under category 1.A.2.a since these gases are used in a variety of processes at the facilities and the specific portion used for sintering cannot be disaggregated.

Steel Production (CRT Category 2.C.1.a)

CO_2 emissions from the production of steel and ferroalloys are reported under CRT category 2.C.1.a Steel since production of ferroalloys is a direct production of specialty steels from iron ore via the electric arc furnace process.

The emissions from steel production were estimated using Equation 4–14:

Equation 4–14

$$E_{CO2_steel} = [CC_{iron} \times M_{iron} + CC_{scrap\ steel} \times M_{scrap\ steel} - CC_{BOF} \times M_{BOF} - CC_{EAF} \times M_{EAF}] \times 44/12 + EF_{EAF} \times P_{EAF} + EF_{BOF} \times P_{BOF}$$

E_{CO2_steel} = process emissions from steel production, kt
CC = carbon content of j, % where j is the pig iron charged, or scrap steel charged in either the electric arc furnace (EAF) or basic oxygen furnace (BOF)
M_j = mass of j used, kt
$44/12$ = ratio of the molecular weight of CO_2 to the molecular weight of carbon
EF_k = emission factors (t CO_2 / t steel produced)
P_k = steel production by either EAF or BOF, kt

According to Equation 4–14, part of the CO_2 emitted from the steel production process is estimated on the basis of the difference between the amount of carbon in the iron and in scrap steel used to make steel and the amount of carbon in the steel produced in basic oxygen furnaces (BOFs) and electric arc furnaces (EAFs). It should be noted that the amount of pig iron fed to steel furnaces (used in Equation 4–14) is not equal to the amount of total pig iron production (used in Equation 4–13). As part of the steel production process, emissions are also generated by the consumption of electrodes in EAFs and in secondary ladle metallurgy. These are accounted for in the last two terms of the equation. Table 4–19 summarizes all the sources of activity data and other variables used in the calculation of Equation 4–14.

It should be noted that RESD data published for any given year is preliminary and subject to revision in subsequent publications. The use of petroleum coke in EAF electrodes is reported by Statistics Canada with all other non-energy uses of petroleum coke. To avoid double counting, the CO_2 emissions from the consumption of electrodes in the steel production process in EAFs are therefore subtracted from the total non-energy emissions. It is assumed that there are no imported electrodes used for steel production in EAFs in Canada. If electrodes are imported, the portion of CO_2 generated by the imported electrodes needs to be subtracted from the emissions from electrode consumption before being subtracted from the total non-energy emissions.

The facility-specific emission factors from the GHGRP are treated as confidential since they are derived from business-sensitive data. However, a range of national emission factors and carbon contents are available in Annex 6.

Table 4–19 **Steel Production Activity Data and Other Variables Used in Equation 4–14**

Variable	Year	Source
M_i – pig iron, scrap steel, and P_k – EAF and BOF production	1990–2003	Statistics Canada (Cat. No. 41-001)
	2004–2012	Statistics Canada (Cat. No. 41-019)
	2013–2017	Canadian Steel Producers Association (CSPA, 2019)
	2018–present	GHGRP (ECCC, 2025a)
CC_i – pig iron, scrap steel, EAF and BOF	1990–2012	Canadian Steel Producers Association (Chan K., 2009)
	2013–2016	constant – average of CSPA value and the national average of GHGRP data for 2017 (ECCC, 2025a)
	2017–present	GHGRP (ECCC, 2025a)
EF_k – emissions factor for EAF and BOF	1990–2012	Canadian Steel Producers Association (Chan K., 2009)
	2013–2016	constant – average of CSPA value and the national average of GHGRP data for 2017 and 2018 (ECCC, 2025a)
	2017–present	GHGRP (ECCC, 2025a)

Pellet Production (CRT Category 2.C.1.e)

In Canada, there were three stand-alone facilities producing iron ore pellets since 1990, of which one closed its operation in 2013. A Tier 1 emission estimate was completed using the 2006 IPCC default factor based on an analysis of facility-reported data, which demonstrated that it was a better representation than the 2019 factor for estimating emissions due to the use of carbonates only. The emissions resulting from combustion at these facilities are currently reported as part of category 1.A.2.g.iii. Mining.

Activity data for this category was obtained from various sources, including the *Canadian Minerals Yearbook* (1990-1999, 2008), Wood Mackenzie (2000-2016), company annual reports (2000-2013), GHGRP (2017-present) and from the annual statistics of mineral productions from Natural Resources Canada (2019-present).

Limestone use in Iron and Steel Furnaces (CRT Category 2.C.1.f)

The methodology used to estimate CO_2 emissions from limestone and dolomite consumed as a flux in iron and steel furnaces is described in section 4.2.3.2.

Data on provincial-level metallurgical coke use from RESD (Statistics Canada, n.d.[e]) was used to distribute national-level emissions to the applicable provinces.

4.4.1.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for the category of Iron and Steel Production. It considered the uncertainties associated with all the parameters used in estimating emissions of each source in this category, such as data on metallurgical coke and natural gas use, the emission factors, data on pig iron and steel production, the carbon content of pig iron and steel, limestone data, iron ore pellet production and associated emission factors. The assessment also considered the error associated with the non-response rate of the Statistics Canada surveys. The uncertainties for CO_2 and CH_4 emission estimates associated with this category are ±4.87% and ±405%, respectively.

4.4.1.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for this category.

4.4.1.5. Recalculations

CO_2 emissions for this category were recalculated due the methodological change to incorporate the production of iron ore pellets, as well as updates to the RESD. The magnitude of the recalculations ranged from +0.54 Mt to +0.79 Mt CO_2 eq and impacted the entire time series from 1990 to 2023.

4.4.1.6. Planned Improvements

Efforts are currently ongoing to determine a country-specific emission factor for the use of carbonates in the production of iron ore pellets and to disaggregate the associated combustion emissions from the Energy category 1.A.2.g.iii. Mining.

4.4.2. Ferroalloy Production (CRT Category 2.C.2)

A 2010 Cheminfo study evaluated the potential emissions from the production of ferroalloys in Canada and found that there were 5 facilities known to have produced ferroalloys since 1990. Four of these facilities were still in operation in 2024, two of which produced ferrosilicon (FeSi) using conventional carbon-reduction-Electric Arc Furnace (EAF) process. The other two facilities use the aluminothermic process to reduce their oxides and thus have no process CO_2 emissions. The fifth facility produced ferromanganese (FeMn) and siliconmanganese (SiMn) from manganese oxide ore, scrap iron and coke using an EAF, however it closed in May 1991.

Emissions from these facilities are included as part of the total production from EAF in CRT category 2.C.1.a Steel since they cannot be disaggregated due to confidentiality concerns.

4.4.3. Aluminium Production (CRT Category 2.C.3)

4.4.3.1. Category Description

The Aluminium Production is a key category that accounted for 5960 kt (0.9%) of Canada's emissions in 2024, representing an overall decrease in emissions of 28% since 2005.

Emissions from the combustion of fossil fuels used in the production of baked anodes are covered in the Energy sector, CRT category 1.A.2.b. Emissions arising from the combustion of volatile matter released during the baking operation and from the baking furnace packing material are accounted for under the Aluminium Production category 2.C.3 (IPCC 2006).

In addition to CO_2 emissions, primary aluminium smelting is a source of carbon tetrafluoride (CF_4) and carbon hexafluoride (C_2F_6), which are included in this submission. This submission also includes a small amount of SF_6 that is emitted from its use as cover gas as well as a degassing (purifying) agent at some aluminium plants that produce high magnesium-aluminium alloys.[14] The consumption of SF_6 is highly variable depending on whether one or both of these operations (SF_6 use as a cover gas and/or purifying agent) occur within a given year, causing significant changes in the trend of SF_6 in this source category.

14 Chaput P. 2007. Personal communication (email from Chaput P to Au A, Environment Canada dated Oct 12, 2007). Aluminium Association of Canada.

Aluminium plants are characterized by the type of anode technology employed. In general, older plants using Søderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The last Søderberg aluminium smelter in Canada was closed in 2015,[15] and the 10 plants currently in operation have focused on modernizing their facilities and improving production efficiency. As a result, the category has seen a downward emission trend, specifically PFC emissions throughout the time series. While PFC emissions in Canada have decreased, production has steadily increased since 1990.

4.4.3.2. Methodological Issues

As of 2013, Canada's aluminium companies, which operate in Quebec and British Columbia, have developed and reported their GHG emissions under the methodological protocols and reporting rules of the Western Climate Initiative, which are based on the Tier 2 methodology documented by the International Aluminium Institute (IAI, 2006) and are consistent with the methods presented in the 2006 IPCC Guidelines. Under a memorandum of understanding signed in 2006 between Environment Canada and the Aluminium Association of Canada (AAC), Environment Canada received the same data sets as those provided by AAC member companies to the provinces. As of the data year 2018, aluminium companies have been reporting their emissions directly to ECCC's GHGRP (ECCC, 2024), which follows a Tier 3 methodology published in the GHGRP Quantification Requirements that is consistent with the 2006 IPCC Guidelines. The main difference between the Tier 2 and Tier 3 estimates is the use of industry typical parameters as defined in the IAI (2006) for the Tier 2 method versus site-specific factors for the Tier 3.

The smelter-specific emission estimates, information on the methodologies used by the aluminium producers to calculate CO_2, PFC and SF_6 emissions, and plant-specific production data for the time series are obtained from AAC from 1990–2017 and ECCC's GHGRP from 2018 to present. According to the methodology documents supplied by the AAC, SF_6 emissions are equal to consumption in the aluminium industry.

Depending on data availability for each year in the time series, the estimation techniques applied vary between Tiers 2 and 3 and depend on the individual facility. All facilities in Canada have reported CO_2 emissions at a Tier 3 level since 2017, PFC emissions at a Tier 3 level since 2016, and SF_6 emissions at a Tier 3 level for the entire time series. Table 4–20 presents Canada's individual Aluminium facilities and when facilities were able to transition from a Tier 2 level estimate to a Tier 3 level using plant-specific parameters. When plant-specific data was not available, companies have used Quebec's Framework Agreement or International Aluminium Institute (IAI) EFs as the default (Alcan, 2010).

Table 4–20 **Aluminium Facilities in Canada: Method Tier and Emission Factor Information**

Aluminium Facility	Years in Operation	CO_2		PFC		SF_6	
		Method / EF		Method / EF		Method	EF
		T2 / CS	T3 / PS	T2 / CS	T3 / PS	Level	
RIO TINTO							
Usine Isle-Maligne	1990–2000	1990–2000	-	1990–2000	-	T3	PS
Usine de Bauhamois	1990–2009	1990–2009	-	1990–2009	-	-	-
Usine Grande-Baie	1990–present	1990–2007	2008–present*	1990–1995	1996–present	T3	PS
Jonquière	1990–2004	1990–2004	-	1990–2004	-	-	-
Usine Arvida	1990–present	1990–2007	2008–present	1990–2006	2007–present	T3	PS
AP-60	2013–present	-	2013–present	2013–2015	2016–present	T3	PS
Usine Laterrière	1990–present	1990–2007	2008–present	1990–2013	2014–present	T3	PS
Usine Shawinigan	1990–2013	1990–2007	2008–2013	1990–2013	-	-	-
Usine Alma	2000–present	2000–2007	2008–present*	2000–2007	2008–present	T3	PS
Kitimat	1990–present	1990–2007	2008–present*	1990–2006	2007–present	T3	PS
ALCOA							
Usine Becancour	1990–present	1990–2016	2017–present*	1990–2004	2005–present	T3	PS
Usine de Baie-Comeau	1990–present	1990–2016	2017–present	1990–2003	2004–present	T3	PS
Deschambault	1993–present	1993–2016	2017–present*	1990–2004	2005–present	T3	PS
ALOUETTE							
Sept-Iles	1992–present	1992–1994	1995–present*	1990–2004	2005–present	T3	PS

Notes:
* Method uses facility specific variables, with the exception of hydrogen content of pitch from anode and cathode baking, which is obtained from IAI (2006).
CS = country specific
PS = plant specific
"-" = Not applicable

15 Banville J. 2020. Personal communication (email from Banville J to Au A, Environment and Climate Change Canada dated June 15, 2020). Environment and Climate Change Canada, Environmental Protection Branch.

4.4.3.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for the Aluminium Production category (i.e., for the CO_2, PFC and SF_6 emission estimates). It takes into account the uncertainties associated with all the parameters used to calculate the emissions. The *Aluminium Sector Greenhouse Gas Protocol* (IAI, 2006) was the main source of uncertainty values for parameters. The uncertainties for the CO_2, PFC and SF_6 estimates are ±7%, ±9% and ±5%, respectively. For the CO_2 and PFC estimates, it should be noted that the uncertainty assessment is done for only one year of the time series (2006 for CO_2 and 2007 for PFC). It is expected that emission estimates of more recent years would have similar uncertainties, while older estimates would have higher uncertainties. For the SF_6 estimate, it is assumed that the uncertainty is equivalent to the 2006 IPCC default for a Tier 2 method Magnesium Casting category, since the method used to develop SF_6 emission estimates is the same for both Aluminium Production and Magnesium Casting. To ensure time series consistency, splicing techniques will be assessed between the Tier 2 and Tier 3 methodology for years where data is available and the results will be shared in the next publication.

4.4.3.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for this category.

4.4.3.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

4.4.3.6. Planned Improvements

No improvements are currently planned for this category.

4.4.4. Magnesium Production (CRT Category 2.C.4)

4.4.4.1. Category Description

From 1990 to 2008, four magnesium production facilities operated in Canada: Norsk Hydro until 2007; Timminco Metals until 2008; Métallurgie Magnola between 2000 and 2003; and MagCan from 1990 to 1991. Review is conducted in-house periodically to ensure that new facilities are included in emission estimates. After 2008, there has been no magnesium production in Canada.

Primary magnesium is commonly produced through an electrolytic or thermal reduction process of mineral sources. CO_2 is released during the calcination of carbonate-based raw materials, which takes place prior to the main electrolytic or thermal reduction process. Of these facilities, two used magnesite as a raw material, one used dolomite and the remaining one used asbestos. Since asbestos is not a carbonate-containing raw material, CO_2 emissions were only estimated for facilities using magnesite and dolomite.

In addition, SF_6 is emitted during both primary magnesium and secondary production (i.e. casting) processes, where it is used as a cover gas to prevent oxidation of the molten metals. Magnesium production (SF_6) is a key category. For magnesium production, fluctuations in SF_6 emissions could be attributed to use of substitutes of SF_6 and variations in productions.

There were 11 magnesium casting companies in operation during the 1990–2004 period (Cheminfo Services, 2005b). Only a few of them had used SF_6 every year during the entire period. Some casters started using SF_6 towards the mid- or late 1990s, whereas others replaced it with an alternative gas, such as sulphur dioxide (SO_2). During the 2005–2008 period, only seven companies were in operation and had used SF_6. In 2009, one company shut down its operations and another moved its operations to the United States. The remaining five magnesium casting companies in operation accounted for 297 kt CO_2 eq in 2024 (< 0.1% of Canada's emissions).

4.4.4.2. Methodological Issues

CO_2 emissions from magnesium production facilities are calculated by applying Tier 1 IPCC default emission factors for magnesite (2.83 t CO_2/t primary Mg produced) and for dolomite (5.13 t CO_2/t primary Mg produced), based on the type of carbonate raw material used, to facility-specific production values.

When facility-specific production data were not available, they were estimated based on total national primary magnesium production obtained from the *Canadian Minerals Yearbook* (NRCan, 1990-2006) and facility-specific production capacities published by the United States Geological Survey (Kramer, 2001). For years where the production capacity data were not available, linear interpolation was done or held constant depending on the situation.

The technique applied to estimate SF_6 emissions from magnesium production and casting is a Tier 2 type method, as it is based on the reporting of facility-specific emission data, consumption data or both. The approach for estimating SF_6 emissions from production and casting companies assumes all SF_6 used as a cover gas is emitted to the atmosphere. Norsk Hydro and Timminco were contacted in 2006 regarding the methodology they had applied to estimate SF_6 emissions. Both companies reported that they had estimated emissions based on the assumption that SF_6 emissions are equivalent to SF_6 consumption.

SF_6 consumption was estimated by companies using a variety of methods, with the accounting method being the most common. In this method, accounting of delivered purchases and inventory changes of SF_6 used are recorded. The purchases must be the actual volumes received in the calendar period; therefore, beginning-of-year and end-of-year inventories are considered. Other methods include: prorating based on production, inventory weighing, inventory difference, and derivation of an annual consumption based on the quantity of bottles of SF_6 consumed over a period within the year. Norsk Hydro confirmed the use of the weight difference method,[16] which involves measuring the weight of gas cylinders used at the facility at the time of purchase and at the time they are returned to suppliers at the end of their usage. Timminco reported using the accounting method for estimating its SF_6 use.[17]

In the cases where facility-specific SF_6 use data were not available for certain years, values prior to 2009 were linearly interpolated, and values for 2010 and after were approximated using province-specific gross output (GO) economic data as a proxy variable. There were also instances where the amounts of magnesium casted were available in lieu of SF_6 use data. In these situations, the Tier 1 default emission factor of 0.001 tonne SF_6/tonne magnesium component produced is applied to quantify the SF_6 use value. Table 4–21 provides a summary of the data sources used to obtain quantities of SF_6 use as cover gas quantities.

Table 4–21 **Data Sources of SF_6 Use as Cover Gas for Magnesium Production and Casting**

Years	Magnesium Production	Magnesium Casting
1990–1998	Voluntary data collection	Cheminfo Services (2002)
		Cheminfo Services (2005b)
		Voluntary data collection
		Linear interpolations
1999–2004	NPRI	Cheminfo Services (2002)
		Cheminfo Services (2005b)
		Voluntary data collection
2005–2007	NPRI	Voluntary data collection
2008	Assumptions based on known facility activities[a]	Voluntary data collection
		Linear interpolations
		Assumptions based on known facility activities[a]
2009	No production	Voluntary data collection
		Assumptions based on known facility activities[a]
		Interpolations using GO data[b]
2010–2016	No production	Voluntary data collection
		Interpolations using GO data[b]
2017–present	No production	Voluntary data collection
		GHGRP[c]
		Interpolations using GO data[b]

Notes:
a. In cases where facility-reported SF_6 use data are not available, reasonable estimates are derived based on known facility circumstances. For instance, for facilities that ceased operations in a given year, SF_6 consumption is typically estimated proportionally to the number of months in operation and historical usage patterns from the preceding year.
b. For 2009 and onwards, province-specific gross output (GO) economic data for NAICS 331520 (Non-Ferrous Metal Foundries) were used as a proxy variable to quantify facility-specific SF_6 use values when reported values were not available.
c. Facilities that reported to the GHGRP confirmed that the SF_6 emission values reported were solely for emissions coming from the use of SF_6 as cover gas and it is assumed that the situation remains the same for subsequent years.

16 Laperrière J. 2006. Personal communication (email from Laperrière J to Au A, Environment and Climate Change Canada dated October 4, 2006). Norsk Hydro.

17 Katan R. 2006. Personal communication (emails from Katan R to Au A, Environment and Climate Change Canada dated March 16–22, 2006). Timminco.

4.4.4.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for CO_2 emissions from Magnesium Production. It considers the uncertainty associated with facility production capacities, total primary magnesium production, interpolated values, and Tier 1 IPCC default emission factors. The uncertainty of CO_2 emissions varied from 5.50% to 42.43% over 1990 to 2008.

The IPCC Tier 1 methodology is used for the time series of 1990-2008 to quantify CO_2 emissions from Magnesium Production.

A combined Tier 1 uncertainty assessment of SF_6 emissions was performed for Magnesium Production and Magnesium Casting. It considered the uncertainty associated with the SF_6 data reported by each facility. The uncertainty varied from ±2.6% to ±20.7% from 1990 to 2024.

The methodology, which equates consumption of SF_6 as a cover gas to emissions of SF_6, is applied over the time series with some assumptions for some historical years, as discussed in the section 4.4.4.2.

4.4.4.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for this category. In addition, checks are done for this category to ensure SF_6 reported by magnesium casting facilities in the GHGRP is solely from its use as a cover gas.

4.4.4.5. Recalculations

Emission estimates for 2010 to 2023 were recalculated for Magnesium Casting, due to: updates in provincial gross output data for 2010 to 2023; and updates to facility-reported data for 2017 to 2023. The changes were between -0.002 to +260 kt CO_2 eq.

4.4.4.6. Planned Improvements

No improvements are currently planned for this category.

4.4.5. Lead and Zinc Production (CRT Category 2.C.5 and 2.C.6)

4.4.5.1. Category Description

There were two primary lead production facilities in Canada throughout the time series using a direct smelting process, with one facility closing permanently in 2018. There were also nine secondary production facilities processing recycled lead for reuse and four of these facilities have since closed.

Zinc was produced at four facilities throughout the time series. Two of these facilities have ceased operation in 2010 and 2020. One of the two remaining facilities uses a pyro metallurgical process and the other a hydrometallurgical process. The two zinc facilities that closed used a hydrometallurgical process.

Based on national production data, a Tier 1 emission estimate was completed for lead and zinc. However, upon further investigation, the use of reductants accounts for most of these emissions. The fuel and reductant use data are reported to the RESD and owing to its aggregated format, it is currently not possible to allocate the appropriate portion of emissions to CRT category 2.C.5 for Lead Production and 2.C.6 for Zinc Production. Thus, emissions are currently accounted for as part of CRT category 2.D.3 Other (Other and Undifferentiated), and Category 1.A.2.b Non Ferrous Metals. Work is ongoing to identify a method to disaggregate the quantity of reductants throughout the time series.

4.4.6. Rare Earths Production (CRT Category 2.C.7.a)

4.4.6.1. Category Description

'Rare earths' is used to refer to the group of 17 chemically similar metallic elements of scandium, yttrium and the lanthanides, i.e.: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium (IPCC, 2019).

Primary production of many rare earth metals and alloys takes place by dissolving and electrolytically reducing rare earth oxides using consumable carbon anodes (i.e. graphite) in a molten salt of rare earth and lithium fluorides. The consumption of carbon anodes results in process emissions of CO_2. Also, PFCs are formed from the carbon anode reacting with the fluorine in the molten salt during a process upset condition called an 'anode effect'. Anode effects occur when the concentration of rare earth oxides in the molten solution is too low to support the intended production reaction (IPCC, 2019).

Saskatchewan Research Council, a provincial crown corporation, has started to develop and operate Canada's first rare earth processing facility in Saskatoon, Saskatchewan, where they smelt neodymium-praseodymium alloys (Saskatchewan Research Council, 2023a, 2023b, 2024; Boulton, 2024). These alloys also contain small amounts of other rare earths: lanthanum, cerium, and samarium (Saskatchewan Research Council, 2024). They produced 100 kg of metal during a test run in 2022 and started commercial production in 2024 (Saskatchewan Research Council, 2023a, 2023b; Boulton, 2024). In 2024, metal production was estimated to be 124 t and emissions were estimated to be 0.1 kt CO_2 eq.

4.4.6.2. Methodological Issues

CO_2 emissions are estimated by multiplying production values by an IPCC default emission factor and an emission correction factor to account for the atomic weight of the produced alloy (IPCC, 2019). PFC emissions are estimated by multiplying production values with default emission factors (IPCC, 2019). Emission factors and the emission correction factor used are available in Table A6.2–10.

Production data and the atomic weight of produced alloy were gathered from online articles about the facility and a facility brochure (Saskatchewan Research Council, 2023a, 2023b, 2024; Boulton, 2024; Hermandez-Roy and Ziemer, 2025). As production data for 2024 were available for certain months only, a full calendar year production estimate was completed using linear interpolation.

4.4.6.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 approach was used to estimate uncertainty. The calculation includes the default activity data uncertainty and the average of the lower and upper-level uncertainties for the default emission factors (IPCC, 2019). It was assumed that the CO_2 emission factor uncertainty included the uncertainty of the CO_2 emission correction factor, The calculation also incorporated the uncertainty of the interpolated production data. The uncertainty of CO_2 emissions ranges from ±25 to 35% and the uncertainty of PFC emissions ranges from ±40 to 45%.

The same emission factors and emission correction factor were used throughout the time-series.

4.4.6.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for this category.

4.4.6.5. Recalculations

This category was introduced for the first time in the NIR. No recalculations occurred for this category for the current inventory edition.

4.4.6.6. Planned Improvements

No improvements are currently planned for this category.

4.5. Non-Energy Products from Fuels and Solvent Use and Use of Urea in Selective Catalytic Reduction Vehicles (CRT Category 2.D)

4.5.1. Category Description

Non-Energy Products from Fuels and Solvent Use (CRT Category 2.D.1 and 2.D.3)

The Non-Energy Products from Fuels and Solvent Use category includes emissions from the non-energy use of fossil fuels that are not accounted for under any of the other categories of the IPPU sector. The following are examples of fuels in non-energy applications: the use of natural gas liquids (NGLs) and refinery output as feedstocks in the chemical industry and the use of lubricants such as engine oil and grease in transportation and industrial applications, with "use" defined as "close-to-production" consumption of fuel, e.g., burning of motor oil in the engine's combustion chamber (excludes waste oil incineration, which is allocated to the Waste sector). All of these activities result in varying degrees of oxidation of the fuel, producing CO_2 emissions. Also included in this category are emissions from the use of hydrocarbons (such as coal) as reductants for base metal smelting as well as petroleum-based solvents, cleaners and paint thinners.

The use of fossil fuels as feedstock, or for other non-energy purposes, is reported in an aggregated manner by Statistics Canada as "non-energy use" for each individual fuel. Also, to avoid double counting, in the event that CO_2 emissions resulting from non-energy fuel use are allocated to another category of the IPPU sector (as is the case for Ammonia Production, Petrochemical Production, Iron and Steel Production, and Aluminium Production), those emissions are subtracted from the total emissions from this category.

The Non-Energy Products from Fuels and Solvent Use, which is a key category, contributed 12 315 kt (1.8%) to Canada's total emissions in 2024, a 24% increase from 2005.

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles (CRT Category 2.D.3)

Selective catalytic reduction (SCR) is an emission reduction technology that can use urea as a liquid-reducing agent to help reduce NO_x emissions from vehicle exhaust. CO_2 emissions from the use of urea-based additives in the catalytic converters are considered non-combustive emissions. It is assumed that manufacturers started introducing SCR technology into their vehicles starting in 2009. Emissions from the use of urea in SCR vehicles are estimated to be 43 kt CO_2 in 2024.

4.5.2. Methodological Issues

Non-Energy Products from Fuels and Solvent Use (CRT Category 2.D.1 and 2.D.3)

Emission factors for non-energy use of fuels were developed based on the total potential CO_2 emission rates and percentages of carbon stored in products. The total potential CO_2 emission factors were derived from the carbon emission factors shown in Jaques (1992), McCann (2000) and CIEEDAC (2006), which are EFs based on natural units of fuel; the IPCC provides energy unit-based EFs. The fractions or percentages of carbon stored used are IPCC default values (IPCC/OECD/IEA, 1997; IPCC, 2006), which are used to determine the "oxidized during use" (ODU) factor (1 minus the percentage of carbon stored).

The types of non-energy fuels that are included in the estimation model for the Non-Energy Products from Fuels and Solvent Use category are outlined in Table 4–22.

Fuel quantity data for non-energy fuel usage was reported by the RESD (Statistics Canada, n.d.[e]). It should be noted that RESD data for any given year is preliminary and subject to revisions in subsequent publications. This data was multiplied by the emission factors shown in Annex 6 to estimate CO_2 emissions for this category. For example, to estimate emissions coming from non-energy use or oxidation of petroleum products, such as petroleum used for other products, RESD data was multiplied by the potential CO_2 emission factor and by the ODU factor (which is 1 minus the percentage of carbon stored). The percentage of carbon stored in petroleum used as other products, which includes waxes, paraffin and unfinished products, was determined to be equivalent to the default factor from the revised 1996 IPCC Guidelines and not that for paraffin wax as per the 2006 IPCC guidelines, because the disaggregation of paraffin wax use is not possible due to the way the activity data is provided. This technique is consistent with the method described in the 2006 IPCC Guidelines and is a Tier 1 type method, as it is based on the use of national consumption data and average national emission factors.

Emissions from lubricating oils and greases are reported under CRT category 2.D.1 Lubricant Use, while all other emissions for this category are reported under CRT category 2.D.3.d Other (Other and Undifferentiated) since only aggregated data is available. Emissions of CH_4 and N_2O are not estimated because there is no methodological guidance provided in the 2006 IPCC Guidelines. Additional details on the method used to calculate emissions from this category can be found in Annex 3.3.

Table 4–22 **Non-Energy Fuel Types Used in the Canadian GHG Inventory**

Gaseous Fuels	Solid Fuels	Liquid Fuels
Natural gas	Canadian bituminous coal	Propane
	Sub-bituminous coal	Butane
	Foreign bituminous coal	Ethane
	Lignite	Petrochemical feedstocks
	Anthracite	Naphthas
	Metallurgical coke	Lubricating oils and greases
	Petroleum coke	Petroleum used for other products[a]

Note:
a. Other products include waxes, paraffin and unfinished products (items that cannot be identified in end-product terms).

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction Vehicles (CRT Category 2.D.3)

The 2006 IPCC Guidelines recommend that Equation 3.2.2 (Volume 2) be used for the estimation of emissions from the use of urea-based additives in catalytic converters (IPCC, 2006).

For estimating emissions from this source, road transportation activity data were considered. More specifically, vehicle population, fuel consumption ratios and kilometre accumulation rates were used to determine the amount of diesel consumed by these vehicles and consequently the volume of urea-based diesel exhaust fluid (DEF) additive consumed by their SCR catalysts. For more information on the sources of this information, refer to section A3.1.4.2.

To determine the portion of the fleet employing this technology (technology penetration ratio), vehicle certification and regulatory data is used to identify the vehicles equipped with SCR. The Canadian Vehicles in Operation Census and R.L. Polk & Co.'s database for light-duty and heavy-duty vehicles, respectively, were consulted to calculate the annual technology penetration ratios.

A dosing rate representing 2% of the diesel consumption has been employed as it is the midpoint of the range suggested in the 2006 IPCC Guidelines (IPCC, 2006). Additionally, the default DEF purity of 32.5% (IPCC, 2006) was corroborated at Environment Canada's national vehicle emission testing facility, where concentration measurements were taken with a refractometer as part of its testing program.[18]

Disaggregated data on the use of urea-based SCR technology in non-road equipment is currently unavailable. Emissions from these sources are included in the Other Uses of Urea CO_2 estimate described in section 4.3.5.2.

4.5.3. Uncertainty Assessment and Time-series Consistency

Non-Energy Products from Fuels and Solvent Use (CRT Category 2.D.1 and 2.D.3)

A Tier 1 uncertainty assessment was performed for the category of Non-Energy Products from Fuels and Solvent Use. The assessment considered the uncertainties associated with the activity data and emission factors (ICF Consulting, 2004). The uncertainty for the category was estimated at ±20%. It should be noted that the uncertainty assessment was done for only one year of the time series (2007).

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction Vehicles (CRT Category 2.D.3)

A Tier 1 uncertainty assessment was performed for the category of CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles. It considered the uncertainty of the diesel fuel consumption data, the DEF dosing rate, and the DEF purity. The overall uncertainty was found to be ±50%.

For both categories, consistent method and data sources were used throughout the time-series, thus, ensuring the time series consistency.

4.5.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for the Non-Energy Products from Fuels and Solvent Use and Use of Urea in Selective Catalytic Reduction (SCR) Vehicles categories.

4.5.5. Recalculations

Non-Energy Products from Fuels and Solvent Use (CRT Category 2.D.1 and 2.D.3)

CO_2 emissions were recalculated for the entire time series due to updates to the RESD, updates to the use of lubricating oils and greases used in off-road two-stroke engines and an update to the emission factor used for Petroleum coke. The overall impact of all the revisions ranges from a maximum of +440 kt in 2023 to a minimum -527 kt in 2001.

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction Vehicles (CRT Category 2.D.3)

CO_2 emissions were recalculated downwards from 2009 to 2023 using revised diesel fuel consumption data. The largest recalculation was -3 kt CO_2 eq for 2011.

18 Rideout G. 2014. Personal communication (email from Rideout, G. to McKibbon S., Environment and Climate Change Canada dated November 4, 2014). Pollution Inventories and Reporting Division, Environment and Climate Change Canada.

4.5.6. Planned Improvements

Non-Energy Products from Fuels and Solvent Use (CRT Category 2.D.1 and 2.D.3)

Emission factors for various non-energy petroleum products and natural gas were developed based on studies conducted in 1992 and 2005, respectively. Findings from Canada's 2023 in-country review recommended that the most critical improvement to be made is to better understand the extent to which the non-energy fuels accounted for by Statistics Canada are emissive or not, specifically for fuels that currently make-up most of the emissions for this category. There is a plan to evaluate the emissive nature of the most impactful fuels (e.g., Petroleum used for Other products) and update the ODU factor as necessary. In addition, as supporting information becomes available (i.e., information that would allow disaggregation of fuel data and allocation to the appropriate source category) for other (more specific) categories (e.g., iron and steel production, Pb and Zn Production), emissions in the Non-Energy Products from Fuels and Solvent Use category will be revised to avoid double counting of emissions and to improve transparency in the inventory.

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction Vehicles (CRT Category 2.D.3)

As noted in section 4.5.2, the Use of Urea in SCR Vehicles category includes CO_2 emissions from the use of urea-based SCR technology in on-road vehicles only. During the 2025 in-country review, the TERT recommended that Canada also include CO_2 emissions from the use of urea-based SCR technology in non-road equipment in this category. Disaggregated data on these sources are currently unavailable, and any CO_2 emissions are currently included in CRT category 2.B.10.b Other (Other Uses of Urea – CO_2 estimates). Work is ongoing to obtain regulatory data on the use of urea-based SCR technology in non-road equipment.

4.6. Electronics Industry (CRT Category 2.E)

4.6.1. Category Description

Industrial processes related to the electronics industry in Canada include the use of perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) in semiconductor manufacturing and in electronics industry quality control testing. This subsector does not include emissions of SF_6 used in electrical equipment or PFCs used as electrical insulation or a dielectric coolant, as these are included under Other Product Manufacture and Use (CRT subsector 2.G).

It is estimated that emissions from the electronics industry in Canada accounted for about 39 kt CO_2 eq in 2024, a 374% increase from 2005. The increase is driven by a large increase in the proportion of SF_6 sales for semiconductor manufacturing applications and an increase in the amount of PFCs and NF_3 sold for this purpose.

4.6.2. Methodological Issues

PFC Emissions from Semiconductor Manufacturing (CRT Category 2.E.1)

The activity data for PFC usage in the semiconductor industry was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRT category 2.F; refer to section 4.7.2). In addition, some users of PFCs for semiconductor manufacturing from the 2014–2020 gas distributor surveys were independently surveyed and provided annual use quantities for processes. 2020 use quantities were held constant for 2021 onwards in the absence of an up to date data collection. There are two main uses of PFCs in the semiconductor manufacturing industry in Canada: plasma etching of silicon wafers and plasma cleaning of chemical vapour deposition (CVD) chambers.

Over the time series, three PFCs have been used for semiconductor manufacturing: perfluoromethane (CF_4), perfluoroethane (C_2F_6), and perfluorocyclobutane (c-C_4F_8). Use of C_2F_6 in semiconductor processes produces emissions of C_2F_6 as well as by-product emissions of CF_4. Use of c-C_4F_8 in semiconductor processes produces emissions of c-C_4F_8 and by-product emissions of CF_4 and C_2F_6.

The IPCC Tier 2 methodology, as shown in Equation 4–15, was used to estimate PFC emissions from the semiconductor manufacturing industry.

Equation 4–15

$$E_{SC,PFC} = E_{FC} + E_{CF_4} + E_{C_2F_6}$$

$E_{SC,PFC}$ = total PFC emissions from PFC use in semiconductor manufacturing
E_{FC} = emissions resulting from the use of PFCs (see IPCC 2006 Volume 3, Equation 6.2)
E_{CF_4} = CF_4 emitted as a by-product during the use of PFCs (see IPCC 2006 Volume 3, Equation 6.3)
$E_{C_2F_6}$ = $C2F_6$ emitted as a by-product during the use of PFCs (see IPCC 2006 Volume 3, Equation 6.4)

Process-specific Tier 2b emission factors were used when information on process use was available from semiconductor manufacturing facilities or gas distributors. When the process use of the gas was unknown, Tier 2a emission factors were used. Default Tier 2a and Tier 2b emission factors used in IPCC 2006 equations 6.2, 6.3, and 6.4 are found in Table 6.3 of the 2006 IPCC Guidelines. The subset of emission factors used for estimating Canadian emissions are presented in Table A6.2–12.

The heel (h) value, which is the amount assumed to remain in purchased gas canisters after use in semiconductor manufacturing, was assumed to equal 0.1, as suggested in the 2006 IPCC Guidelines. The heel value was not applied when semiconductor users provided data on PFCs fed into processes based on weighing canisters before and after use. As no information on emission control technologies for these processes in Canada was available for 1990–2013 data years, it was assumed that no emission control technologies were used. Two facilities provided annual gas-specific and process-specific values for the fraction of gas volume fed into process types with emission control technology and the fraction of gas destroyed by the emission control technology (respectively a_i and d_i in the IPCC Guidelines) for 2014–2020 data years. These fractions were used to estimate emissions from these facilities and data years. For all other 2014–2020 users, since no information on emission control technologies was available, it was assumed that none were used. In line with holding 2020 activity data constant in 2021 onwards, emission control use rates and destruction efficiencies were held constant at 2020 levels for 2021 onwards, resulting in a constant emissions trend.

NF_3 Emissions from Semiconductor Manufacturing (CRT Category 2.E.1)

NF_3 use in semiconductor manufacturing can result in emissions of NF_3 and by-product emissions of CF_4 (Equation 4–16) (IPCC, 2006). A mix of the Tier 2a and 2b methodologies from the 2006 IPCC Guidelines was used to estimate NF_3 emissions from semiconductor manufacturing. The Tier 2a default factor approach was used for supplier-provided activity data, while the Tier 2b process-specific default factor approach was used for facility-provided activity data. During years when both supplier and facility data were used, the two sources were compared and reconciled to ensure that no double-counting was occurring. Data gaps were filled through interpolation or holding data constant. Table 4–23 summarizes the data sources used to prepare the estimate.

Table 4–23 **Data Sources used to calculate NF_3 Emissions from Semiconductor Manufacturing**

Variable	Years	Data Source Description
Amount of NF_3 used	1990–2009	Activity data was not used in the emissions estimate. The midpoint of the supplier sales range collected in 1986 for the Domestic Substances List (EC, 1986) was used to develop a Tier 2a emission estimate for 1986. 1990–2009 emissions were interpolated between the 1986 estimate (Tier 2a) and the 2010 estimate (mixed Tier 2a and 2b) to avoid a discontinuity from the use of different sets of emission factors. NF_3 use reported in the CRT is interpolated between 1986 and 2010.
	2010–2013	Gas supplier sales data and 2013 semiconductor facility data held constant back to 2010 (Cheminfo, 2013).
	2014–2020	Annual semiconductor facility data.
	2021–present	No data was collected. Held constant at 2020 levels.
Heel remaining in gas containers	1990–2013	The default heel value (IPCC, 2006) is applied to supplier sales data.
	2010–present	The heel is set to zero for semiconductor facility data because it was developed by weighing gas containers before and after use.
Fractional use rate of NF_3 and by-product CF_4 emission factor	1990–2013	Tier 2a default factors (IPCC, 2006) were applied to supplier sales data.
	2010–present	Tier 2b process-specific default factors (IPCC, 2006) were applied to semiconductor facility data.
Emission control technology use rate and destruction efficiency	1990–present	The emission control technology use rate was confirmed to be zero for years 2014–2020 by the sole semiconductor facility user and was assumed to be zero for all years.

Equation 4–16

$$E_{SC,NF_3} = E_{NF_3} + E_{CF_4}$$

E_{SC,NF_3} = total emissions from NF_3 use in semiconductor manufacturing
E_{NF_3} = NF_3 emissions resulting from the use of NF_3 (see IPCC 2006 Volume 3, Equation 6.2)
E_{CF_4} = CF_4 emitted as a by-product during the use of NF_3 (see IPCC 2006 Volume 3, Equation 6.3)

SF_6 Emissions from Semiconductor Manufacturing (CRT Category 2.E.1)

SF_6 use in semiconductor manufacturing can result in emissions of SF_6 (IPCC, 2006). However, unlike the use of PFCs and NF_3, there are no fluorocarbon by-product emissions from SF_6 use. A modified version of the Tier 2a methodology in the 2006 IPCC Guidelines was used to estimate SF_6 emissions from semiconductor manufacturing (Equation 4–17). Data gaps were filled through interpolation, extrapolation using a proxy variable, or holding data constant. Due to data unavailability, the methodology used to estimate 1990 to 2003 emissions differs. An overlap method was used to adjust the 1990 to 2003 data to ensure time-series consistency. Table 4–24 summarizes the data sources used to prepare the estimate.

Equation 4–17

$$E_{SC,SF_6} = (1 - h) \times [FC \times (1 - U) \times \left(1 - \sum_{f=1}^{n} (s_f \times a_f \times d_f)\right)]$$

E_{SC,SF_6} = total emissions from SF_6 use in semiconductor manufacturing
h = heel value of 12%, as provided by two major SF_6 gas suppliers
FC = amount of SF_6 used in the semiconductor manufacturing industry (SF_6 import data multiplied by the annual fraction of SF_6 sales attributed to semiconductor manufacturing)
U = fractional use rate of SF_6 (fraction destroyed or transformed in process), equal to 0.8 (IPCC, 2006)
s_f = facility-specific share of the gas supplier SF_6 sales data attributed to semiconductor manufacturing
a_f = facility-specific emission control technology use fraction
d_f = facility-specific emission control technology SF_6 destruction efficiency

National SF_6 emissions are allocated to provinces with known semiconductor manufacturing facilities (Alberta, British Columbia, Ontario and Quebec) using ECCC economic data on the Computer and Electronic Products Manufacturing industry.

Table 4–24 **Data Sources used to calculate SF_6 Emissions from Semiconductor Manufacturing**

Variable	Years	Data Source Description
Amount of SF_6 used	1990–1994	No data is available. Held constant at 1995 levels with an overlap technique (IPCC, 2006) applied to ensure a consistent trend with the methodology used from 2004 onwards.
	1995–2003	SF_6 sales to semiconductor facilities were reported by suppliers. To ensure a consistent trend with the methodology used from 2004 onwards, an overlap technique (IPCC, 2006) was applied for these data years.
	2004–2009	Annual SF_6 import data (Statistics Canada, n.d.[f]) were multiplied by the annual fraction of SF_6 sales attributed to semiconductor manufacturing. Fractions were developed using data voluntarily collected from gas suppliers.
	2010–2011	Annual SF_6 import data (Statistics Canada, n.d.[f]) were multiplied by the annual fraction of SF_6 sales attributed to semiconductor manufacturing. Fractions were interpolated between 2009 and 2014 in the absence of a gas supplier data collection.
	2012–2013	SF_6 import data were discontinued after 2011. Annual SF_6 import data were extrapolated from 2011 using ECCC economic data (ECCC, 2025b) and multiplied by the annual fraction of SF_6 sales attributed to semiconductor manufacturing. Fractions were interpolated between 2009 and 2014 in the absence of a supplier data collection.
	2014–2020	Annual SF_6 import data were extrapolated from 2011 using ECCC economic data (ECCC, 2025b) and multiplied by the annual fraction of SF_6 sales attributed to semiconductor manufacturing. Fractions were developed using data voluntarily collected from gas suppliers.
	2021–present	Annual SF_6 import data were extrapolated from 2011 using ECCC economic data (ECCC, 2025b) and multiplied by the 2020 annual fraction of SF_6 sales attributed to semiconductor manufacturing in the absence of a gas supplier data collection.
Heel remaining in gas containers	1990–present	A country-specific heel value of 12% was provided and confirmed by two major SF_6 gas suppliers.
Fractional use rate of SF_6	1990–present	The tier 2a default factor (IPCC, 2006) was applied.
Emission control technology use fraction and SF_6 destruction efficiency	1990–2013	No data is available. The emission control technology use rate is assumed to be zero.
	2014–2020	Annual semiconductor facility data was incorporated into the estimate using their facility-specific share of the gas supplier SF_6 sales data attributed to semiconductor manufacturing (variable sf in Equation 4–17).
	2021–present	No data was collected. Held constant at 2020 levels.

PFC Emissions from Other Emissive Applications (CRT Category 2.E.5)

This category comprises PFCs used for the purposes of electronics industry quality control testing, including electrical environmental testing, gross leak testing, thermal shock testing, and failure analysis and short detection applications. Perfluoromethane (CF_4), perfluoroethane (C_2F_6), perfluorocyclobutane (c-C_4F_8) and perfluorohexane (C_6F_{14}) have been used for these applications during the time series.

The activity data for PFC usage in Other Emissive Applications was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRT category 2.F; refer to section 4.7.2). Uses for these applications have been intermittently recorded in surveys during the time series.

Emissions from PFCs used in electronics quality control testing applications are assumed to be prompt and to have a similar emissive time profile to the uses of ozone-depleting substance substitutes in aerosols and solvents applications. The Tier 1a methodology from Equation 7.18 of the 2006 IPCC Guidelines was used to estimate emissions at the application level. Since no emission factors for Other Emissive Applications were available in the 2006 IPCC Guidelines, the default emission factor from the IPCC 2000 Good Practice Guidance document was applied, where 50% of the initial charge is emitted during the first year and the remaining in the following year.

4.6.3. Uncertainty Assessment and Time-series Consistency

Uncertainty assessments were developed for all Electronics Industry categories. The assessments account for the uncertainty of activity data, emission factors, and gap-filling techniques used in estimating emissions as much as possible. In some cases, uncertainty values were calculated for a single year and are assumed to be representative of the entire time-series. Table 4–25 presents a summary of the uncertainty ranges by category and gas.

Time-series consistency was assured as much as possible through use of the splicing techniques described in Volume 1, Chapter 5 of the 2006 IPCC Guidelines (IPCC, 2006).

Table 4–25 **Summary of Uncertainty Assessments for the Electronics Industry**

Category	CRT Category	Uncertainty Assessment Tier Level	Gas	Uncertainty Range	Year Range
Semiconductor Manufacturing	2.E.1	Tier 1	PFCs	±19% to ±321%	1995–present
		Tier 1	NF_3	±261% to ±310%	1990–present
		Tier 1	SF_6	±45%	1990–present
Other Emissive Applications	2.E.5.b	Tier 1	PFCs	±50%	1995–present

4.6.4. QA/QC and Verification

Categories under the Electronics Industry subsector have undergone checks as outlined in section 4.1.

In addition, the following informal checks are conducted for estimating PFCs, NF_3, and SF_6 emissions from semiconductor manufacturing:

- Large inter-year changes in activity data (i.e., the annual number of users and quantities of specific gases sold by each gas distributor) prompt verification and explanation from the data provider.
- User-level purchase and use data are compared against the sales reports of gas distributors.
- At a facility-level, the specific gas/process combinations are compared between years for consistency.
- Facility-provided destruction efficiencies for abatement equipment are compared with those provided by the equipment manufacturers and are cross-checked against the Tier 2a and Tier 2b default efficiency parameters in IPCC 2006, Volume 3, Table 6.6.

4.6.5. Recalculations

SF_6 Emissions from Semiconductor Manufacturing (CRT Category 2.E.1)

Emissions were recalculated for years 2012–2023 due to the revision of ECCC economic data for the Computer and Electronic Products Manufacturing industry. The largest impact of these recalculations was -1 kt CO_2 eq in 2023.

No recalculations occurred for PFC or NF_3 emissions from this category for the current inventory edition.

4.6.6. Planned Improvements

Voluntary data surveys for 2021–2024 were not collected, and 2021–2024 use levels and emissions were held constant at 2020 levels. A voluntary data collection of 2021–2024 data is pending to obtain updated PFC, SF_6, and NF_3 use data.

4.7. Product Uses as Substitutes for Ozone-Depleting Substances (CRT Category 2.F)

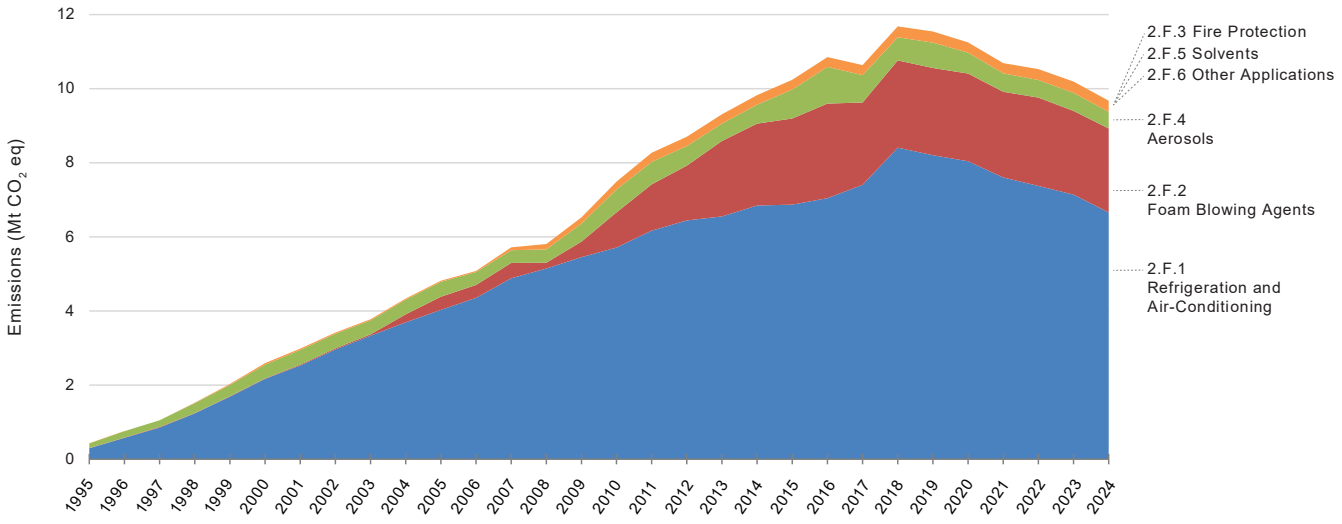
4.7.1. Category Description

Product Uses as Substitutes for Ozone-Depleting Substances, HFCs

Before the Montreal Protocol ban on the production and use of chlorofluorocarbons came into effect in 1996, very few hydrofluorocarbons (HFCs) were produced and used globally (IPCC/OECD/IEA, 1997). Canadian emissions from HFC consumption were considered negligible for the 1990–1994 period, and HFC consumption in Canada is assumed to begin in 1995. HFCs are used in a variety of applications, including refrigeration, air-conditioning, fire protection, aerosols, solvents, and foam blowing agents. No production of HFCs has occurred in Canada, so all HFCs consumed are imported in bulk or in manufactured items (e.g., refrigerators).

HFC releases contributed approximately 9 679 kt CO_2 eq (1.4%) to Canada's total emissions in 2024, a 101% increase from 2005 that can be explained by their phase-in as substitutes for ozone-depleting substances. The Refrigeration and Air-Conditioning (CRT 2.F.1) and Foam Blowing Agents (CRT 2.F.2) applications are the largest sources of HFC emissions and are key categories (Figure 4–2). Since a peak in 2018 at 11 682 kt CO_2 eq, HFC emissions have declined by 17%, in part due to reduced imports of bulk HFCs. This reduction coincides with the implementation of the Ozone-depleting Substances and Halocarbon Alternatives Regulations. As of 2024, these regulations limit national net HFC imports (expressed in CO_2 equivalent mass) to 60% of a 2011 to 2013 consumption baseline.[19]

Figure 4–2 **Emissions from HFCs used as Substitutes for Ozone-Depleting Substances, by Application**



19 The Ozone-depleting Substances and Halocarbon Alternative Regulations can be accessed here: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2016-137/.

Product Uses as Substitutes for Ozone-Depleting Substances, PFCs

Perfluorocarbon (PFC) consumption in Canada began in 1995. Like HFCs, PFCs are also used as substitutes for Ozone-Depleting Substances (ODS) being phased out under the Montreal Protocol (IPCC, 2006). However, the uses of PFCs are very limited compared to HFCs in Canada. Canadian applications that have used PFCs as Substitutes for ODS over the time series include Refrigeration and Air-Conditioning, Foam Blowing Agents, and Solvents. Emissions of PFCs contribute to the key category of Refrigeration and Air-Conditioning (CRT 2.F.1) in the most recent data year, though emissions of HFCs make up the majority of emissions from this category.

PFC releases contributed to approximately 6 kt CO_2 eq in 2024, a 217% increase from 2005.

4.7.2. Methodological Issues

Product Uses as Substitutes for Ozone-Depleting Substances, HFCs

Activity Data

Canadian HFC use data is derived from bulk imports, and imports and exports of manufactured items. Canada occasionally re-exports small quantities of unused HFCs in bulk.

Data on bulk HFC imports and exports or domestic sales are available for most of the time-series and were collected through a mix of mandatory and voluntary surveys. A data gap for the year 2016 was filled in using extrapolation from 2015. Most recently, for calendar years 2017 onwards, bulk HFC data has been collected from mandatory reporting under the *Ozone-depleting Substances and Halocarbon Alternatives Regulations*.[20]

Data on HFCs in manufactured item imports and exports are available until 2015 and were collected sporadically through a mix of mandatory and voluntary surveys. Data gaps were filled using interpolation or extrapolation. The last comprehensive manufactured item data year is 2010. Imports and exports of manufactured items have been extrapolated from 2011 onwards using proxy variables such as deflated economic data to estimate the growth or decline in HFC consumption for a given end-use (application or sub-application).

All activity data has been provided at a Tier 2a sub-application level or is broken down to a sub-application level using ratios from detailed reporting in previous data years or through in-house research of the companies involved. More information on the received data, the applications and sub-applications, the disaggregation methodology, and the extrapolation methodologies are available in section A3.3.3.

The full list of HFCs and the activity data years in which they appeared are shown in Table 4–26.

Table 4–26 **HFCs Used in Canada and Years of Appearance in Activity Data**

HFC Type	Years	HFC Type	Years
HFC-125	1995–2015, 2017–2024	HFC-23	1995–2004, 2008–2015, 2017–2024
HFC-134	2008–2009, 2015, 2017–2024	HFC-236fa	1996–1998, 2000–2004, 2008, 2010, 2012–2013, 2020–2021
HFC-134a	1995–2015, 2017–2024	HFC-245fa	2001–2015, 2017–2024
HFC-143	2013 and 2023	HFC-32	1995–2015, 2017–2024
HFC-143a	1995–2015, 2017–2024	HFC-365mfc	2008–2015, 2017–2020
HFC-152	2024	HFC-41	1999–2000
HFC-152a	1995–2015, 2017–2024	HFC-4310mee	1998–2015, 2018–2020, 2024
HFC-227ea	1995–2015, 2017–2024		

Table 4–27 shows the breakdown of 2024 bulk HFC import data by HFC type and by assigned application.

There are two facilities in Canada, Fielding Environmental in Mississauga, Ontario and Refrigerant Services Inc. in Dartmouth, Nova Scotia, that can reclaim refrigerants (HRAI, 2023). Until May 31st, 2021, SUEZ Waste Services in Swan Hills, Alberta destroyed refrigerants.[21] PureSphera in Bécancour, Quebec may also recover and/or destroy HFCs from end-of-life refrigeration equipment.[22] However, no data is publicly available on the amount of HFCs destroyed or reclaimed in Canada.

20 Lists of HFC consumption allowance holders by calendar year can be accessed here: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/permits/authorizations-ozone-depleting-substances.html.

21 Czajko, C., Larsen, N. Personal communication (Microsoft Teams meeting discussion between Czajko, C., Larsen, N., and Industry Section of the Pollutant Inventories and Reporting Division of ECCC dated April 12, 2021). Heating, Refrigeration and Air Conditioning Institute of Canada – Refrigerant Management Canada.

22 PureSphera's recovery process is described here: https://www.puresphera.com/en/technologies-propres.

Table 4–27 **2024 Bulk HFC Imports by Type per Application**

HFC Type	2.F.1 Refrigeration and Air-Conditioning	2.F.2 Foam Blowing Agents	2.F.3 Fire Protection	2.F.4 Aerosols	2.F.5 Solvents	2.F.6 Other Applications	Total bulk HFC imports
HFC-23	0.0%	-	-	-	-	-	0.0%
HFC-32	19.2%	-	43.1%	-	100.0%	-	12.4%
HFC-4310mee	-	-	-	0.1%	-	-	0.0%
HFC-125	28.5%	-	56.9%	-	0.0%	-	18.2%
HFC-134a	42.4%	9.7%	-	2.6%	0.0%	0.6%	29.4%
HFC-143a	9.6%	-	-	-	0.0%	-	6.1%
HFC-152	0.1%	-	-	-	-	-	0.1%
HFC-152a	0.0%	90.3%	-	97.4%	-	99.4%	33.8%
HFC-227ea	0.1%	-	-	-	-	-	0.1%
HFC-245fa	-	-	-	-	0.0%	-	0.0%
Application share of total bulk imports	63.8%	19.3%	0.0%	16.8%	0.1%	0.0%	100.0%

Notes:
2024 bulk HFC import quantitites were obtained through reporting under the Ozone-depleting Substances and Halocarbon Alternatives Regulations. Data was disaggregated to applications and sub-applications at the company and gas level using ratios from detailed reporting in previous data years or through in-house research. See Annex 3, section A3.3.3 for more details on the data disaggregation methodology.
Totals may not add up due to rounding.
""-"" indicates that there were no imports of the HFC type assigned to the application.
0.0% indicates that imports were assigned to the application, but were small and are truncated due to rounding.

Emission Factors

Surveys were performed in 2012 to document practices in HFC use and disposal in the refrigeration and air-conditioning industry to support the development of country-specific emission factors that are representative of Canada's circumstances (Environmental Health Strategies Inc., 2013; ECCC, 2015). Additional information on survey results and quality control procedures can be found in section A3.3.3.3. The country-specific emission factors were applied for the entire time-series.

For all other applications, default Tier 1 emission factors from Volume 3, Chapter 7 (IPCC, 2006) were used. All emission factors are presented with references in Annex 6.

Estimation Methodology

Because the actual numbers of the various types of equipment are not available for Canada, the IPCC Tier 1a/2a approach (IPCC, 2006) was used with the annual quantities of HFC consumed by application and sub-application, as discussed in Volume 3, Chapter 7, section 7.1.2.1 (IPCC, 2006). Tier 2a methods were used for the refrigeration and air conditioning applications, applying country-specific emission factors (IPCC, 2006). Tier 1a methods were used for all other applications, where sub-application-level activity data were multiplied by default emission factors for the application (IPCC, 2006). For the calculation of the net consumption of each HFC in each sub-application, Equation 7.1 from Volume 3, Chapter 7 (IPCC, 2006) has been adapted to the Canadian context and used. Refer to section A3.3.3 for additional details on methodology.

The lifecycle of each HFC is tracked by sub-application and year, and annual emissions are estimated for each applicable lifecycle stage (assembly of the product, in-service operation of the product and end-of-life decommissioning). The annual quantity of each HFC that remains in products (in stock) after assembly, during the in-service life of the product, and at the end-of-life decommissioning stage is also calculated. In this way, the mathematically expanded version of the method discussed in Volume 3, Chapter 7, section 7.1.2.2 (IPCC, 2006) and subsequent sections are applied. Emissions for each lifecycle stage are estimated for each sub-application by multiplying the HFC quantity in that stage by its corresponding emission factor. The HFC emission estimation equations applied for each unique application or sub-application are explained in more detail in section A3.3.3.

Once calculated at the national level, emissions for each year, sub-application, and lifecycle stage are allocated to provinces and territories using proxy variables such as population, floor space, and economic data.

Product Uses as Substitutes for Ozone-Depleting Substances, PFCs

The 2006 IPCC Tier 1a/2a methodologies were used to estimate emissions from the consumption of PFCs in various applications for the years 1995 onwards. Details of the methods are found in the following subsections. The 1995–2000 activity data was obtained through the 1998 and 2001 PFC surveys conducted by Environment Canada. As 2001 and 2002 data was unavailable, emission estimates were developed based on the assumption that the use quantities in various applications stayed constant after 2000. Environment Canada conducted a voluntary collection of 2003–2007 PFC use data from major distributors in 2008 and 2009. The data from the major distributors was then integrated with existing PFC use data. The 2008 and 2009 PFC use data from major distributors was voluntarily collected in 2009 and 2010. 2014–2020 PFC data was collected from gas distributors in 2019, 2020 and 2021 voluntary surveys. 2020 use quantities were held constant for 2021 onwards in the absence of PFC data collection. To estimate PFC use for the 2010–2013 period, sub-application use quantities were interpolated between the 2009 and 2014 activity data.

In addition, 2008–2015 HFC/PFC blend activity data was collected through 2014 and 2016 mandatory HFC surveys, and 2017–2024 HFC/PFC blend activity data was collected through mandatory HFC surveys in 2018 onwards. 2016 HFC/PFC blend activity data was interpolated between the 2015 and 2017 activity data. The PFC component of the blend activity data was disaggregated using IPCC 2006, Volume 3, Table 7.8.

Emission factors applied for the use of PFCs as ODS Substitutes are presented in Table A6.2–14.

Refrigeration and Air Conditioning (CRT Category 2.F.1, PFCs)

The IPCC Tier 2a methodology, i.e., equations 12, 13 and 14 from Volume 3, Chapter 7, section 7.5 of the 2006 IPCC Guidelines, was used to estimate the emissions from the assembly, operation and disposal of the following sub-applications: commercial refrigeration and stationary air conditioning systems. No other refrigeration and air conditioning sub-applications have been reported in surveys throughout the time series.

The assembly losses (k values) and annual operating leakage rates (x values) used were chosen from a range of values that were provided for each sub-application in the 2006 IPCC Guidelines. Loss and leakage rates by sub-application can be seen in Table A6.2–14.

The refrigerant "bank" used for this calculation includes the amount of PFCs contained in imported or manufactured equipment in Canada and excludes the amount of PFCs exported and lost during assembly.

PFC use in Canada began in 1995. It is assumed that there were no PFC emissions from the disposal of refrigeration and stationary air conditioning systems between 1995 and 2009 since these systems have an average lifespan of 15 years (IPCC 2006). An additional assumption is that there are no recovery or recycling technologies in place and therefore 100% of the quantities remaining in systems are released once the end of the lifespan is reached, i.e. any remaining refrigerant in a refrigeration system built in 1995 would be emitted in the year 2010. Fluctuations in annual emissions are to be expected during years where the lifespans have been reached and the remaining PFCs in the systems are disposed of.

Over the time series, perfluoromethane (CF_4), perfluoroethane (C_2F_6), and perfluoropropane (C_3F_8) have been used as commercial refrigerants or in commercial refrigerant blends, and as of 2020, a small quantity of C_2F_6 continues to be imported annually in R-508B blends for the service and maintenance of commercial refrigerators.

In addition, C_2F_6 (or blends containing it) have been used in stationary air-conditioning. Use was last reported in 2008, although in-service and end-of-life emissions continued to be estimated through 2023.

Uses of PFCs in commercial refrigeration contribute a total of around 4 kt CO_2 eq in 2024.

Foam Blowing Agents (CRT Category 2.F.2, PFCs)

The use of perfluoropentane (C_5F_{12}) in closed-cell foam was reported in the 1995–1997 activity data collection that took place in 1998. A facility used C_5F_{12} for the manufacturing of rigid phenolic foam boards until it closed in August 1997. Since then, no other uses of PFCs in closed-cell foam have been reported.

Uses of PFCs in open-cell foams has never been reported in any data collection. Therefore, emissions from this source are expected to be negligible.

To estimate emissions from closed-cell foams, a Tier 2a approach for a specific process was applied using IPCC 2006 Phenolic Block sub-application default emission factors for HFC-245fa/HFC-365mfc/HFC-227ea. Equation 7.7 from Volume 3, Chapter 7, section 7.4, of the 2006 IPCC Guidelines was used to estimate the emissions from closed-cell foam sub-applications. During the production of closed-cell foam, approximately 45% of the PFCs used in manufacturing are emitted. The remaining quantity of PFCs is trapped in the foam and is slowly emitted at a rate of 0.75% of the original charge per year over a period of approximately 15 years (IPCC, 2006).

The estimated in-service emissions from the C_5F_{12} used as a closed-cell foam blowing agent expired in 2011.

Fire Protection (CRT Category 2.F.3, PFCs)

Uses of PFCs in Fire Protection applications has never been reported in any data collection. Therefore, emissions from this source are expected to be negligible.

Aerosols (CRT Category 2.F.4, PFCs)

Uses of PFCs as aerosol propellants has never been reported in any data collection. Therefore, emissions from this source are expected to be negligible. Emissions from PFCs imported in aerosol cans that are used as solvents are reported in the Solvents category.

Solvents (CRT Category 2.F.5, PFCs)

Uses of CF_4, C_2F_6, perfluorocyclobutane (c-C_4F_8), C_5F_{12} and perfluorohexane (C_6F_{14}) as solvents has been recorded during the time series. Main sub-applications include electronics cleaning, laboratory solvents, and carrier solvents for various products (e.g., protective coating, mould release agents, lubricants).

The IPCC Tier 1a methodology presented in the 2006 IPCC Guidelines was used to estimate PFC emissions from solvents. A product lifetime of two years was assumed and a default IPCC emission factor of 50 percent of the initial charge/year was used (IPCC, 2006). Equation 7.5 from Volume 3, Chapter 7, section 7.2, of the 2006 IPCC Guidelines was used to estimate emissions for each year and is calculated to be half of the PFCs used as solvents in the estimated year plus half of the PFCs used as solvents in the previous year. The amount of PFCs used each year is equal to the amount of PFCs produced and imported as solvents and excludes the amount of PFCs exported as solvents.

In 2024, emissions from the uses of CF_4 and C_2F_6 in solvent applications contributed less than 3 kt CO_2 eq.

4.7.3. Uncertainty Assessment and Time-series Consistency

Product Uses as Substitutes for Ozone-Depleting Substances, HFCs

A Monte Carlo uncertainty assessment was performed for the consumption of HFCs. It took into account the uncertainties associated with all sub-applications, such as commercial refrigeration, mobile air conditioning, etc. Uncertainties related to activity data (Cheminfo Services, 2005c) and emission factors from Volume 3, Chapter 7 (IPCC, 2006) were used to determine the uncertainty for each sub-application. The uncertainty associated with the category as a whole was ± 11%.

Time-series consistency was assured through the use of splicing techniques described in Volume 1, Chapter 5 of the 2006 IPCC Guidelines (IPCC, 2006).

Product Uses as Substitutes for Ozone-Depleting Substances, PFCs

A Tier 1 uncertainty assessment was performed for PFC consumption for the years 1995–2008. As in the case of HFC consumption, uncertainties related to activity data (IPCC, 2006) and emission factors (Japan Ministry of the Environment, 2009) were taken into account in the assessment for PFC consumption. The uncertainty associated with the category as a whole for the time series ranged from ±9% to ±23%. The current year uncertainty is assumed to be ±23%, equal to the highest and most recent (2008) uncertainty in the range assessed. The base year (1990) uncertainty is zero since the use of PFCs as ODS substitutes did not begin until 1995.

For emissions of PFCs, time-series consistency was retained using splicing techniques described in Volume 1, Chapter 5 of the 2006 IPCC Guidelines (IPCC, 2006). These techniques included interpolation and trend extrapolation in the absence of data collection for certain years, as described in section 4.7.2.

4.7.4. QA/QC and Verification

The general Tier 1 quality control procedures described in section 4.1 were applied for HFCs and PFCs in this category.

In addition, the following checks have been performed:

- Check to ensure that there is no double-counting between the same-year activity data from the voluntary surveys of PFCs collected from gas distributors and the mandatory surveys on HFC/PFC blends.
- Check to compare HFC data reported by companies against their consumption allowances under the Ozone-Depleting Substances and Halocarbon Alternatives Regulations.

4.7.5. Recalculations

Product Uses as Substitutes for Ozone-Depleting Substances, HFCs

There are recalculations for this category for 2010–2023 due to corrections made to bulk HFC data processing and the use of updated proxy variables used in extrapolations. The recalculations range from -407 kt CO_2 eq (-4%) in 2014 to +229 kt CO_2 eq (+2%) in 2018. Provincial estimates were also recalculated using updated proxy variables.

Product Uses as Substitutes for Ozone-Depleting Substances, PFCs

No recalculations occurred for PFC emissions from this category for the current inventory edition.

4.7.6. Planned Improvements

Product Uses as Substitutes for Ozone-Depleting Substances, HFCs

A data gap exists with the manufactured item import and export data, for which the last completely surveyed year is 2010. Quantities from 2010 along with some incomplete 2011–2015 data are extrapolated forward using proxy variables to complete the time-series. To fill in the data gap and to address a 2025 in-country TERT recommendation, an investigation is being carried out on existing statistical data on the imports, exports and sales of manufactured items that can contain HFCs. As well, communication with industry stakeholders is ongoing, so that information necessary for integration into the inventory can be obtained.

The end-of-life disposal loss factors for the refrigeration and air-conditioning application were selected using the results of a 2012 study and an in-house review (EHS, 2013; ECCC, 2015). For all other applications, Tier 1 default disposal loss factors from Volume 3, Chapter 7 are used (IPCC, 2006). To validate (or update) these factors and to address a 2025 in-country TERT recommendation, searches and communication with various stakeholders, such as refrigerant management programs and reclamation and destruction facilities are being made.

Product Uses as Substitutes for Ozone-Depleting Substances, PFCs

Voluntary data surveys for 2021–2024 were not collected, and 2021–2024 use levels were held constant at 2020 levels for most applications. A voluntary data collection of 2021–2024 data is pending to obtain updated PFC distribution and use data.

Solvents (CRT Category 2.F.5, PFCs)

Some of the recent (2014–2020) voluntary data surveys completed by gas distributors are annual sales reports with company names and the quantities sold and no additional information on end-use. A large portion of the quantity of PFCs attributed to use as solvents is based on research conducted by inventory compilers. Given the wide variety of possible uses of solvents (and PFCs), the categorical allocation and emissions profiles of solvent uses have a high degree of uncertainty. Users of PFCs as solvents will be contacted to confirm the categorical allocation and emissions profile of their solvent use (if possible).

4.8. Other Product Manufacture and Use (CRT Category 2.G)

4.8.1. Category Description

The Other Product Manufacture and Use category includes emissions from the use of Sulphur Hexafluoride (SF_6) in electrical equipment (CRT category 2.G.1), Nitrous Oxide (N_2O) emissions from medical applications (CRT category 2.G.3.a), N_2O emissions from use as a propellant (CRT category 2.G.3.b) and Perfluorocarbon (PFC) Emissions from Other Contained Product Uses (CRT category 2.G.4) such as uses as an electrical insulator or as a dielectric coolant, which are not ODS substitutes or electronics industry-related.

In electric utilities, SF_6 is used as an insulating and arc-quenching medium in high-tension electrical equipment, such as electrical switchgear, stand-alone circuit breakers and gas-insulated substations. In Canada, SF_6 is primarily used in high-voltage circuit breakers and related equipment. Emissions during equipment use are a result of leakages during gas transfer and handling operations and leakages during normal operation of the equipment. To keep equipment properly charged and operational, utilities must fill their equipment to replace the amount that has escaped.

Nitrous Oxide of Canada (NOC) in Maitland, Ontario, is the only known producer of compressed N_2O for commercial sales in Canada. It supplies N_2O to two of the three primary N_2O gas distributors that essentially account for the total commercial market in Canada. These companies sell cylinders of N_2O to a relatively large number of sub-distributors. It is estimated that there may be 9000 to 12 000 final end-use customers for N_2O in Canada, including dental offices, clinics, hospitals and laboratories (Cheminfo Services, 2006). In addition to domestic sales of N_2O produced in Canada, a portion of N_2O used is imported. Quantities of N_2O imported were obtained by the 2006 Cheminfo study for 1990 to 1997; through Statistics Canada for 2008 to 2011; and linearly interpolated from 2012 onwards due to changes in the disaggregation of Statistics Canada information.

Of all applications in which N_2O can be used in Canada, only anaesthetic and propellant uses of N_2O are considered emissive. Anaesthetic use represents the largest type of N_2O end use in Canada and it is assumed that none of the N_2O is metabolized (IPCC 2006). Use as a propellant in food products is the second-largest type of end use in Canada, with only emissions coming from N_2O in whipped cream being considered significant. N_2O is not reacted during the anaesthetic and propellant processes; therefore, all N_2O used is emitted to the atmosphere (Cheminfo Services, 2006).

Other areas where N_2O can be used include production of sodium azide (a chemical that is used to inflate automobile airbags), atomic absorption spectrometry and semiconductor manufacturing. According to the distributors surveyed during the 2006 study, approximately 82% of their N_2O sales volume is used in dentistry/medical applications, 15% in food processing propellants and only 3% for the other uses (Cheminfo Services, 2006).

PFCs can be used as electrical insulation or as a dielectric coolant in contained product use applications, including waveguide radar systems and circuit breakers. Emissions of PFCs occur over the product lifetime, such as during product assembly, through slow leaks or normal operations (while the equipment is in-service) and at the end-of-life during deconstruction or landfilling of the equipment.

The Other Product Manufacture and Use category contributed about 684 kt (<0.1%) to Canada's total emissions in 2024, a 35% increase from 2005.

4.8.2. Methodological Issues

Sulphur Hexafluoride Emissions from Electrical Equipment (CRT Category 2.G.1)

A modified Tier 3 method was used to estimate SF_6 emissions from electrical equipment in utilities for years 2006 onwards, in place of the previous top-down approach (which assumed that all SF_6 purchased from gas distributors replaces SF_6 lost through leakage). The SF_6 emission estimates by province for 2006 onwards are provided by the Canadian Electricity Association (CEA), which represent electricity companies across Canada. CEA data was prepared following the SF_6 Emission Estimation and Reporting Protocol for Electric Utilities ("the Protocol") (Environment Canada and Canadian Electricity Association). Note that CEA does not provide corresponding activity data. However, the quantification of emissions in the methodologies used is based on the mass of SF_6 injected into the equipment or contained in the cylinders. The national SF_6 estimate for each year during the 2006–2024 period was the sum of all provincial estimates. The Protocol is the result of a collaborative effort between Environment Canada, CEA and Hydro-Québec.

In summary, the Protocol explains how the (country-specific) modified Tier 3 method was derived from the IPCC Tier 3 life-cycle methodology. It also explains the different options available for estimating the equipment life-cycle emissions. These are equal to the sum of SF_6 used to top up the equipment and the equipment disposal and failure emissions (which are equal to either nameplate capacity less recovered quantity for disposal emissions or simply to nameplate capacity for failure emissions). A more detailed description of the methodology is provided in Annex 3.3.

Estimates were not available from CEA or Hydro-Québec for the years 1990 to 2005 because a systematic manner for taking inventory of the quantities of SF_6 from these organizations only started in the 2006 data year. Hence, the application of the Protocol was not possible. Surveys of SF_6 distributors were used to obtain usage data prior to the application of the Protocol. To resolve this issue of data availability and to ensure a consistent time series, an overlap technique (IPCC 2006, Volume 1, Chapter 5) was applied. In this case, the overlap was assessed between four sets of annual estimates (2006–2009) derived from the distributor surveys and obtained under the Protocol.

Emissions at provincial/territorial levels were estimated based on the national emission estimates (obtained from the use of the overlap approach) and the percent of provincial shares (based on the reported 2006–2009 data).

Nitrous Oxide Emissions from Medical Applications (CRT Category 2.G.3.a) and Propellant Usage (CRT Category 2.G.3.b)

N_2O emission estimates for these categories are based on a consumption approach. Since it is virtually impossible to collect consumption data from all end users, it is assumed that domestic sales and imports (obtained directly from NOC) equal domestic consumption. Equation 8.24 of the 2006 IPCC Guidelines was used to estimate N_2O emissions and covers more than one calendar year because both supply and use are assumed to be continuous over the year; for example, N_2O supplied in the middle of a calendar year is not fully used until the middle of the following calendar year.

The producer and distributors were surveyed to obtain sales data by market segment and qualitative information to establish the 2005 Canadian N_2O sales pattern by application (Cheminfo Services, 2006). The sales patterns for 2006 onwards are assumed to be the same as that for 2005. The amounts of N_2O sold for anaesthetic and propellant purposes are calculated from the total domestic sales volume and their respective share of sales.

Provincial and territorial estimates were developed by distributing the national-level estimates based on provincial/territorial population data (Statistics Canada, n.d.[d]).

Perfluorocarbon Emissions from Other Contained Product Uses (CRT Category 2.G.4)

The activity data on PFCs used in Other Contained Products were collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRT category 2.F; refer to section 4.7.2). Over the time series, perfluoromethane (CF_4), perfluoroethane (C_2F_6) and perfluorohexane (C_6F_{14}) have been used for electrical insulation within contained products and perfluoropropane (C_3F_8) and C_6F_{14} have been used as dielectric coolants within contained products.

The IPCC Tier 1 method for other contained applications of ODS substitutes (IPCC, 2006) is used to calculate PFC Emissions for Other Contained Product Uses. Since no emission factors are available in the 2006 IPCC Guidelines, default emission factors from the IPCC 2000 Good Practice Guidance document are used. They assume a leakage rate of approximately 1% during the manufacturing process and an annual leakage rate of 2% during the equipment lifetime of 15 years (IPCC, 2000). It is assumed that there are no recovery or recycling technologies in place and therefore 100% of the PFCs remaining in Other Contained Products are released once the end of the lifespan is reached. These emission factors are presented in Table A6.3–2 and are applied to the PFC data in accordance with Equation 7.19 of the 2006 IPCC Guidelines.

4.8.3. Uncertainty Assessment and Time-series Consistency

Sulphur Hexafluoride Emissions from Electrical Equipment (CRT Category 2.G.1)

A Tier 1 uncertainty assessment was performed for the category of SF_6 from Electrical Equipment. It should be noted, however, that the uncertainty assessment was done using 2007 data. It is expected that emission estimates of this submission would have much lower uncertainty values. The uncertainty for the category was estimated at ±30.0%. Depending on the years, the data source and methodology used for SF_6 from electrical equipment could vary, as explained in section 4.8.2 (Methodological Issues).

Nitrous Oxide Emissions from Medical Applications (CRT Category 2.G.3.a) and Propellant Usage (CRT Category 2.G.3.b)

A Tier 1 uncertainty assessment was performed for the categories of N_2O Emissions from Medical Applications and Propellant Usage. It considered the uncertainties associated with domestic sales, import, sales patterns and emission factors. The uncertainty for these combined categories was evaluated at ±20%. It is expected that the uncertainty for this sector would not vary considerably from year to year as the data sources and methodology applied are the same.

Perfluorocarbon Emissions from Other Contained Product Uses (CRT Category 2.G.4)

A Tier 1 uncertainty assessment was performed for the category of PFC Emissions from Other Contained Product Uses. Uncertainties related to the gas distributor and facility activity data are assumed to be 2% and the emission factor uncertainty was assessed to be 50% (Japan Ministry of the Environment, 2009). The current year uncertainty is 51%, and the base year uncertainty is zero since emissions of PFCs for these applications did not begin until 1995.

For emissions of PFCs, time-series consistency was retained using splicing techniques described in Volume 1, Chapter 5 of the 2006 IPCC Guidelines (IPCC, 2006). These techniques included interpolation and trend extrapolation in the absence of data collection for certain years, as described in section 4.7.2.

4.8.4. QA/QC and Verification

The general Tier 1 quality control procedures and informal checks described in section 4.1 were applied for this category.

4.8.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

4.8.6. Planned Improvements

Sulphur Hexafluoride Emissions from Electrical Equipment (CRT Category 2.G.1)

As mentioned previously, SF_6 is used as an insulating and arc-quenching medium in electrical transmission and distribution equipment. To enhance performance in cold weather, SF_6 gas can be mixed with carbon tetrafluoride (CF_4) gas. Currently, Canada only reports SF_6 from this source category (CRT category 2.G.1). There are plans to collect CF_4 emission data to report in future inventory submissions.

Sulphur Hexafluoride and Perfluorocarbon Emissions from Other Product Use (CRT Category 2.G.2)

This category is a catch-all for product uses of SF_6 and PFCs that are not covered under other CRT categories and is currently reported as "NE" in the CRT reporter. Historical sales data collected from gas suppliers through voluntary data surveys indicate some use of SF_6 and PFCs for applications mentioned in the 2006 IPCC Guidelines (Volume 3, section 8.3).

A 2025 in-country TERT recommendation also suggested assessing the category significance based on a top-down methodology using, for example, import/export data. As such, a voluntary data collection survey is being planned.

Nitrous Oxide Emissions from Medical Applications (CRT Category 2.G.3.a) and Propellant Usage (CRT Category 2.G.3.b)

There are plans to validate the current Canadian N_2O sales pattern by application, and if necessary, updating it to improve the accuracy of N_2O emissions under CRT categories 2.G.3.a and 2.G.3.b.

Perfluorocarbon Emissions from Other Contained Product Uses (CRT Category 2.G.4)

This category is country-specific. A 2025 in-country review comment recommended the reallocation of all activity data in this category to other categories to improve the comparability of the inventory. Legacy data sources are being examined to ensure that emission estimates are reattributed to the correct category(ies).

CHAPTER 5

AGRICULTURE (CRT SECTOR 3)

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5.1. Overview

The contribution of the Agriculture sector was 7% of Canada's total greenhouse gas (GHG) emissions from 1990 until 2020, when the contribution rose to 8% through 2024 as a result of decreases in emissions in other sectors, while agricultural emissions remained constant. Emissions in the sector increased by 32% between 1990 and 2024. Emission source categories in the Agriculture sector include Enteric Fermentation (methane [CH_4]) and Manure Management (nitrous oxide [N_2O] and CH_4), for emissions associated with livestock production and Agricultural Soils (N_2O), and Field Burning of Agricultural Residues (CH_4 and N_2O), for emissions associated with crop production. Carbon dioxide (CO_2) emissions from Liming and Urea Application are reported in the Agriculture sector; however, CO_2 emissions from and removals by agricultural land are accounted for in the Cropland category of the Land Use, Land-Use Change and Forestry (LULUCF) sector (see Chapter 6). GHG emissions from on-farm fuel combustion are reported in the Energy sector (Chapter 3).

The largest sectors in Canadian agriculture are beef cattle (Non-Dairy Cattle category), swine, cereal and oilseed production. There are also substantial poultry and dairy industries. Sheep are raised, but production is highly localized and small compared to the beef, swine, dairy and poultry industries. Other alternative livestock, namely bison,[1] llamas, alpacas, horses, goats, elk, deer, wild boars, foxes, minks, rabbits, and mules and asses, are produced for commercial purposes, but production is small.

Canadian agriculture is highly regionalized due to historical and climatic influences. Approximately 75% of beef cattle and more than 90% of wheat, barley and canola are produced in the Prairies, a semi-arid to sub-humid ecozone, while approximately 75% of the dairy cattle herd, 60% of swine and poultry and over 75% of corn and soybeans are produced in the humid Mixedwood Plains ecozone in eastern Canada.

In 1990, Canada had 10.5 million beef cattle, 1.4 million dairy cattle, 10 million swine, and 101 million poultry. The beef cattle and swine populations peaked in 2005 at 15 million head each.

Beef populations have decreased to 11 million head since 2005, while swine populations decreased to 12.5 million head in 2010, rebounded to 14 million head in 2016, and have since remained stable. Since 1990, poultry populations increased to 154 million by 2016 and subsequently decreased to 151 million by 2024, while dairy cattle populations have decreased until recently, with some fluctuations, stabilizing at just under 1 million head in 2024.

Cropping practices have changed in Canada over the years. Canola production increased by nearly a factor of 6 from 3.3 Mt in 1990 to 19 Mt in 2024. Grain corn production has roughly doubled, increasing from 7 Mt to 15 Mt, and soybean production has increased by a factor of 5 from 1.3 Mt to 7 Mt. From 1990 to 2002, wheat production fell off sharply, decreasing from 32 Mt to 16 Mt, but has increased in recent years and typically varies between 20 and 35 Mt. With the changes in crop production, inorganic nitrogen (N) fertilizer consumption has almost tripled, increasing from 1.2 Mt in 1990 to 3.2 Mt in 2024, while land under conservation tillage has increased by 17 million hectares (Mha).

As a result of these combined changes in livestock and crop production, Canada's GHG emissions from the Agriculture sector rose from 43 Mt in 1990 to 56 Mt in 2024 (Table 5–1).[2] This 32% increase is mainly due to emissions associated with the greater use of inorganic N fertilizers (168% increase in N shipments), larger swine populations (37% increase), and changes in animal weight, feed and manure handling practices in the beef, dairy and swine industries.

1 In the Common Reporting Tables (CRT), bison emissions are reported under the Intergovernmental Panel on Climate Change (IPCC) category "Buffalo," although the species referred to is the North American bison (*Bison bison*), which is raised for meat using methods similar to those used for beef cattle. In the text of the NIR, this livestock category will be referred to as Bison.

2 Unless explicitly stated otherwise, all emissions estimates given in Mt represent emissions of GHGs in Mt CO_2 eq.

Emissions of CH_4 from livestock accounted for 28 Mt in 1990 and 31 Mt in 2024, with an uncertainty range of -6% to +20% for the mean estimates. Over the 1990 to 2024 time series, mean CH_4 emissions are estimated to have increased by 3.0 Mt, an 11% increase, which is associated with an uncertainty range of -10% to +17%. Emissions of N_2O from agricultural soils and livestock represented 13 Mt in 1990 and 22 Mt in 2024, with an uncertainty range of approximately -27% to +29% of the mean estimates. Over the time series, mean N_2O emissions increased by 8.5 Mt, an increase of 63%.

Emissions from the Agriculture sector peaked in 2005 and decreased to 50 Mt in 2011, with reductions occurring in emissions from livestock production as animal populations decreased (see the Enteric Fermentation and Manure Management source categories, Table 5–1). Since 2011, livestock populations have stabilized, while emissions associated with fertilizer use have increased, and the proportion of the area of perennial cropland has decreased. These trends, in combination with high crop production in recent years, have caused emissions to increase from their low point in 2011 to 56 Mt in 2024.

Table 5–1 **Overview of Greenhouse Gas Emissions from the Agriculture Sector, Selected Years**

GHG Source Category		GHG Emissions (kt CO_2 eq)							
		1990	2005	2019	2020	2021	2022	2023	2024
Agriculture TOTAL[a]		**43 000**	**57 000**	**55 000**	**57 000**	**56 000**	**56 000**	**55 000**	**56 000**
Enteric Fermentation 3.A. (CH_4)		**25 000**	**35 000**	**27 000**	**27 000**	**27 000**	**27 000**	**26 000**	**26 000**
Dairy Cattle 3.A.1.a.		4 400	3 600	3 900	3 900	4 000	4 000	3 900	4 000
Beef cattle[b] 3.A.1.b.		20 000	29 000	22 000	22 000	22 000	22 000	21 000	21 000
Others[c] 3.A.2-4.		820	1 500	1 200	1 200	1 200	1 200	1 200	1 200
Manure Management 3.B.		**6 200**	**9 000**	**8 300**	**8 300**	**8 300**	**8 200**	**8 100**	**8 200**
Dairy Cattle 3.B.1.a.	CH_4	510	800	1 100	1 100	1 100	1 100	1 100	1 100
	N_2O	460	310	240	240	240	240	230	230
Beef cattle[b] 3.B.1.b.	CH_4	920	1 400	1 100	1 100	1 100	1 100	1 100	1 100
	N_2O	1 700	2 600	2 100	2 100	2 100	2 100	2 000	2 000
Swine 3.B.3.	CH_4	1 300	2 300	2 200	2 300	2 300	2 200	2 200	2 300
	N_2O	90	60	50	50	50	40	40	50
Poultry 3.B.4.g.	CH_4	180	220	220	220	220	220	220	220
	N_2O	380	480	530	520	510	510	510	510
Others[d] 3.B.4.	CH_4	40	60	40	40	40	40	40	40
	N_2O	80	150	100	100	90	90	90	90
Indirect Source 3.B.5.	N_2O	520	640	540	540	530	530	530	530
Agricultural Soils (N_2O) 3.D.		**10 000**	**12 000**	**17 000**	**18 000**	**17 000**	**18 000**	**18 000**	**18 000**
Direct sources 3.D.1.		7 900	9 000	13 000	14 000	13 000	14 000	14 000	15 000
Inorganic nitrogen fertilizers 3.D.1.a.		3 900	4 700	8 100	9 100	9 000	8 600	9 300	9 700
Organic nitrogen fertilizers 3.D.1.b.		1 000	1 300	1 300	1 300	1 300	1 300	1 300	1 300
Crop residue decomposition 3.D.1.d.		2 200	2 700	3 800	3 900	3 100	3 800	3 700	3 900
Cultivation of organic soils 3.D.1.f.		220	220	220	220	220	220	220	220
Mineralization of soil organic carbon 3.D.1.e.		230	290	500	690	680	1 300	420	530
Conservation tillage[e,f] 3.D.1.		-360	-1 000	-2 200	-2 300	-2 100	-2 200	-2 200	-2 500
Irrigation[f] 3.D.1.		490	690	1 100	1 200	1 000	1 100	1 100	1 200
Urine and dung deposited by grazing animals 3.D.1.c.		200	230	180	170	170	170	170	170
Indirect sources 3.D.2.		2 300	2 700	3 500	3 700	3 500	3 600	3 700	3 800
Field Burning of Agricultural Residues (CH_4 & N_2O) 3.F.		**240**	**50**	**50**	**60**	**40**	**50**	**50**	**50**
Liming and Urea Application (CO_2) 3.G.		**1 200**	**1 400**	**2 700**	**3 000**	**3 100**	**2 800**	**3 100**	**3 400**

Notes:
a. Totals may not add up due to rounding.
b. Beef cattle include dairy heifers. This corresponds to the Non-Dairy Cattle category in the CRF tables.
c. Others, Enteric Fermentation, includes bison, goats, horses, sheep, llamas/alpacas, swine, deer/elk, and wild boars.
d. Others, Manure Management, includes bison, goats, horses, sheep (CRT - 3.B.2), llamas/alpacas, foxes, minks, rabbits, deer/elk, and wild boars.
e. The negative values reflect reduced N_2O emissions due to the adoption of conservation tillage.
f. Applies to all 3.D.1. CRT subcategories from the application of N fertilizer or mineralization of organic N in croplands, except pastures and organic soils

In this submission, 1990 emissions were revised by +0.23 Mt; 2005 emissions by +0.51 Mt; and 2023 emissions by 0.28 Mt compared to the previous submission, representing recalculations of +0.53%, +0.09%, and +0.50%, respectively (Table 5–2).

Recalculations are the result of (i) an updated method to estimate methane conversion factors (MCF) for dairy and swine liquid manure; (ii) accounting for a 5% impurity of limestone and dolomite; and (iii) a method correction for calculating the amount of crop residue C in Cropland resulting in changes in N_2O estimates from the loss of soil organic carbon (SOC). See Table 5–2, Table 5–3 and Annex 3.4 for more details on recalculations and revisions to methodology.

Rice is not produced in Canada and therefore does not contribute to CH_4 emissions. The prescribed burning of savannahs is not practiced in Canada.

This chapter provides a brief introduction to each emission source category, as well as a short description of methodological issues; uncertainties and time-series consistency; quality assurance / quality control (QA/QC) and verification processes; recalculations; and planned improvements. Detailed inventory methodologies and sources of activity data are described in Annex 3.4.

Table 5–2 **Summary of Recalculations for the Agriculture Sector, Selected Years**

GHG Source Category		GHG Emissions (kt CO_2 eq)							
		1990	2005	2018	2019	2020	2021	2022	2023
Agriculture									
Previous submission (2025 NIR)		42 541	56 286	54 146	54 287	55 986	55 109	55 912	55 150
Current submission (2026 NIR)		42 767	56 793	54 804	54 911	56 682	55 787	56 183	55 429
Change in Emissions	kt CO_2 eq	225	508	658	625	697	678	271	280
	%	0.53	0.89	1.20	1.14	1.23	1.22	0.48	0.50
Manure Management 3.B [a]									
Previous submission (2025 NIR)		2 757	4 377	4 320	4 341	4 340	4 381	4 340	4 307
Current submission (2026 NIR)		2 971	4 771	4 715	4 739	4 769	4 810	4 757	4 717
Change in Emissions	kt CO_2 eq	214	394	395	398	429	429	417	410
	%	7.20	8.26	8.38	8.39	8.99	8.91	8.76	8.70
Agricultural Soils 3.D.1.									
Previous submission (2025 NIR)		198	170	179	265	409	421	1 438	542
Current submission (2026 NIR)		228	292	450	500	685	679	1 301	420
Change in Emissions	kt CO_2 eq	30	122	271	235	276	258	-137	-122
	%	13.16	41.78	60.22	47.00	40.29	38.00	-10.53	-29.05
Liming – CO_2 Emissions 3.G.									
Previous submission (2025 NIR)		1 191	1 421	2 597	2 678	3 037	3 117	2 857	3 091
Current submission (2026 NIR)		1 171	1 412	2 588	2 670	3 028	3 109	2 848	3 082
Change in Emissions	kt CO_2 eq	-20	-9	-9	-8	-9	-8	-9	-9
	%	-1.71	-0.64	-0.35	-0.30	-0.30	-0.26	-0.32	-0.29

Note:
Totals may not add up due to rounding.

Table 5–3 **Qualitative Summary of the Revisions to Methodologies, Corrections and Improvements Carried out for Canada's 2026 Submission**

Correction or Improvement	Recalculation Categories Affected	Years Affected
Updated method to estimate methane conversion factors for dairy and swine liquid manure management systems	Manure Management – CH_4 Emissions	Complete time series
Inclusion of 5% impurity in limestone and dolomite applied to agricultural soils.	Agricultural Soils – CO_2 Emissions from Liming	Complete time series
Method correction to estimates of Carbon storage in the LULUCF Cropland category, which modified the N_2O emissions resulting from SOC loss from agricultural soils	Agricultural Soils – Direct N_2O Emissions	Complete time series

5.2. Enteric Fermentation (CRT Category 3.A)

5.2.1. Category Description

Methane is produced during the normal digestive process of enteric fermentation in herbivores, including species raised in agricultural animal production. Microorganisms in the gastrointestinal tract breakdown carbohydrates and proteins into simple molecules for absorption and CH_4 is produced as a by-product. This process results in an accumulation of CH_4 in the rumen emitted by eructation and exhalation. Some CH_4 is released later in the digestive process by flatulence, but this accounts for less than 5% of total emissions. Large ruminant animals, such as cattle, generate the most CH_4.

In Canada, animal production varies from region to region. In western Canada, beef cattle production dominates, combining intensive production systems with high animal densities finished in feedlots and low-density, pasturing systems for cow-calf operations. Most dairy production occurs in eastern Canada in high-production, high-density facilities, and production has intensified significantly since 1990, affecting both milk productivity and management approaches. Eastern Canada has also traditionally produced swine in high-density, intensive production facilities. Over the past 20 years, some swine production has shifted to western Canada. Other animals that produce CH_4 by enteric fermentation, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boars and sheep, are raised as livestock, but populations of these animals have traditionally been low. In Canada, over 95% of Enteric Fermentation emissions come from cattle.

5.2.2. Methodological Issues

The diversity of animal production systems and regional differences in production facilities complicate emission estimation. For each animal category/subcategory, CH_4 emissions are calculated, by province, by multiplying the animal population of a given category/subcategory by its corresponding regionally derived emission factor.

For cattle, CH_4 emission factors are estimated using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodology, based on the equations provided in the 2006 IPCC Guidelines (IPCC, 2006). A national study by Boadi et al. (2004) broke down cattle subcategories, by province, into sub annual production stages and defined their physiological status, diet, age class, sex, weight, growth rate, activity level and production environment. These data were integrated into IPCC Tier 2 equations to produce annual emission factors for each individual animal subcategory that consider provincial production practices. The data describing each production stage were obtained by surveying beef and dairy cattle specialists across the country.

For dairy cattle, the basic subcategory classes developed by Boadi et al. (2004) were accurate for the mid-2000s when the Tier 2 model was populated; however, it was recognized that certain dairy production parameters were not static over time and these parameters could impact all aspects of emissions from the dairy sector. Further work was carried out and implemented in the 2018 inventory analysis to refine estimates of certain Tier 2 parameters for dairy and to create a time series that better captures changes in dairy production practices. Increased milk production associated with improved genetics, as well as improved feed quality in dairy cattle herds over the period from 1990 to 2024, are reflected in a 24% increase in CH_4 emission factors from this animal category. As milk production increases, the requirement of energy for lactation (NE_l) becomes greater and requires increased food consumption.

In beef cattle, changes in mature body weight influence maintenance and growth energy (NE_m and NE_g) requirements and, consequently, feed consumption. From 1990 to 2003, larger breeds became popular and emission factors increased by 7.4% during that period. Since then, beef cattle weights have remained relatively stable, while the weights of slaughter animals have continued to increase at a lower rate. Emission factors have since decreased because of a combination of the stabilization of cattle weights and a shift in cattle subcategory populations. Since 2005, beef cow and replacement heifer populations have decreased substantially, while finishing animal populations (slaughter heifers and steers) have remained constant. As a result, the proportion of finishing animals in the national herd has increased from 17% to 20%. Since finishing animals have a lower emission factor, the overall emission factor for the Non-Dairy Cattle category has decreased from its peak in 2005.

For non-cattle animal categories, CH_4 emissions from the process of enteric fermentation continue to be estimated using the IPCC Tier 1 methodology (IPCC, 2006). The poultry, rabbits and fur-bearing animal categories are excluded from the estimates for the Enteric Fermentation category since no emission factors are currently available.

Activity data consist of domestic animal populations for each animal category/subcategory, by province, and are obtained from Statistics Canada (Annex 3.4, Table A3.4–1). The data are based on the *Census of Agriculture*, conducted every five years and updated annually by semi-annual or quarterly surveys for cattle, swine and sheep.

5.2.3. Uncertainty Assessment and Time-Series Consistency

An uncertainty analysis was performed on the methodology used to estimate CH_4 emissions from agricultural sources using a Monte Carlo technique. The analysis considered the uncertainty in the parameters defined in Boadi et al. (2004) as they are used within the IPCC Tier 2 methodology equations (IPCC, 2006). Details of this analysis can be found in section A3.4.2.4. Uncertainty distributions for parameters were taken from Karimi-Zindashty et al. (2012), although some additional parameters and updates were included in this analysis. For 2024, uncertainty ranges from the 2012 analysis are applied to new emission estimates. An uncertainty analysis of the updated dairy model has not yet been performed and reported uncertainty estimates are based on the methodology of Boadi et al. (2004).

The uncertainty range for CH_4 emissions from the Enteric Fermentation category was similar from 1990 to 2024, and mean estimates in 2024 lie within a range of -14% to +17% (Table 5–4). Over the time series of 1990 to 2024, mean emissions are estimated to have increased by 1.4 Mt, an 5.4% increase. The observed increase falls within an uncertainty range of +4.4% to +13%.

The uncertainty in emissions was mainly associated with the calculation of the emission factor. The range of uncertainty around the calculation of the Non-Dairy Cattle Tier 2 emission factors was the largest contributor to uncertainty. Calculations of uncertainty in emissions and emission factors were the most sensitive to the use of IPCC default parameters (IPCC, 2006) in the Tier 2 calculation methodology, in particular the methane conversion rate (Y_m) and the factor associated with the estimation of the net energy of maintenance (Cf_i) (Karimi-Zindashty et al., 2012).

The methodology and parameter data used in the calculation of emission factors are consistent throughout the entire time series (1990–2024), except for milk production for dairy cattle. The time series of milk production from 1990 to 1998 is estimated. Two milk production data sets exist in Canada: (1) publishable records that represent production data for genetically elite animals within the Canadian herd from 1990 to present, and (2) management records that provide a more accurate estimate of production from the entire Canadian dairy herd from 1999 to present. An estimate of milk production for the entire Canadian herd from 1990 to 1998 was calculated based on the average ratio between the publishable and the management data from 1999 to 2007.

Table 5–4 **Uncertainty in the Estimates of CH_4 Emissions from Enteric Fermentation**

Livestock Category	Uncertainty Source		Mean Value[a,b]	2.5% Probability[b]	97.5% Probability[b]
Dairy Cattle	Population (1000 head)		966	915 (-5.2%)	1 017 (+5.2%)
	Tier 2 emission factor (kg/head/year)		147	126 (-15%)	176 (+19%)
	Emissions (Mt CO_2 eq)		4.0	3.3 (-16%)	4.8 (+20%)
Non-Dairy Cattle	Population (1000 head)		10 497	10 296 (-1.9%)	10 710 (+2.0%)
	Tier 2 emission factor (kg/head/year)		72	61 (-15%)	85 (+18%)
	Emissions (Mt CO_2 eq)		21	18 (-16%)	26 (+21%)
Other Livestock	Emissions (Mt CO_2 eq)		1.2	0.97 (-18%)	1.4 (+18%)
Total emissions	Emissions (Mt CO_2 eq)	1990	25	21 (-16%)	30 (+21%)
		2024	26	23 (-14%)	31 (+17%)
	Trend	1990–2024	1.4 (+5.4%)	0.99 (+4.4%)	2.8 (+13%)

Notes:
a. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2024.
b. Values in parentheses represent the uncertain percentage of the mean, with the exception of the Trend, where the values in parentheses represent the percentage change between 1990 and 2024.

5.2.4. QA/QC and Verification

Enteric Fermentation, as a key category, has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes are documented and archived in electronic form. The IPCC Tier 2 emission factors for cattle, derived from Boadi et al. (2004), have been reviewed by independent experts (McAllister and Basarab, 2004).

Internal Tier 2-level QC checks carried out in 2010 and 2011 included a complete review and rebuild of calculation methodology and input data, and a review and compilation of Canadian research on the process of enteric fermentation (MacDonald and Liang, 2011). The literature review suggested that no specific bias can be clearly identified in the enteric emission estimate. Based on the sensitivity analyses carried out in the uncertainty analysis and the literature review, improvements to the cattle model require the development of country-specific parameters that consider specific regional management influences on emissions, replacing IPCC defaults (IPCC, 2006) currently used in the emission model, as has been done for Dairy Cattle category. Details of this review can be found in Annex 3.4. A recent top-down quality assurance study was carried out using low-altitude aircraft-based flux technology (Desjardins et al., 2018). Though reconciling the top-down estimates with the bottom-up estimates was challenging due to difficulties in differentiating agricultural CH_4 emissions from wetland emissions, the top-down estimates were consistent with the bottom-up estimates in areas where wetland emissions were minimal.

5.2.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.2.6. Planned Improvements

In general, the enteric fermentation methodology is robust; improvements are mainly dependent on the ability to collect more complete data on the composition of the diet fed to livestock, as that will facilitate the development of parameters specific to animal subcategories within different regions of Canada. Dairy feed information is currently being processed to update the time series for changes to dairy feed in recent years.

A study undertaken with Canadian beef industry experts to update and improve the beef production model was carried out, to characterize the variability in animal management strategies in different regions across Canada. However, no immediate plans are in place to modify the emission method.

5.3. Manure Management (CRT Category 3.B)

In Canada, the animal waste management systems (AWMS) typically used in animal production include (1) liquid storage, (2) solid storage and drylot, and (3) pasture and paddock. To a lesser extent, AWMS also include other systems such as composting and biodigesters. No manure is burned as fuel.

Both CH_4 and N_2O are emitted during handling and storage of livestock manure. The magnitude of emissions depends on the quantity of manure handled, its characteristics, and the type of manure management system. In general, anaerobic or poorly aerated manure management systems generate high CH_4 emissions but relatively low N_2O emissions, whereas well-aerated (aerobic) systems generate high N_2O emissions but relatively low CH_4 emissions.

Manure management practices vary regionally, by animal categories, and over time. Most dairy, swine and poultry production occurs in modern high-density production facilities in Canada. The dairy industry has experienced a shift in manure storage practices since 1990, with larger operations with liquid systems replacing smaller operations with solid systems. The swine industry produces large volumes of liquid manure, and there has been an increase in the use of liquid manure systems in swine production since 1990, while poultry manure is predominantly managed in solid form. Both swine and poultry manure are spread on a limited land base. Feedlot beef production results in large volumes of dry lot and solid manure, whereas low-density pasturing systems for beef result in widely dispersed manure in pastures and paddocks. Other animals, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boars, sheep, and mules and asses, are generally raised in pasture and/or medium-density production facilities producing mainly solid manure. Fur-bearing animals also produce solid manure.

5.3.1. CH_4 Emissions from Manure Management (CRT Category 3.B [a])

5.3.1.1. Category Description

Shortly after manure is excreted, the decomposition process begins. In well-aerated conditions, decomposition is an oxidation process producing CO_2. However, if little oxygen is present, carbon is reduced, resulting in the production of CH_4. The quantity of CH_4 produced depends on manure characteristics and the type of manure management system. Manure characteristics are, in turn, linked to animal category and animal nutrition.

5.3.1.2. Methodological Issues

Methane emissions from the Manure Management category are calculated for each animal category/subcategory by multiplying its population by the corresponding emission factor (see Annex 3.4 for detailed methodology). The animal population data are the same as those used for the Enteric Fermentation category (see section 5.2.2). Methane emission factors for Manure Management are estimated using the IPCC Tier 2 methodology (IPCC, 2006; 2019).

Tier 2 parameters were taken from expert consultations described in Boadi et al. (2004) and Marinier et al. (2004, 2005) or from the 2006 IPCC Guidelines (IPCC, 2006). For dairy and beef cattle, the Boadi et al. (2004) Tier 2 animal production model was used to derive gross energy of consumption (GE). However, for dairy cattle and swine, some parameters within the model were replaced with updated values to better capture trends in feeding practices and/or animal weights, as described in Annex 3.4. For dairy cattle, the digestibility (DE) of feed is responsive to animal diet, and for swine, volatile solids excreted in manure are adjusted based on trends in body weights and growth rates. Volatile solids (VS) were estimated using Equation 10.23 of the 2006 IPCC Guidelines (IPCC, 2006) and manure ash contents from Marinier et al. (2004). For all other livestock, parameters taken from Marinier et al. (2004) were used to calculate VS based on ash content and digestible energy derived from expert consultations. Urinary energy (UE) coefficients were applied according to the

2006 IPCC Guidelines (IPCC, 2006). VS for swine were corrected for animal mass as described in Annex 3.4. For sheep and poultry categories, different animal subcategory parameters were used based on animal size for lambs and adult sheep and turkeys, broilers and layers in the poultry category.

Emission factors were derived using the CH_4 producing potential (B_0), CH_4 conversion factors (MCF) and the proportion of manure handled by AWMS for each animal category. For major livestock categories other than dairy and swine, the MCF was taken from the 2006 IPCC Guidelines (IPCC, 2006) and AWMS proportions were taken from Marinier et al. (2005) for each province, considering regional differences in production practices and manure storage systems. For swine and dairy cattle, regionalized manure storage system time series were developed based on the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2006; 2019) and assumptions from Hung et al. (2022) and Ewen et al. (2025) with and without crust and covers. Regional values of MCF were assigned to AWMS subsystems, and a weighted MCF was calculated for each AWMS based on the proportion of manure in each subsystem. For minor animals (fur-bearing animals, rabbits, deer and elk, and mules and asses), Tier 1 emission factors were used. A more complete description of the derivation of the proportional distribution of manure storage systems is provided in section A3.4.3.3.

Increases in cattle emission factors over the period from 1990 to 2024 (see section A3.4.3) reflect higher gross energy intake for dairy cattle due to changes in feed, herd characteristics and increased milk productivity. Most importantly, emission factors for dairy also reflect trends in manure storage practices, primarily, a shift from solid systems to liquid systems. For non-dairy cattle, changes are due to changes in live body weights (see section 5.2.2). Changes in swine emission factors (see section A3.4.3.6) for sows are related to the shift in swine production from eastern to western Canada, and in the case of growing swine are a result of increases in growth rates and final carcass weights.

5.3.1.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty analysis of CH_4 emissions from agricultural sources using the Monte Carlo technique included CH_4 emissions from management of manure. The analysis used parameter estimates and uncertainty distributions from Marinier et al. (2004) supplemented with information from Karimi-Zindashty et al. (2012), and additional and updated parameters specific to this analysis. Details of this analysis can be found in section A3.4.3.8.

The CH_4 emission estimate of 4.7 Mt from the management of livestock manure in Canada in 2024 lies within an uncertainty range of -28% to +23% (Table 5–5). The emission estimate for 1990, 3.0 Mt, has a slightly larger uncertainty range, -44% to +36%, due to the greater uncertainty associated with the distribution of manure management system types in 1990. The estimate of a 60% increase in mean emissions between 1990 and 2024 lies within an uncertainty range of +45% to +66%.

As was the case with the Enteric Fermentation category, most uncertainty in the emission estimate is associated with the calculation of the emission factor. The uncertainty range around the mean emission factor is as high as 110% in the case of dairy cattle. The uncertainty in emissions is most sensitive to the use of 2006 IPCC default parameters in the Tier 2 calculation methodology; in particular, the MCF that is applied to all regions of Canada and all animal types, and the maximum B_0 (Karimi-Zindashty et al., 2012). An uncertainty analysis on the new dairy and swine models has not yet been performed, but because the MCF factor is driving uncertainty for manure management, they would be expected to reduce national manure-management uncertainty.

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2024), except for milk production for dairy cattle and bull weights. Milk production from 1990 to 1999 in Ontario and the western provinces, and bull carcass weights, were estimated as described in section 5.2.3.

Table 5–5 **Uncertainty in the Estimates of CH_4 Emissions from Manure Management**

Livestock Category	Uncertainty Source		Mean Value[a]	2.5% Probability[b]	97.5% Probability[b]
Dairy Cattle	Population (1000 head)		966	915 (-5.2%)	1 017 (+5.2%)
	Tier 2 emission factor (kg/head/year)		42	23 (-45%)	57 (+37%)
	Emissions (Mt CO_2 eq)		1.1	0.6 (-45%)	1.55 (+37%)
Non-Dairy Cattle	Population (1000 head)		10 497	10 296 (-1.9%)	10 710 (+2.0%)
	Tier 2 emission factor (kg/head/year)		3.7	2.8 (-25%)	5.4 (+45%)
	Emissions (Mt CO_2 eq)		1.1	0.8 (-27%)	1.64 (+51%)
Swine	Population (1000 head)		13 985	13 654 (-2.4%)	14 323 (+2.4%)
	Tier 2 emission factor (kg/head/year)		5.8	2.7 (-54%)	8.4 (+45%)
	Emissions (Mt CO_2 eq)		2.3	1.2 (-49%)	3.2 (+42%)
Other Livestock	Emissions (Mt CO_2 eq)		0.25	0.17 (-31%)	0.29 (+14%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	3.0	1.7 (-44%)	4.0 (+36%)
		2024	4.7	3.4 (-28%)	5.8 (+23%)
	Trend	1990–2024	1.8 (+60%)	1.1 (+45%)	1.6 (+66%)

Notes:
a. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2024.
b. Values in parentheses represent the uncertain percentage of the mean, with the exception of the Trend, where values in parentheses represent the percentage change between 1990 and 2024.

5.3.1.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data and methodologies are documented and archived in electronic format. The IPCC Tier 2 CH_4 emission factors for manure management practices by all animal categories derived from Marinier et al. (2004) have been reviewed by independent experts (Patni and Desjardins, 2004). These documents have been archived in electronic form.

Internal Tier 2 QC checks carried out in 2010–2011 included a complete review and rebuild of calculation methodology, input data and review and compilation of Canadian research on manure management (MacDonald and Liang 2011). No specific bias can be clearly identified in the IPCC Tier 2 model parameters due to the high variability in research results and the lack of supporting information for research carried out on manure storage installations. There is no clear standard for evaluating whether IPCC parameters are appropriate for estimating emissions from manure management systems in the Canadian context. More standardized and detailed research is required in Canada to improve upon the current Tier 2 methodology. Details of this review can be found in section A3.4.3.7.

5.3.1.5. Recalculations

A recalculation was made to the MCF to liquid manure management time series for dairy and swine production to reflect Canadian regional practices and climate. Emissions were revised upward by 0.2 Mt in 1990, 0.4 Mt in 2005, and by 0.4 Mt in 2023 (Table 5–6). The long-term emission trends increased from 56% to 59% and the short-term trend changed from a -2% decrease to a -1% decrease.

Table 5–6 **Recalculations of CH_4 Emission Estimates and Their Impact on Emission Trends from Manure Management**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change in Category Emissions (%)	Old Trend (%)	New Trend (%)
Manure Management	1990	2025	2 757	214	8	Long term (1990–2023)	
		2026	2 971			56	59
	2005	2025	4 377	394	9		
		2026	4 771			Short term (2005–2023)	
	2023	2025	4 307	410	10	-2	-1
		2026	4 717				

5.3.1.6. Planned Improvements

Analysis of the manure management model suggested that improvements could be made to the values used for the distribution of AWMS based on Statistics Canada's farm environmental management surveys (FEMS). Using the FEMS data for the period from 2017 to 2021 (Ewen et al., 2025), combined with information from Canadian publications on livestock management (Sheppard et al., 2009a, 2009b, 2010, 2011a, 2011b; Sheppard and Bittman, 2011, 2012), an updated manure management time series for dairy and swine production in Canada is under development, and work is being considered for other major livestock categories. The improved estimate of MCF in swine and dairy liquid manure management is planned to be included in the future uncertainty analysis. Further refinements to parameters used in the calculation of VS based on changes in animal feed are being considered for implementation in the medium-term. Further uncertainty work for dairy cattle and swine will be carried out to establish an updated level and trend uncertainty estimate.

5.3.2. N_2O Emissions from Manure Management (CRT Category 3.B [b])

5.3.2.1. Category Description

The production of N_2O during storage and treatment of animal waste occurs during nitrification and denitrification of N contained in the manure. Nitrification is the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-), and denitrification is the reduction of NO_3^- to N_2O or N_2. Manure from the non-dairy cattle, sheep, goats, horses, and other minor livestock categories is mostly handled in solid and dry-lot systems, which are the types of manure management systems that emit the most N_2O. N_2O emissions from urine and dung deposited by grazing animals are reported separately (see section 5.4.1.4).

5.3.2.2. Methodological Issues

N_2O emissions from manure management are estimated for each livestock category by multiplying the population of each category by its N excretion rate and the emission factor associated with the AWMS.

For dairy cattle, N excretion is calculated using the mass balance approach provided in the IPCC Tier 2 methodology, based on the difference between N intake and N retention. N intake is calculated based on gross energy and the percentage of crude protein in the diet, while N retention is calculated using milk production and cattle weight statistics as described in Annex 3.4. Default IPCC N_2O emission factors are assigned to AWMS subsystems (see section A3.4.3.3), and weighted AWMS N_2O emission factors are developed using the proportion of manure handled by each AWMS subsystem.

N excretion by swine is calculated for market and breeding animals using the IPCC Tier 1 methodology, as well as a country-specific animal mass time series for market animals. Default IPCC N_2O emission factors are assigned to AWMS subsystems (see section A3.4.3.3), and weighted AWMS N_2O emission factors are developed using the proportion of manure handled by each AWMS subsystem.

For all other livestock categories, N excretion is estimated using the IPCC Tier 1 methodology. The average annual N excretion rates for livestock are taken from the 2006 IPCC Guidelines (IPCC, 2006).

The animal characterization data are the same as those used for the Enteric Fermentation (see section 5.2) and Manure Management (see section 5.3.1) estimates. The 2006 IPCC default emission factors (IPCC, 2006) for a developed country with a cool climate are used to estimate manure N emitted as N_2O for each type of AWMS.

5.3.2.3. Uncertainty Assessment and Time-Series Consistency

An uncertainty analysis using the Monte Carlo technique was carried out to estimate emissions of N_2O from agricultural sources (Karimi-Zindashty et al., 2014). For N_2O emissions from Manure Management, the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines (IPCC, 2006) and all uncertainty in AWMS systems, animal populations and characterizations, were identical to those used in the analysis of CH_4 from Enteric Fermentation and Manure Management category defined in sections 5.2.3 and 5.3.1.3. Details of this analysis can be found in section A3.4.6.

The estimate of direct N_2O emissions of 2.9 Mt from Manure Management in 2024 lies within an uncertainty range of 1.7 Mt (-43%) to 4.4 Mt (+51%) (Table 5–7). Most uncertainty is associated with the IPCC Tier 1 emission factor (±100% uncertainty). Due to the size of the N_2O model, the initial uncertainty analysis was limited to providing sound estimates of uncertainty for emission source categories and a basic sensitivity analysis. A complete analysis of the trend uncertainty has not yet been completed due to limitations in software capabilities. An uncertainty analysis of the dairy and swine models has not yet been performed.

The same methodology, emission factors and data sources are used for the entire time series (1990–2024).

5.3.2.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodology and changes to methodologies were documented and archived in both paper and electronic form. A complete Tier 2 QC was carried out on all calculation processes and parameters during the rebuilding of the agricultural N_2O emission database.

There are very few published data on N_2O emissions from manure management and storage in Canada or in regions with practices and climatic conditions comparable to those of Canada. More standardized and detailed research is required in Canada to improve on the current methodology.

5.3.2.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.3.2.6. Planned Improvements

Data from direct measurements of N_2O emissions from manure management in Canada are scarce. Recent scientific advances in analytical techniques allow direct measurements of N_2O emissions from point sources. However, it will likely take several years before N_2O emissions can be reliably measured and verified for various manure management systems in Canada.

As noted in section 5.3.1.6, implementing an AWMS time series is the main source of improvement available for this emission source. Improvements to dairy and swine have been implemented based on Statistics Canada farm environmental management surveys, and plans are in place to incorporate this analysis for other livestock categories.

Furthermore, as noted in section 5.2.6, data have been collected to develop a time series that accounts for changes in animal nutrition and country-specific N excretion rates. These data have been integrated for dairy cattle, but a similar analysis is still to be completed for swine. For select other livestock categories, changes will be incorporated over the medium term.

Further uncertainty analyses will be carried out to establish trend uncertainty and consider changes in the livestock models over the medium term.

5.3.3. Indirect N_2O Emissions from Manure Management (CRT Category 3.B.5)

5.3.3.1. Category Description

The production of N_2O from manure management can also occur indirectly through NH_3 volatilization and leaching of N during storage and handling of animal manure. A fraction of the N in stored manure is transported off-site through volatilization in the form of NH_3 and NO_x and subsequent redeposition. Furthermore, solid manure exposed to rainfall will be prone to loss of N through leaching and runoff. The N transported from the manure storage site in this manner is assumed to undergo subsequent nitrification and denitrification elsewhere in the environment and, consequently, produce N_2O.

5.3.3.2. Methodological Issues

Indirect emissions of N_2O from manure management are estimated by applying N loss factors to the quantity of manure N contained in each AWMS, and then multiplying by an N_2O emission factor. The N loss factors are calculated differently for both dairy cattle and swine, compared with other livestock categories.

For dairy cattle and swine, the amount of manure N subject to loss by leaching and volatilization of NH_3 and NO_x during storage is estimated using a revised version of the Canadian NH_3 emission model (Sheppard et al., 2010; Sheppard et al., 2011b; Chai et al., 2016) to generate ecoregion-specific N loss factors by animal type and manure management system.

For all other livestock categories, the amount of manure N subject to losses from volatilization of NH_3 during storage is calculated for each animal type and manure management system using default values provided in the 2006 IPCC Guidelines (IPCC, 2006). Leaching losses are not estimated because no country-specific leaching loss factors are available.

Emission factors of N_2O from volatilization during manure storage and handling in dry and wet climates are taken from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2006), whereas the N_2O emission factors for N leached from manure storage and handling are taken from the 2006 IPCC Guidelines (IPCC, 2006), for all livestock categories.

5.3.3.3. Uncertainty Assessment and Time-Series Consistency

A full uncertainty analysis using a Monte Carlo technique has not been carried out on the estimation of indirect N_2O emissions from manure management. The uncertainties associated with livestock populations, manure N excretion rates, AWMS, N leaching and NH_3 volatilization fractions, and indirect N_2O emission factors are available but have not been used in a Monte Carlo analysis to date. The overall uncertainty is assumed to be equivalent to that associated with indirect emissions from agricultural soils.

The same methodology, emission factors and data sources are used for the entire time series (1990–2024).

5.3.3.4. QA/QC and Verification

This category underwent Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) following the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodology and databases have been documented and archived in electronic form.

5.3.3.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.3.3.6. Planned Improvements

As noted in section 5.3.1.6, country-specific NH_3 volatilization fractions and N leaching coefficients, stratified by livestock subcategory and AWMS, are being developed for beef cattle. Non-Dairy Cattle Tier 2 parameters might be revised based on recent information.

5.4. N_2O Emissions from Agricultural Soils (CRT Category 3.D)

N_2O emissions from agricultural soils occur in direct and indirect forms: directly from anthropogenic N inputs to soils and indirectly through various pathways. Changes in crop rotations and management practices, such as tillage and irrigation, affect direct N_2O emissions by altering the mineralization rates of organic N, nitrification and denitrification. Indirect emissions occur through two pathways: (1) the volatilization of N from inorganic fertilizer and manure applied to fields as NH_3 and NO_x and its subsequent deposition off-site; and (2) the leaching and runoff of inorganic fertilizer, manure, biosolids and crop residue N.

5.4.1. Direct N_2O Emissions from Managed Soils (CRT Category 3.D.1)

Direct sources of N_2O from soils include the application of organic and inorganic N fertilizers, crop residue decomposition, losses of soil organic matter through mineralization, and cultivation of organic soils. In addition, Canada also reports two country-specific sources of emissions/removals: tillage practices and irrigation. Emissions/removals from these sources are estimated based on N inputs from the application of organic and inorganic N fertilizers and crop residue N.

5.4.1.1. Inorganic Nitrogen Fertilizers (CRT Category 3.D.1.a)

5.4.1.1.1. Category Description

Inorganic fertilizers add large quantities of N to agricultural soils. This added N undergoes transformations such as nitrification and denitrification that can release N_2O. Emission factors associated with fertilizer application depend on many factors, such as soil texture, climate, topography, cropping system, farming practices, and environmental conditions (Gregorich et al., 2005; Rochette et al., 2008a; Rochette et al., 2018).

5.4.1.1.2. Methodological Issues

Canada has developed a Tier 2 methodology using country-specific emission factors to estimate N_2O emissions from inorganic N fertilizer application on agricultural soils, which considers moisture regimes, soil texture, N sources, cropping systems, and topographic conditions. Emissions of N_2O are estimated for each ecodistrict and scaled up to provincial and national scales. The amount of N applied to the land is estimated from yearly N fertilizer shipments to Canadian agriculture markets. All inorganic N fertilizers sold by retailers are assumed to be applied for crop production purposes in Canada. The quantity of fertilizers applied to forests is deemed negligible. More details on the inventory method can be found in Annex 3.4.

Table 5–7 **Uncertainty in the Estimates of N_2O Emissions from Manure Management and Agricultural Soils in 2024**

Emission Source		Mean Value[a]	2.5% Probability[b]	97.5% Probability[b]
		Mt CO_2 eq		
MANURE MANAGEMENT (N_2O)				
Direct emissions		2.9	1.7 (-43%)	4.4 (+51%)
Indirect emissions		0.53	0.21 (-60%)	0.90 (+70%)
AGRICULTURAL SOILS (N_2O)		**18**	**12 (-36%)**	**28 (+52%)**
Direct N_2O emissions from managed soils		15	10 (-28%)	19 (+34%)
	Inorganic N fertilizers	9.7	6.3 (-35%)	14 (+43%)
	Organic N fertilizers	1.3	0.89 (-33%)	1.9 (+41%)
	Crop residues	3.9	2.5 (-35%)	5.6 (+45%)
	Cultivation of organic soils	0.22	0.046 (-79%)	0.43 (+96%)
	Mineralization associated with loss of soil organic matter	0.53	0.35 (-35%)	0.77 (+45%)
	Urine and dung deposited by grazing animals	0.17	0.067 (-60%)	0.29 (+75%)
	Soil N mineralization/immobilization	-1.3	-0.73 (-44%)	-2.0 (+55%)
Indirect N_2O emissions from managed soils		3.8	1.5 (-60%)	6.5 (+70%)
	Atmospheric Deposition	0.92	0.23 (-75%)	1.9 (+110%)
	Leaching and runoff	2.9	0.59 (-80%)	5.9 (+100%)

Notes:
a. Mean value reported from database.
b. Values in parentheses represent the uncertain percentage of the mean.

5.4.1.1.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty analysis, using the Monte Carlo technique on the methodology used to estimate emissions of N_2O from agricultural sources noted in section 5.3.2.3, includes all direct and indirect emissions from soils (Table 5–7). For N_2O emissions from fertilizer, the analysis considers the uncertainty in the parameters defined in the previous country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors, the uncertainty in provincial fertilizer sales, and the uncertainty in crop areas and production at the ecodistrict level. An updated Monte Carlo uncertainty analysis is planned to quantify uncertainty included in the updated country-specific soil N_2O emission factors. The quantification of uncertainty is expected to be improved due to the larger and more complete dataset for quantifying emission factors. Consequently, uncertainty analysis will rely less on expert judgement to establish probability distributions for factors used in deriving regional emission factors.

Based on past analysis, it is estimated that N_2O emissions of 9.7 Mt from the application of inorganic fertilizers on agricultural soils in 2024 lies within a range of 6.3 Mt (-35%) to 14 Mt (+43%) (Table 5–7).

The same methodology and emission factors were used for the entire time series (1990–2024).

5.4.1.1.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

While Statistics Canada conducts QC checks before the release of inorganic nitrogen fertilizer consumption data, the Pollutant Inventories and Reporting Division of Environment and Climate Change Canada carries out its own Tier 2 QC checks through historical records and consultations with regional and provincial agricultural industries.

Emissions of N_2O associated with inorganic fertilizer N applications on agricultural soils in Canada vary on a site-by-site basis. There is, however, an agreement between the previous IPCC default emission factor of 1% (IPCC, 2006), the revised humid environment emission factor of 1.6% (IPCC, 2019), the measured emission factor of 1.2% in eastern Canada, excluding emissions during the spring thaw period (Gregorich et al., 2005; Desjardins et al., 2010), and the range of emission factors developed in this methodology.

5.4.1.1.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.4.1.1.6. Planned Improvements

The current method does not account for mitigation measures that reduce soil N_2O emissions, which may include practices such as enhanced efficiency fertilizers, split N application and N fertilizer placement. Canada plans to develop more robust ratio factors or modifiers to account for these mitigation measures over the medium term of three to five years as research results and activity data become available.

5.4.1.2. Organic Nitrogen Fertilizers Applied to Soils (CRT Category 3.D.1.b)

5.4.1.2.1. Category Description

The application of organic N sources as fertilizer to agricultural soils can increase the rate of nitrification and denitrification and result in enhanced N_2O emissions. Emissions from this category include (i) all manure managed by dry lot, liquid and other AWMSs; and (ii) human biosolids managed by municipal wastewater treatment plants.

5.4.1.2.2. Methodological Issues

As is the case for N_2O emissions from inorganic N fertilizers, a Tier 2 methodology is used to estimate N_2O emissions from organic manure applied to agricultural soils using country-specific emission factors that consider moisture regimes (long-term growing season precipitation and potential evapotranspiration), soil texture, N sources, cropping systems, and topographic conditions. Emissions are calculated by multiplying the amount of organic N applied to agricultural soils by a weighted emission factor calculated for each ecodistrict, summed at the provincial and national levels. All manure handled by AWMSs, except for the urine and dung deposited by grazing animals, is assumed to be subsequently applied to agricultural soils after accounting for N losses during storage. Nitrogen in biosolids is applied to specific crop types per ecodistrict based on provincial regulations and crop requirements, and subsequent emissions are calculated using the country-specific Tier 2 emission factors for organic N.

5.4.1.2.3. Uncertainty Assessment and Time-Series Consistency

In the case of N_2O emissions from the application of organic N fertilizer, the uncertainty analysis considers the uncertainty associated with the parameters used to produce estimates of manure N, as noted in section 5.3.2.3, as well as the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) previously used to develop N_2O emission factors, as noted in section 5.4.1.1.3. An updated Monte Carlo uncertainty analysis is planned, to quantify the uncertainty in the updated country-specific soil N_2O emission factors, including the ratio factor used for organic N. The quantification of uncertainty associated with emissions from organic N application is expected to be improved due to the availability of a larger and more complete data set for differentiating organic and inorganic N fertilizers (Rochette et al., 2018; Liang et al., 2020), which provides improved probability distributions for parameters.

Based on analyses, it is estimated that N_2O emissions of 1.3 Mt from application of organic N fertilizers in 2024 lie within an uncertainty range of 0.9 Mt (-33%) to 1.9 Mt (+41%) (Table 5–7). The main source of uncertainty in the calculation of emissions from organic N fertilizer is the slope of the regression equation used for estimating N_2O emission factors, animal N excretion rates, emission factor modifiers for texture (RF_TX) and tillage (RF_TILL), and N content of biosolids.

The same methodology and emission factors are used for the entire time series (1990–2024).

5.4.1.2.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies have been documented and archived in electronic form.

5.4.1.2.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.4.1.2.6. Planned Improvements

The current method does not account for mitigation measures that reduce soil N_2O emissions, such as the timing of organic N applications. Canada plans to develop more robust ratio factors to account for mitigation measures over the medium term of three to five years.

5.4.1.3. Crop Residues (CRT Category 3.D.1.d)

5.4.1.3.1. Category Description

When a crop is harvested, a portion is left in the field to decompose. This remaining plant matter serves as a source of N, which subsequently undergoes nitrification and denitrification and can thus contribute to N_2O production.

5.4.1.3.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of N in crop residues on annual and perennial cropland multiplied by a corresponding emission factor at the ecodistrict level and scaled up to the provincial and national levels. The amount of N contained in crop residues is estimated using country-specific crop characteristics (Janzen et al., 2003). Emission factors are determined using the same approach as for organic N fertilizer application (see section 5.4.1.2.2).

5.4.1.3.3. Uncertainty Assessment and Time-Series Consistency

For N_2O emissions from crop residue decomposition, the uncertainty analysis considers the uncertainty in crop production, as well as the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emissions of 3.9 Mt from crop residue decomposition in 2024 is associated with an uncertainty range of -35% to +45%, or 2.5 Mt to 5.6 Mt respectively (Table 5–7). The main sources of uncertainty in the calculation of emissions from crop residue decomposition include the slope of the regression equation used to estimate the N_2O emission factors, and the emission factor modifiers for texture (RF_TX) and tillage (RF_TILL). An updated Monte Carlo uncertainty analysis is planned, to account for the uncertainty in the updated country-specific soil N_2O emission factors, including the ratio factor used for organic N.

The same methodology and emission factors are used for the entire time series (1990–2024).

5.4.1.3.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) following the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.3.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.4.1.3.6. Planned Improvements

Future improvements will focus on differentiating organic N fertilizers from crop residue N over the medium term (i.e. three to five years).

5.4.1.4. Urine and Dung Deposited by Grazing Animals (CRT Category 3.D.1.c)

5.4.1.4.1. Category Description

When urine and dung are deposited by grazing animals, the N in the manure undergoes various transformations, such as ammonification, nitrification and denitrification. During these transformation processes, N_2O can be emitted.

5.4.1.4.2. Methodological Issues

N_2O emissions from manure excreted by grazing animals are calculated using a country-specific IPCC Tier 2 method that was derived from field flux measurements (Rochette et al., 2014; Lemke et al., 2012). Details of these new emission factors can be found in section A3.4.5. Emissions are calculated for each animal category by multiplying the number of grazing animals for that category by the appropriate N excretion rate and by the fraction of manure N available for conversion to N_2O.

5.4.1.4.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty associated with the new estimates of N_2O emissions from urine and dung deposited by grazing animals is estimated based on the previous uncertainty analysis using the parameters and uncertainty distributions defined in the Tier 1 methodology in the 2006 IPCC Guidelines (IPCC, 2006), except for new emission factors. Livestock populations, the proportion of animals on pasture systems and their characterizations are identical to those used in the analysis of CH_4 emissions in the Enteric Fermentation and Manure Management categories defined in sections 5.2.3 and 5.3.1.3.

According to these assumptions, the estimate of N_2O emissions of 0.17 Mt from pasturing Canadian livestock in 2024 lies within an uncertainty range of -60% to +75%, or 0.067 Mt to 0.29 Mt, respectively (Table 5–7).

The same methodology and emission factors are used for the entire time series (1990–2024).

5.4.1.4.4. QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. QC checks and cross-checks have been carried out to identify data entry errors and calculation errors.

5.4.1.4.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.4.1.4.6. Planned Improvements

No improvements are currently planned for this category. Further uncertainty work will be carried out to consider changes made to the pasture, range and paddock (PRP) model and to establish trend uncertainty over the medium term.

5.4.1.5. Mineralization Associated with Loss of Soil Organic Matter (CRT Category 3.D.1.e)

5.4.1.5.1. Category Description

Carbon loss in soils because of changes in land management practices, crop productivity, and manure application is accounted for in the Cropland category of the LULUCF sector (Chapter 6). Nevertheless, N mineralization associated with the loss of soil organic carbon contributes to the overall N balance of agricultural lands. This N, once in an inorganic form, is prone to loss in the form of N_2O during either nitrification or denitrification and consequently must be considered because of its contribution to soil N_2O emissions.

5.4.1.5.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of N in soil organic matter that is lost because of changes in cropland management practices, crop productivity and/or manure application, multiplied by the emission factor at the ecodistrict level, and scaled up to the provincial and national levels.

The quantity of soil organic carbon loss at an ecodistrict level from 1990 to 2024 is derived from the carbon reported for the Cropland Remaining Cropland category of LULUCF, excluding the effects from forest land converted to cropland within 20 years (i.e., N_2O emissions resulting from the disturbance of land converted to cropland, since emissions resulting from the disturbance of forest land converted to cropland are already reported under LULUCF), perennial above-ground biomass and cultivation of histosols. A data set on quantities of soil organic carbon and N in all major soils in Saskatchewan was used to derive the average C:N ratio for cropland soils. Ecodistrict-based soil N_2O emission factors (EF_BASE) are the same as those used to estimate emissions from the application of organic fertilizer on annual crops. Emission factors are based on climatic and soil characteristics in the individual ecodistrict in which organic matter mineralization occurs.

5.4.1.5.3. Uncertainty Assessment and Time-Series Consistency

Uncertainty parameters are based on the standard deviation for the soil database, uncertainty estimates of carbon loss and the uncertainty surrounding ecodistrict-based emission factors. Impacts on the uncertainty associated with agricultural soils will be re-evaluated during the next full round of uncertainty assessments when they are renewed. Owing to its small contribution to total emissions, this source would not likely affect overall emission uncertainty. Currently, uncertainty estimates for this category are considered the same as those for emissions from crop residue decomposition. According to these assumptions, the estimate of N_2O emissions of 0.53 Mt from mineralization associated with the loss of soil organic matter in 2024 lies within an uncertainty range of -35% to +45%, or 0.35 Mt to 0.77 Mt, respectively (Table 5–7).

5.4.1.5.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.5.5. Recalculations

A correction was made to the quantity of crop residue returned to the soil in the LULUCF methodology for the Cropland category, which resulted in changes in estimates of carbon storage in soils and consequently on soil N_2O emissions. Emissions increased by 30 kt in 1990, 122 kt in 2005 and decreased by 122 kt in 2023 (Table 5–8). The short-term trend shifted downwards from 174% to 84% and the long-term trend from 219% to 44%.

Table 5–8 **Recalculations of N_2O Emission Estimates and Their Impact on Emission Trends from Mineralization of Soil Organic Carbon**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change in Category Emissions (%)	Old Trend (%)	New Trend (%)
Mineralization of Soil Organic Carbon	1990	2025	198	30	15	Long term (1990–2023)	
		2026	228			174	84
	2005	2025	170	122	72		
		2026	292			Short term (2005–2023)	
	2023	2025	542	-122	-23	219	44
		2026	420				

5.4.1.5.6. Planned Improvements

As is the case for crop residue N, future improvements in this category will focus on differentiating N_2O emission factors for organic and inorganic N sources. The uncertainty for this category will be calculated in the next round of uncertainty analyses.

5.4.1.6. Cultivation of Organic Soils (CRT Category 3.D.1.f)

5.4.1.6.1. Category Description

Cultivation of organic soils (histosols) for crop production usually involves drainage, lowering the water table and increasing aeration, which enhances the decomposition of organic matter and N mineralization. The enhancement of decomposition upon the cultivation of histosols can result in greater denitrification and nitrification and thus in higher N_2O production (Mosier et al., 1998).

5.4.1.6.2. Methodological Issues

The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils (IPCC, 2006). Emissions of N_2O are calculated by multiplying the area of cultivated histosols by the IPCC default emission factor.

Areas of cultivated histosols at a provincial level are not surveyed in the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada have resulted in an estimated area of 16 kha and 30 kha of cultivated organic soils for annual and perennial crop production in Canada, a constant level for the period 1990–2024 (Liang et al., 2004a).

5.4.1.6.3. Uncertainty Assessment and Time-Series Consistency

For N_2O emissions from organic soils, the uncertainty analysis considers the uncertainty in cultivated organic soils and in the default emission factors.

The N_2O emission estimate of 0.22 Mt from organic soils in 2024 lies within an uncertainty range of -79% to +96%, or 0.046 Mt to 0.43 Mt, respectively (Table 5–7). The main source of uncertainty is the IPCC Tier 1 default emission factors.

The same methodology and emission factors are used for the entire time series (1990–2024).

5.4.1.6.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies, and changes to methodologies are documented and archived in paper and electronic form.

5.4.1.6.5. Recalculations

Minor refinements were made to the distribution of areas classified as organic soils in the soils database, but no impacts to emissions occurred as a result of these changes.

5.4.1.6.6. Planned Improvements

No improvements are currently planned for this category.

5.4.1.7. Changes in N_2O Emissions from Adoption of No-Till and Reduced Tillage

5.4.1.7.1. Category Description

Emissions in this category are not derived from additional N inputs (i.e., fertilizer, manure or crop residues). Rather, it is implemented as a modification to N_2O emission factors to account for the change from conventional to conservation tillage practices, specifically reduced tillage (RT) and no-till (NT).

5.4.1.7.2. Methodological Issues

Compared with conventional or intensive tillage, the practice of direct seeding or no-till, as well as reduced tillage, results in changes to several factors that influence N_2O production, including decomposition of soil organic matter, soil carbon and N availability, soil bulk density, and water content (McConkey et al., 1996, 2003; Liang et al., 2004b). As a result, compared with conventional tillage, conservation tillage (i.e., RT and NT) generally reduces N_2O emissions for the Prairies (Malhi and Lemke, 2007) and can increase N_2O emissions for the non-Prairie regions of Canada (Liang et al., 2020; Rochette et al., 2008b) but results were highly variable on a broader analysis (Pelster et al. 2023). Following an expert review process with Canadian agricultural research scientists, the tillage factor for prairie regions from Liang et al. (2020) is implemented, while the factor for non-prairie regions is not implemented, pending further analysis. The net result across the country is a reduction in emissions. This reduction is reported separately as a negative estimate (Table 5–1).

Changes in N_2O emissions resulting from the adoption of NT and RT are estimated through the modification of soil N_2O emission factors and applied to inorganic fertilizers, organic N applied to cropland, and crop residue N decomposition. This subcategory is kept separate from the fertilizer and crop residue decomposition source categories to preserve transparency in reporting. However, this separation causes negative emissions to be reported. An empirically derived tillage factor (RF_TILL), defined as the ratio of mean N_2O fluxes on NT or RT to mean N_2O fluxes on intensive tillage (IT) (N_2O_{NT}/N_2O_{IT}), represents the effect of NT or RT on N_2O emissions (see Annex 3.4).

5.4.1.7.3. Uncertainty Assessment and Time-Series Consistency

For N_2O emissions from the adoption of conservation tillage practices, the uncertainty analysis considers the uncertainty in tillage practice areas, manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emission reduced by 1.3 Mt from conservation tillage practices in 2024. The reduced estimate lies within an uncertainty range of -44% to +55%, based on the uncertainty range of the combined emissions from tillage, irrigation and summer fallow practices (Table 5–7). Tillage practice calculations are dependent on all soil emission calculations, and uncertainty is therefore influenced by all factors described in previous uncertainty sections, in particular the emission factor modifier for tillage (RF_TILL).

The same methodology and emission factors are used for the entire time series (1990–2024).

5.4.1.7.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies are documented and archived in paper and electronic form.

5.4.1.7.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.4.1.7.6. Planned Improvements

Work is ongoing to develop level and trend uncertainty estimates using the IPCC Tier 2 method. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.8. N_2O Emissions from Irrigation

5.4.1.8.1. Category Description

As in the case of tillage practices, the effect of irrigation on N_2O emissions is not derived from additional N input but rather reflects changes in soil conditions that affect N_2O emissions. Higher soil water content under irrigation increases the potential for N_2O emissions through increased anaerobic biological activity, reducing soil aeration (Jambert et al., 1997) and thus enhancing denitrification.

5.4.1.8.2. Methodological Issues

The methodology used is country-specific and is based on the assumptions that (i) irrigation water stimulates N_2O production in a way similar to rainfall; and (ii) irrigation is applied at rates such that the combined amounts of precipitation and irrigation water are equal to potential evapotranspiration under local conditions. Consequently, the effect of irrigation on N_2O emissions from agricultural soils was estimated using an EF_Base estimated at P=PE (precipitation equivalent to potential evapotranspiration) for the irrigated areas of a given ecodistrict (Liang et al., 2020). To improve transparency, the effect of irrigation on soil N_2O emissions is also reported separately from other source categories.

5.4.1.8.3. Uncertainty Assessment and Time-Series Consistency

For N_2O emissions from irrigation, the uncertainty analysis considers the uncertainty associated with irrigated areas and the manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, as well as the uncertainty defined in the previous country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors as noted in section 5.4.1.1.3. A future update to the uncertainty analysis is planned to take account of the incorporation of updated soil N_2O emission factors and the irrigation emission factor included in this submission.

The estimate of N_2O emissions of 1.1 Mt from irrigated land in 2024 has an uncertainty range of -44% to +55%, based on the uncertainty range of the combined emissions from tillage, irrigation and summer fallow practices. The irrigated land emission factor for a given ecodistrict is a function of all soil emission factor calculations, and uncertainty is therefore influenced by all factors described in the previous uncertainty sections. An updated uncertainty analysis is planned to incorporate the revised soil N_2O emission factors included in this submission.

The same methodology and emission factors are used for the entire time series (1990–2024).

5.4.1.8.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data and methodology are documented and archived in electronic form.

5.4.1.8.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.4.1.8.6. Planned Improvements

No improvements are currently planned for this category. Further uncertainty work will be carried out to establish an updated level and trend uncertainty estimate over the medium term.

5.4.2. Indirect N_2O Emissions from Managed Soils (CRT Category 3.D.2)

A fraction of the N from organic and inorganic fertilizers applied to agricultural fields is transported off-site through leaching, runoff or volatilization in the form of NH_3 and NO_x and subsequent re-deposition. This N that is transported off-site from agricultural fields results in eventual N accumulation in other ecosystem sites and subsequently undergoes nitrification or denitrification to produce N_2O.

5.4.2.1. Atmospheric Deposition of Nitrogen (CRT Category 3.D.2.a)

5.4.2.1.1. Category Description

When organic or inorganic fertilizer is applied to cropland, a portion of the N is lost through volatilization in the form of NH_3 or NO_x, which can then be redeposited elsewhere and undergo further transformation, resulting in off-site N_2O emissions. The quantity of this volatilized N depends on several factors, such as rates of fertilizer and manure N application, fertilizer types, methods and timing of N application, soil texture, rainfall, temperature, and soil pH.

5.4.2.1.2. Methodological Issues

There are few published scientific data that determine N_2O emissions from atmospheric deposition of NH_3 and NO_x. Leached or volatilized N may not be available for the process of nitrification and denitrification for many years, particularly in the case of N leaching into groundwater. Although indirect soil N_2O emissions from agricultural soils are a key source category for level and trend assessments for Canada, there are difficulties in defining the duration and boundaries for this source of emissions because no standardized method for deriving the IPCC Tier 2 emission factors is provided in the 2006 IPCC Guidelines (IPCC, 2006).

A country-specific method is used to estimate ammonia emissions from the application of inorganic fertilizer N and dairy and swine manure N to soils. The method for deriving ammonia emission factors from inorganic N closely follows the model used by Sheppard et al. (2010) to calculate specific emission factors for various ecoregions in Canada. Ammonia emission factors are derived based on the type of inorganic N fertilizer, degree of incorporation into soil, crop type and soil chemical properties.

Canadian agricultural soils range from semi-arid to humid. On the basis of the analysis presented in the most recent IPCC methodological update, it was determined that the use of the default IPCC emission factors of 0.014 kg N_2O-N kg^{-1} N for wet climates and 0.005 kg N_2O-N kg^{-1} N for dry climates (IPCC, 2019) would provide more accurate estimates of indirect emissions under Canadian conditions than the default emission factor published in the 2006 IPCC Guidelines (IPCC, 2006).

For dairy cattle and swine, the amount of manure N subject to losses from volatilization of NH_3 following application is estimated using a revised version of the Canadian NH_3 emission model (Sheppard et al., 2011b; Chai et al., 2016) to generate ecoregion-specific N loss factors by animal type and AWMS. For all other animal manure applied to fields, default volatilization fractions provided in the 2006 IPCC Guidelines (IPCC, 2006) were used to estimate N loss as NH_3.

5.4.2.1.3. Uncertainty Assessment and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N_2O emissions from the atmospheric deposition of N considers the uncertainty surrounding the parameters defined in the Tier 1 methodology in the 2006 IPCC Guidelines (IPCC, 2006), as well as the uncertainty in the estimate of NH_3.

The estimate of N_2O emissions of 0.92 Mt from volatilization and redeposition in 2024 has an uncertainty range of -75% to +110%, or 0.23 Mt to 1.9 Mt respectively (Table 5–7). Most of the uncertainty is associated with the IPCC Tier 1 emission factor of 1% (uncertainty range, 0.2% to 5%). An updated uncertainty analysis will be carried out at a future date; however, the replacement of the default IPCC emission factor from the 2006 IPCC Guidelines (IPCC, 2006), with the climate-specific factors from the 2019 Refinement of the 2006 IPCC Guidelines (IPCC, 2019), is expected to decrease uncertainty based on the smaller range of uncertainty for the new factors.

The same methodology and emission factors are used for the entire time series (1990–2024).

5.4.2.1.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies are documented and archived in paper and electronic form.

5.4.2.1.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.4.2.1.6. Planned Improvements

No improvements are currently planned for this category.

5.4.2.2. Nitrogen Leaching and Runoff (CRT Category 3.D.2.b)

5.4.2.2.1. Category Description

When organic and inorganic fertilizers, and crop residues, are added to cropland, a portion of the N from these sources is lost through leaching and runoff. The magnitude of this loss depends on several factors, such as the application rate and method, crop type, soil texture, rainfall and landscape. This portion of lost N can undergo further transformations, such as nitrification and denitrification, and can produce off-site N_2O emissions.

5.4.2.2.2. Methodological Issues

There are few published scientific data that determine N_2O emissions from leaching and runoff in Canada. As in the case of N_2O emissions from volatilization and deposition of NH_3 and NO_x, this source is poorly defined because no standardized method for deriving the IPCC Tier 2 emission factors is provided in the 2006 IPCC Guidelines (IPCC, 2006).

A modified IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from leaching and runoff of fertilizers, manure, and crop residue N from agricultural soils. Indirect N_2O emissions, from runoff and leaching of N at the ecodistrict level, are estimated using the fraction of N that is lost through leaching and runoff ($FRAC_{LEACH}$), multiplied by the amount of inorganic and organic N, and by an emission factor of 0.0075 kg N_2O-N kg^{-1} N (IPCC, 2006).

The default value for $FRAC_{LEACH}$ in the Revised 1996 Guidelines is 0.3. However, $FRAC_{LEACH}$ can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration, such as in the Prairies (IPCC, 2006). Accordingly, it is assumed that $FRAC_{LEACH}$ would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with no moisture deficit during the growing season (May to October), the maximum $FRAC_{LEACH}$ value of 0.3 recommended by the 2006 IPCC Guidelines (IPCC, 2006) is assigned. The minimum $FRAC_{LEACH}$ value of 0.05 is assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts, $FRAC_{LEACH}$ is estimated by the linear extrapolation of the two end-points described above.

5.4.2.2.3. Uncertainty Assessment and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N_2O emissions from N leaching and runoff considers the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines (IPCC, 2006) and the uncertainty in the estimate of total N.

The estimate of N_2O emissions of 2.9 Mt from N leaching and runoff in 2024 lies within an uncertainty range of -80% to +100%, or 0.59 Mt to 5.9 Mt respectively (Table 5–7). Most uncertainty is associated with the IPCC Tier 1 emission factor of 0.75% of total N leached (uncertainty range of 0.05% to 2.5%) (IPCC, 2006).

The same methodology and emission factors are used for the entire time series (1990–2024).

5.4.2.2.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.2.2.5. Recalculations

Revisions to Cropland SOC mineralization had a minor impact on emissions in this category (< 1 kt CO_2 eq).

5.4.2.2.6. Planned Improvements

No improvements are currently planned for this category.

5.5. CH_4 and N_2O Emissions from Field Burning of Agricultural Residues (CRT Category 3.F)

5.5.1. Category Description

Crop residues are sometimes burned in Canada, as a matter of convenience and for disease control through residue removals. However, this practice has declined in recent years because of concerns over soil quality and environmental issues. Field burning of agricultural residues is a net source of CH_4, CO, NO_x, and N_2O (IPCC, 2006).

5.5.2. Methodological Issues

There are no published data on emissions of N_2O and CH_4 from field burning of agricultural residues in Canada. Thus, the IPCC default emission factors and parameters from the 2006 IPCC Guidelines (IPCC, 2006) were used for estimating emissions.

A complete time series of activity data on the type and percent of each crop residue subject to field burning was developed based on Statistics Canada's FEMS[3] and on expert consultations (Coote et al., 2008).

Crop-specific parameters required for estimating the amount of crop residue burned, such as moisture content of the crop product and ratio of above-ground crop residue to crop product, were obtained from Janzen et al. (2003) and are consistent with the values used to estimate emissions from crop residue decomposition.

5.5.3. Uncertainty Assessment and Time-Series Consistency

The uncertainties associated with CH_4 and N_2O emissions from field burning of agricultural residues are determined using an IPCC Tier 1 method (IPCC, 2006).

The uncertainties associated with CH_4 and N_2O emissions from field burning of agricultural residues are the amount of field crop residues burned and emission factors. Based on the area of specific seeded crop, the uncertainty in the amount of crop residues burned is estimated to be ±50% (Coote et al., 2008). The uncertainties associated with the emission factors are not reported in the 2006 IPCC Guidelines (IPCC, 2006), but are assumed to be similar to those associated with burning of Savanna and grassland: ±40% for CH_4 and ±48% for N_2O (IPCC, 2006). The level uncertainties for CH_4 and N_2O emission estimates are ±64% and ±69%, respectively.

5.5.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data and methodologies are documented and archived in paper and electronic form.

5.5.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.5.6. Planned Improvements

No improvements are currently planned for this category.

5.6. CO_2 Emissions from Liming (CRT Category 3.G)

5.6.1. Category Description

In Canada, agricultural limestone is sometimes used in the production of certain crops, such as alfalfa, to neutralize acidic soils, increase the availability of soil nutrients, particularly phosphorus, reduce the toxicity of heavy metals, such as aluminum, and improve the crop growth environment. During this neutralization process, CO_2 is released in bicarbonate equilibrium reactions that occur in the soil. The rate of release will vary with soil conditions and the compounds applied.

3 https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5044

5.6.2. Methodological Issues

Emissions associated with the use of lime were calculated from the amount of lime applied annually and the proportion of carbonate in the minerals used for liming soils that breaks down and is released as CO_2. Methods and data sources are outlined in Annex 3.4.

5.6.3. Uncertainty Assessment and Time-Series Consistency

The 95% confidence limits for data on annual lime consumption in each province are estimated to be ±30%. This uncertainty is assumed to include the uncertainty in lime sales, uncertainty in when lime sold is actually applied, and uncertainty in the timing of emissions from applied lime. The uncertainty in the emission factor is -50% based on the 2006 IPCC Guidelines (IPCC, 2006). The overall mean and uncertainties were estimated to be 0.16 ± 0.14 Mt for the level uncertainty.

The same methodology is used for the entire time series of emission estimates (1990–2024).

5.6.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.6.5. Recalculations

The inclusion of impurities had a minor impact on the CO_2 emissions. Emissions decreased by 20 kt in 1990, 9 kt in 2005 and by 9 kt in 2023 (Table 5–9). The long-term trend shifted upwards from 160% to 163% and the short-term trend remained unchanged at 118%.

5.6.6. Planned Improvements

No improvements are currently planned for this category.

Table 5–9 **Recalculations of CO_2 Emissions Estimates and Their Impact on Emission Trends from Liming application**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change in Category Emissions (%)	Old Trend (%)	New Trend (%)
Liming application	1990	2025	1 191	-20	-2	Long term (1990–2023)	
		2026	1 171			160	163
	2005	2025	1 421	-9	-1		
		2026	1 412			Short term (2005–2023)	
	2023	2025	3 091	-9	0	118	118
		2026	3 082				

5.7. CO_2 Emissions from Urea Application (CRT Category 3.H)

5.7.1. Category Description

When urea [$CO(NH_2)_2$] or urea-based N fertilizers are applied to soil to augment crop production, CO_2 is released when the urea undergoes hydrolysis. According to the 2006 IPCC Guidelines (IPCC, 2006), the quantity of CO_2 released into the atmosphere should be accounted for as an emission. In addition to urea, Canadian farmers also use significant amounts of urea ammonium nitrate (28-0-0) with a mixture of 30% $CO(NH_2)_2$.

5.7.2. Methodological Issues

Emissions associated with urea application were calculated from the amount of urea or urea-based fertilizers applied annually, and the quantity of carbon contained in the urea released as CO_2 after hydrolysis. Methods and data sources are outlined in Annex 3.4.

5.7.3. Uncertainty Assessment and Time-Series Consistency

The 95% confidence limit for data on the annual urea or urea-based fertilizer consumption are estimated to be ±15%. The uncertainty estimate associated with the emissions is based on simple error propagation using survey uncertainty and an uncertainty of -50% associated with the emission factor specified in the 2006 IPCC Guidelines (IPCC, 2006). The overall mean and uncertainties are estimated to be 2.9 ± 1.4 Mt for the level of uncertainty.

The same methodology and data sources are used for the entire time series of emission estimates. Urea consumption in Canada increased significantly from 1990 to 2024 with a relatively high inter-annual variability in a range of up to ±25% annually. Although we cannot identify specific factors that result in inter-annual variability, urea-based fertilizer shipments in Canada vary due to price fluctuations, climate factors influencing crop production, and other factors.

5.7.4. QA/QC and Verification

This category has undergone Tier 1 QC checks following the QA/QC plan (see section 1.3, Chapter 1), which is consistent with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.7.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

5.7.6. Planned Improvements

No improvements are currently planned for this category.

CHAPTER 6

LAND USE, LAND-USE CHANGE AND FORESTRY (CRT SECTOR 4)

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6.1. Overview

The Land Use, Land-Use Change and Forestry (LULUCF) sector reports greenhouse gas (GHG) fluxes between the atmosphere and Canada's managed lands, as well as fluxes associated with land-use changes and emissions from harvested wood products (HWP) derived from these lands. This assessment includes emissions and removals of carbon dioxide (CO_2) associated with carbon (C) stock changes, and emissions of CO_2, methane (CH_4), nitrous oxide (N_2O) and carbon monoxide (CO)[1] due to controlled biomass burning. It also covers CO_2, CH_4 and N_2O emissions from drained organic forest soils, and wetland-specific activities such as drainage and rewetting; and N_2O released following land conversion to cropland.

The estimated net GHG flux in the LULUCF sector, calculated as the sum of CO_2[2] fluxes, non-CO_2 emissions and CO_2 removals, amounted to net emissions of 61 Mt in 1990, 81 Mt in 2005 and 4.3 Mt in 2024.[3] When applied to the national totals, the net flux estimates result in an increase of 10% in 1990, 11% in 2005 and 0.64% in 2024 in total Canadian GHG emissions. Table 6–1 provides the net flux estimates for the major LULUCF categories and subcategories for 1990, 2005 and more recent years. The full time series of LULUCF sector estimates is available in Table 10 of the common reporting table (CRT) series.

The Forest Land, Cropland and Harvested Wood Products categories had the greatest influence on the totals for the sector. Positive net fluxes (i.e., C emissions) were reported in the LULUCF sector during all but one year (2023) of the time series.[4] Carbon emissions increased from 1990 to 2005 by 20 Mt and subsequently declined due to the downward trend in net emissions in the Forest Land category, though the trend is impacted by interannual variability in the Cropland category.

Emissions and removals from the forest sector in Canada consist of the net fluxes from forest stands that are of harvest origin or commercially mature stands that have recovered from natural disturbances, and the corresponding net change in global storage of carbon in HWP extracted from Canadian forests that results from new products and the disposal of products that have either reached the end of their useful life or have been burned for bioenergy. Forest management resulted in an increase in net emissions from 80 Mt to 146 Mt between 1990 and 2005 in the Forest Land category. This increase in emissions reflects the influence of increased forest harvest and, to a lesser extent, increased insect-related mortality which, together, resulted in a net reduction in C removals from the atmosphere by the anthropogenic component of the managed forest. Net emissions from Forest Land have then returned to and fallen below earlier levels, and now represent a net removal of 1.2 Mt as of 2024, mainly due to reduced harvest levels relative to rates observed in the early 2000s and an evolving forest age-class structure.

1 Emissions of CO are reported as CO in CRT Table 4, but are not included in the sectoral totals, and are instead reported as indirect CO_2 in CRT Table 6. Unless otherwise indicated, all emissions and removals reported for the LULUCF sector do not include emissions of indirect CO_2 from CO.

2 Unless otherwise indicated, all emissions and removals are shown in CO_2 equivalents (CO_2 eq).

3 All figures associated with estimates and activity data have been rounded, except in cases when an explanation of specific details of estimates or trends that may be masked by rounding is required.

4 Complete time series data for all tables are available on open data: https://data.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/.

Net flux in the Harvested Wood Products category[5] have ranged between -61 Mt and +1.0 Mt during the 1990–2024 period. These trends are closely related to current and legacy harvesting. The legacy effect occurs as C from products harvested decades ago is gradually emitted during the reporting period, while new harvests stores new C in the HWP pool. The minimum value (storage of -61 Mt) was recorded in 2004 corresponding with peak harvest rates, while the maximum value (a net loss of +1.0 Mt) occurred in 2009 when harvest rates were at their minimum (Figure 6–2).

The combined net flux from the Forest Land and Harvested Wood Products categories—the latter including HWP from forest conversion activities and firewood harvest from non-forest lands since 1990—amounted to a net emission of 40 Mt in 1990 and a net removal of 1.8 Mt in 2024, peaking at net emissions of 90 Mt in 2005.

Emissions and removals from stands recovering from natural disturbances, beyond the control of human intervention, are tracked separately from the anthropogenic component of emissions. Nonetheless, natural disturbances can result in substantial emissions and subsequent removals of GHGs within the managed forest and display large interannual variability that masks the role of forest management activities on forest carbon (see section 6.3.1.2 for more details). Since 1990, the net flux from lands impacted by natural disturbances has ranged from removals of 141 Mt in 1992 to peak emissions of 940 Mt in 2023 (peak wildfire year in the reporting period). Emissions and removals have tended to be higher since the mid-2000s than in the early part of the inventory reporting period (Table 6–1) due to the increased frequency of wildfires and insect disturbances. Since 2018, on average, emissions from lands impacted by natural disturbances, both wildfire and insect disturbance, are estimated to be 290 Mt and have been a net source of emissions since the early 2000s. Wildfire impacts have steadily increased in Canadian Forest Land over the reporting period, culminating in 2023 with a total area burned of 7.9 Mha in the managed forest, the largest area burned since national records have been maintained.

Table 6–1 **Overview of Net Greenhouse Gas Flux Estimates in the Land Use, Land-Use Change and Forestry Sector, Selected Years**

Sectoral Category	Net GHG Flux (kt CO_2 eq)[b]							
	1990	2005	2019	2020	2021	2022	2023	2024
LAND USE, LAND-USE CHANGE AND FORESTRY TOTAL[a]	**61 000**	**81 000**	**16 000**	**26 000**	**14 000**	**46 000**	**-8 700**	**4 300**
Forest Land 4.A.	**79 000**	**150 000**	**36 000**	**36 000**	**29 000**	**15 000**	**1 300**	**-1 200**
Forest Land Remaining Forest Land 4.A.1	80 000	150 000	36 000	36 000	29 000	15 000	1 400	-1 200
Land Converted to Forest Land 4.A.2	-1 000	-950	-300	-240	-170	-130	-130	17
Cropland 4.B.	**5 600**	**-20 000**	**-12 000**	**-10 000**	**-14 000**	**24 000**	**-21 000**	**-3 600**
Cropland Remaining Cropland 4.B.1	-7 000	-25 000	-19 000	-17 000	-21 000	17 000	-27 000	-10 000
Land Converted to Cropland 4.B.2	13 000	5 000	6 200	6 600	6 800	6 800	6 500	6 500
Grassland 4.C.	**0.7**	**0.9**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**
Grassland Remaining Grassland 4.C.1	0.7	0.9	1.3	1.3	1.3	1.3	1.3	1.3
Land Converted to Grassland 4.C.2	NO	NO	NO	NO	NO	NO	NO	NO
Wetlands 4.D.	**10 000**	**7 000**	**5 600**	**5 600**	**6 000**	**5 700**	**5 500**	**5 400**
Wetlands Remaining Wetlands 4.D.1	4 300	6 300	5 000	4 900	4 900	4 900	4 800	4 800
Land Converted to Wetlands 4.D.2	5 900	660	620	640	1 100	820	740	680
Settlements 4.E.	**4 900**	**5 100**	**5 000**	**4 700**	**4 600**	**4 500**	**4 600**	**4 300**
Settlements Remaining Settlements 4.E.1	-3 900	-4 000	-4 100	-4 100	-4 000	-4 000	-4 000	-4 000
Land Converted to Settlements 4.E.2	8 800	9 100	9 000	8 800	8 700	8 600	8 600	8 300
Other Land 4.F.	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**
Harvested Wood Products 4.G.	**-39 000**	**-57 000**	**-18 000**	**-10 000**	**-11 000**	**-3 000**	**730**	**- 630**
Forest conversion[c]	*27 000*	*20 000*	*20 000*	*20 000*	*20 000*	*19 000*	*19 000*	*19 000*
Indirect CO_2[d]	*490*	*570*	*450*	*440*	*450*	*390*	*340*	*340*
Natural disturbances[e]	*-130 000*	*8 500*	*140 000*	*2 700*	*290 000*	*89 000*	*1000 000*	*430 000*

Notes:
NE = Not estimated
NO = Not occurring
a. Totals may not add up due to rounding.
b. A negative sign indicates net removals of CO_2 from the atmosphere.
c. Not a reporting category; it overlaps with the Land Converted to Cropland, Land Converted to Wetlands, and Land Converted to Settlements subcategories.
d. Indirect emissions of CO_2 from the atmospheric oxidation of CO that results from controlled biomass burning, reported in CRT Table 6.
e. Not a reporting category; this line is provided solely for transparency purposes and shows the net balance of emissions/removals resulting from natural disturbances in managed forests, including indirect emissions of CO_2 due to the atmospheric oxidation of CO that results from wildfires.

5 Includes HWP from managed forests and deforested lands (forest conversion) and firewood harvested from non-forest lands.

Changes in agricultural land management practices in Western Canada, such as the extensive adoption of conservation tillage practices combined with the reduced use of summer fallow and increasing crop yields—which increase C input to soils—have resulted in an increase in net removals of CO_2 in the Cropland category from 1990 to 2006. This trend was further reinforced by reductions in the conversion of other lands to cropland over the same period. However, since 2006, a decrease in the conservation tillage adoption rate, a trend towards the conversion of perennial crops to annual crops and, most recently, some increases in the conversion of Forest Land and Grassland to Cropland, have resulted in a levelling off and decline in Cropland removals. This trend is partially attenuated by higher soil C inputs from annual crop practices. However, periodic crop failures and exceptional yields, due mainly to weather variations, increase interannual variability in soil C inputs and, therefore, in emissions and removals. Examples include the peak emissions in the years 1993 (8.2 Mt), 2003 (9.7 Mt) and 2022 (24 Mt), associated with the drought in Western Canada, and the peak removals in 2009 (34 Mt) and 2014 (40 Mt), associated with high crop yields. As a result, short-term trends must be interpreted with care.

Over the period from 1990 to 2024, net emissions in the Wetlands category (Peat Extraction, Flooded Lands and resource extraction) ranged from a peak of 10 Mt (1990) to a low of 5.4 Mt (2024). Trends in this category are mainly driven by the creation of large reservoirs before 1990, resulting in higher residual emissions over the period from 1990 to 1993. Emissions from Flooded Lands (reservoirs) accounted for 71% of all emissions in the Wetlands category in 2024, compared to 94% in 1990. Emissions from the conversion of forest and other lands during expansions of peat extraction and the development of reservoirs (in the Land Converted to Wetlands category) mainly in the early part of the time series, decreased from 5.9 Mt to 0.7 Mt over the reporting period.

Net emissions reported in the Settlements category fluctuated between 3.7 Mt (1995) and 6.3 Mt (2014), driven mainly by rates of conversion of forested land and wetlands, which accounted for 7.9 Mt and 0.31 Mt of emissions in 2024, respectively. Relatively steady removals of around 4.0 Mt per year from the growth of urban trees offset these emissions on average by 47% over the reporting period.

Forest conversion is not a reporting category per se since it overlaps with the Land Converted to Cropland, Land Converted to Wetlands, and Land Converted to Settlements categories. Considering these categories together, the emissions due to forest conversion decreased from 27 Mt in 1990 to 18 Mt in 2010 and were 19 Mt in 2024. The long-term decrease relative to 1990 is primarily driven by a decrease in the conversion of forest to cropland, wetlands and settlements, which reduced emissions by 5.2 Mt, 2.5 Mt, and 0.78 Mt, respectively. From 2010 to 2024, overall emissions remained relatively consistent at approximately 18-20 Mt, reflecting offsetting changes among the land-use categories rather than a continued decline in conversion rates; by 2024, emissions from conversion to cropland had increased by 3.0 Mt relative to 2010, while emissions from conversion to wetlands and settlements had declined by 1.4 Mt and 0.6 Mt, respectively.

To avoid double counting, the estimates of C stock changes in CRT tables 4.A to 4.E exclude C emissions emitted as CO_2, CH_4 and CO, due to biomass burning, and CO_2 and CH_4 emissions, due to the drainage and rewetting of organic soils. Carbon emissions from biomass burning emitted as CO_2 and CH_4 are reported in CRT Table 4(V) along with N_2O emissions. Carbon emissions in the form of CO_2 and CH_4, from the drainage of organic forest soils and wetland drainage, and rewetting are reported in CRT Table 4(II) along with emissions of N_2O. Carbon emissions in the form of CO are reported as such in CRT Table 4, but are not included in the sectoral totals, and are instead reported as indirect CO_2 in CRT Table 6. Emissions and removals of CO_2 and emissions of CH_4, N_2O and CO are automatically tallied in CRT Table 4.

The combined impact of recalculations in the LULUCF sector (Table 6–2) were upward recalculations of 11Mt CO_2 eq in 1990, 15 Mt CO_2 eq in 2005, and a downward revision of 13 Mt CO_2 eq in 2023.

See sections 6.3 to 6.9, Table 6–2 and 6–3 and Chapter 8 for additional details on the changes implemented.

Environment and Climate Change Canada (ECCC) has established governance mechanisms for LULUCF reporting through memoranda of understanding with Agriculture and Agri-Food Canada (AAFC) and the Canadian Forest Service of Natural Resources Canada (NRCan-CFS) for planning, coordinating, and developing estimates in the Forest Land and Cropland categories. In addition, the Department collaborates with many groups of scientists and experts across various levels of government and research institutions to produce estimates for other land-use categories.

Planned improvements include continued refinements and improved transparency of communication of anthropogenic emissions and removals resulting from forest management, continued refinements to the HWP model structure and activity data, the completion of uncertainty estimates for all LULUCF categories, and the gradual integration of missing land-use and land-use change categories. More details can be found in sections 6.3 to 6.9 and in Chapter 8, section 8.3.1 and Table 8–5.

The remainder of this chapter provides more detail on each LULUCF category. Section 6.2 gives an overview of how managed lands are defined and represented; section 6.3 provides a short description of the Forest Land category; section 6.4 describes the Harvested Wood Products category; sections 6.5 to 6.8 describe the Cropland, Grassland, Wetlands and Settlements categories; and section 6.9 focuses on the cross-category estimates of forest conversion.

Detailed inventory methodologies and sources of activity data are described in Annex 3.5 and a compilation of emission factors and other parameters used to develop and report the LULUCF estimates is provided in section A6.5.

Table 6–2 **Summary of Recalculations in Reported Estimates for the Land Use, Land-Use Change and Forestry Sector, Selected Years**

Sectoral Category		1990	2005	2019	2020	2021	2022	2023
LAND USE, LAND-USE CHANGE AND FORESTRY TOTAL[a]	**kt**	**11 000**	**15 000**	**1 700**	**750**	**- 450**	**-5 000**	**-13 000**
	%	**23%**	**23%**	**12%**	**3.0%**	**-3.0%**	**-10%**	**-310%**
Forest Land 4.A.	**kt**	**6 200**	**10 000**	**-4 000**	**-4 000**	**-5 200**	**-7 000**	**-22 000**
	%	**9%**	**8%**	**-10%**	**-10%**	**-15%**	**-32%**	**-94%**
Forest Land Remaining Forest Land 4.A.1	kt	6 300	10 000	-4 000	-4 000	-5 200	-7 000	-22 000
	%	9%	8%	-10%	-10%	-15%	-32%	-94%
Land Converted to Forest Land 4.A.2	kt	-87	-63	-12	-0.11	0.89	2.3	-2.1
	%	9%	7.1%	4.3%	0.04%	-0.5%	-1.8%	1.7%
Cropland 4.B.	**kt**	**97**	**250**	**3 000**	**2 600**	**2 100**	**-1 300**	**1 100**
	%	1.8%	-1.2%	-20%	-20%	-13%	-5.4%	-5.1%
Cropland Remaining Cropland 4.B.1.	kt	650	490	2 000	750	320	-2 800	- 120
	%	-8.4%	-1.9%	-9.6%	-4.2%	-1.5%	-14%	0.4%
Land Converted to Cropland 4.B.2	kt	- 550	- 240	1 000	1 800	1 800	1 500	1 200
	%	-4.2%	-4.6%	20%	38%	36%	28%	23%
Grassland 4.C.	**kt**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	%	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Grassland Remaining Grassland 4.C.1	kt	-	-	-	-	-	-	-
	%	-	-	-	-	-	-	-
Wetlands 4.D.	**kt**	**5 000**	**4 300**	**2 900**	**2 700**	**3 200**	**3 000**	**2 900**
	%	97%	160%	110%	95%	120%	120%	110%
Wetlands Remaining Wetlands 4.D.1	kt	3 100	4 100	2 700	2 600	2 600	2 500	2 400
	%	270%	190%	120%	120%	110%	110%	100%
Land Converted to Wetlands 4.D.2	kt	1 900	150	190	68	660	530	500
	%	22%	1.7%	2.0%	0.72%	6.9%	5.7%	5.4%
Settlements 4.E.	**kt**	**130**	**340**	**- 290**	**- 580**	**- 850**	**- 700**	**- 460**
	%	**2.7%**	**7.2%**	**-5.4%**	**-11%**	**-16%**	**-13%**	**-9.2%**
Settlements Remaining Settlements 4.E.1	kt	2.0	36	56	56	78	86	84
	%	-0.05%	-0.89%	-1.4%	-1.4%	-1.9%	-2.1%	-2.0%
Land Converted to Settlements 4.E.2	kt	130	300	- 340	- 640	- 930	- 790	- 550
	%	1.4%	3.5%	-3.6%	-6.8%	-10%	-8.4%	-6.0%
Harvested Wood Products 4.G.	**kt**	**-150**	**23**	**110**	**14**	**250**	**1 000**	**5 800**
	%	0.40%	-0.04%	-0.65%	-0.14%	-2.2%	-26%	-110%
Forest conversion[b]	*kt*	*2 500*	*2 900*	*2 200*	*2 500*	*2 400*	*2 100*	*2 100*
	%	*9.9%*	*17%*	*12%*	*14%*	*14%*	*12%*	*12%*

Notes:
A hyphen (-) indicates no recalculations
a. Totals may not add up due to rounding.
b. Not a reporting category.

Table 6–3 **Summary of Changes in the Land Use, Land-Use Change and Forestry Sector**

List of Changes	Change Category	Years Affected
Forest Land		
Computing architecture modifications and code refinements	Continuous improvement	Complete time series
Dead Organic Matter parameters update	Continuous improvement	Complete time series
Afforestation activity updates	Activity data updates	2020
Afforestation/reforestation activity updates under the two billion trees (2BT) program	Activity data updates	2023-2024
Deforestation activity data – P6 mapping period update	Activity data updates	2015-2024
Forest management	Activity data updates	2020-2023
Residential Firewood activity data refinements	Activity data updates	Complete time series
Wildfire	Activity data updates	2023-2024
Corrections to 2024 insect activity data	Continuous improvement	Complete time series
Cropland		
Revised the C input from crop residues estimation procedure and minor refinements to crop yields	Continuous improvement	Complete time series
Minor revisions to area under the organic soils	Continuous improvement	Complete time series
Deforestation activity data – P6 mapping period update	Activity data updates	2015-2024
Wetlands		
Updated time series on different activity data, updated EF with Canadian specific conditions, for flooded lands	Continuous improvement	Complete time series
New methodology for reporting wetland management for resource extraction activities	TERT Recommendation	Complete time series
Deforestation activity data – P6 mapping period update	Activity data updates	2015-2024
Settlements		
Transfers of carbon to the HWP pool now reported in the source Land category	TERT Recommendation	Complete time series
New methodology for reporting wetland land-use change for resource extraction activities	TERT Recommendation	Complete time series
Deforestation activity data – P6 mapping period update	Activity data updates	2015-2024
Harvested Wood Products		
Residential bionergy and appliance type	Activity data updates	1990-2024
Industrial bioenergy	Activity data updates	1990-2023
Updated HWP commodity conversion parameters based on latest Food and Agriculture Organization (FAO) statistics	Continuous improvement	Complete time series
Updated waste incineration activity data	Activity data updates	Complete time series

6.2. Land Category Definitions and Representation of Managed Lands

To harmonize all land-based estimates, common working definitions of land categories were developed and adopted by all groups involved in estimate preparation. Definitions are consistent with the IPCC (2006) land categories, while remaining relevant to land management practices, prevailing environmental conditions and available data sources in Canada. This framework applies to all LULUCF estimates reported under the United Nations Framework Convention on Climate Change (UNFCCC).

The Forest Land category includes all treed areas of 1 ha or more, with a minimum tree crown cover of 25% and trees of 5 m in height, or having the potential to reach this height. Not all Canadian forests are under the direct influence of human activities, prompting the non-trivial question of what areas properly embody managed forests. For the GHG inventory, managed forests are those managed for timber and non-timber resources (including parks) or subject to fire protection. Section A3.5.2 provides more details on the implementation of the managed forests definition.

Agricultural land includes both the Cropland and Grassland (for agricultural use) categories. Cropland includes all land in annual crops, summer fallow and perennial crops (mostly forage, but also including berries, grapes, nursery crops, vegetables, and fruit trees and orchards). Grassland used for agriculture is defined as unimproved pasture or rangeland exclusively used for grazing domestic livestock. It occurs only in geographical areas where the grassland would not naturally regrow to forest if abandoned (i.e., natural shortgrass prairies in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia). All agricultural land that is not classified as grassland is classified de facto as cropland, including unimproved pastures where the natural vegetation would be forest (Eastern Canada and most of British Columbia).

Vegetated areas that do not meet the definition of Forest Land or Cropland are generally classified as Grassland. Extensive areas of tundra in the Canadian North are considered unmanaged grassland.

Wetlands are areas where permanent or recurrent saturated conditions allow the establishment of vegetation and the development of soils typical of these conditions and that do not fall in the Forest Land, Cropland or Grassland categories. Currently, managed lands included in the Wetlands category are those where human interventions have directly altered the water table—which include peatlands drained for peat extraction, peatland disturbances due to resource extraction activities, and land flooded for reservoirs (IPCC, 2006).

The Settlements category includes all built-up land: urban, rural residential, and industrial and recreational land; roads, rights-of-way and other transportation infrastructure; and land used for resource exploration, extraction and distribution (mining, oil and gas). The diversity of this category has so far precluded a complete assessment of its extent in the Canadian landscape. However, the conversion of Forest Land, Cropland and unmanaged Grassland (tundra) to Settlements and the area of urban trees are assessed under this category.

The Other Land category comprises areas of rock, ice or bare soil, and all land areas that do not fall into any of the other five categories. Currently, emissions from the conversion of Other Land to Flooded Land (reservoirs), and Peat Extraction are reported under the Wetlands category.

Because of the land categorization scheme, some land-use transitions cannot occur—for example, the conversion of forest to agricultural grassland, since, by definition, the Grassland category excludes areas where forests can grow naturally. Since grassland is defined as native grassland, this transition does not occur under this framework.

The IPCC default transition period of 20 years for land-use change is used for all land-use change categories, except for Land Converted to Peat Extraction, when a transition period of one year is used. The one-year period represents the land conversion practices of draining and clearing the surface vegetation layer (acrotelm) in preparation for peat extraction. The use of the default 20-year transition period is simply procedural, since higher tier estimation methods are employed for most emission and removal estimates.

The Canadian land use and land-use change matrix (Table 6–4) illustrates the land-use areas (diagonal cells) and annual land-use change areas (non-diagonal cells) in 2024. The diagonal cells related to the Forest Land category show the total area of managed forest associated with each of two components (anthropogenic or natural disturbance impacts). Therefore, the Forest Land category includes all managed forest areas with anthropogenic impacts (GHG estimates for these areas are reported in CRT tables 4.A, 4(II) and 4(V)), as well as forest areas with natural disturbance impacts (see section 6.3.1.2 and Table 6–5 for more details on the approach used by Canada to isolate the effect of anthropogenic activities on managed forests). The diagonal cells related to the Cropland category refer to total land-use areas; the diagonal cells related to the Grassland category to total managed agricultural grassland; and the diagonal cells related to the Wetlands and Settlements categories only to areas where activities causing GHG emissions or CO_2 removals have occurred. The Grassland Converted to Settlements subcategory is used to report emissions from the conversion of unmanaged tundra to settlements in Northern Canada (see section 6.8.2.2). Each column total equals the total land area reported in the CRT for each land category. The full time series of the land-use and land-use change matrix is available in Table 4.1 (Land Transition Matrix) of the CRT series.

The LULUCF framework includes the conversion of unmanaged forests, grassland and lands with previously undefined land use to other land categories. In all cases, unmanaged land converted to any use is subsequently considered managed land. Parks and protected areas are included in managed lands.

The LULUCF estimates, as reported in the CRT tables, are attached spatially to reporting zones (Figure 6–1). These reporting zones are essentially the same as Canada's terrestrial ecozones (Marshall and Shut, 1999), with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into eastern and western components to form four reporting zones, and the Prairies ecozone is divided into semi-arid and sub-humid components. Estimates are reported for 17 of the 18 reporting zones. The only exception is the Arctic Cordillera ecozone, the northernmost ecozone in Canada, where no direct human-induced GHG emissions or removals have been detected for the LULUCF sector. More details on the spatial estimation and reporting framework can be found in section A3.5.1.

The land areas reported in the CRT tables represent those used for annual estimate development, but not always the total land area of a land category or subcategory in a specific inventory year. For example, the area of land converted to flooded land (reservoirs) represents only those lands flooded within the 20-year transition period, not the total reservoir area in Canada. To approximate the total reservoir extent, both Flooded Land Remaining Flooded Land and Land Converted to Flood Land areas would need to be considered together.

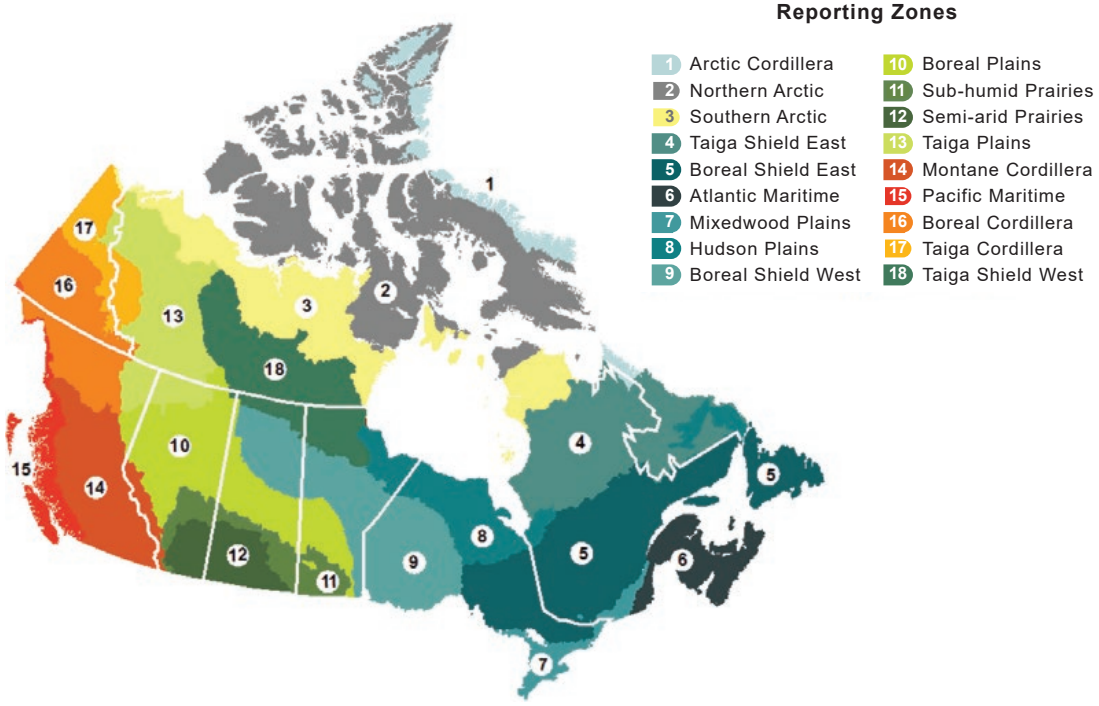
Similarly, the areas of land conversion reported in the relevant CRT sectoral background tables refer to the cumulative total land area converted over the last 20 years and should not be confused with annual rates of land-use change. The trends observed in the CRT land conversion categories (e.g., Land Converted to Forest Land and Land Converted to Cropland) result from the balance between the area of land newly converted to a category and the transfer of lands converted more than 20 years ago to the "land remaining land" categories (e.g., Forest Land Remaining Forest Land and Cropland Remaining Cropland).

Table 6–4 **Land Use and Land-Use Change Matrix for the 2024 Inventory Year**

Initial Land Use	Final Land Use (kha)						
	Forest Land[a]		Cropland	Grassland[b]	Wetlands[c]	Settlements[c]	Other
	Anthropogenic component	Natural disturbance component					
Forest Land[a]	161 183	64 141	30	NO	0.74	24	NO
Anthropogenic component	*161 385*	*663*	*30*	*NO*	*0.74*	*24*	*NO*
Natural disturbance component	*- 202*	*63 478*	*NO*	*NO*	*NO*	*NO*	*NO*
Cropland	8.0	NO	45 525	NO	NE[d]	11	NO
Grassland	NO	NO	0.10	7 067	NE[d]	2.8	NO
Wetlands[c]	NO	NO	NE[d]	NO	6 381	0.25	NO
Settlements[c]	NO	NO	NE[d]	NO	NO	992	NO
Other	NO	NO	NO	NO	0.46	NO	NE[d]

Notes:
NE = Not estimated
NO = Not occurring
kha = kilohectare
Non-diagonal cells refer to annual rates of land-use change, i.e., total land converted during the latest inventory year.
Areas presented in this table are not rounded to keep consistency within the table between numbers with different orders of magnitude, and with areas reported in the CRT tables. However, caution is advised when interpreting these estimated areas due to the uncertainty associated with these values.
a. Includes all managed forest areas subject to either anthropogenic or natural disturbances.
b. Only includes areas of agricultural grassland.
c. Only includes areas for which estimates are reported in the CRT.
d. These areas are classified as Not Estimated (NE). In the CRT 4.1 reporting tables, they are reported as 'Included Elsewhere (IE)' because only the total unmanaged land area is reported.

Figure 6–1 **Reporting Zones for Land Use, Land-Use Change and Forestry Sector Estimates**



Annual estimates of managed and unmanaged forest areas are reported separately in CRT Table 4.1 and the remaining unmanaged land area reported in this CRT Table 4.1 includes both unmanaged and managed non-forest land for which there are no estimates of emissions and removals. These areas are reported in this table to fulfill the requirement of the UNFCCC Reporting Guidelines to report the total land mass area of the country (see section A3.5.1 for more details).

6.3. Forest Land (CRT Category 4.A)

Forests and other wooded lands cover 410 million hectares (Mha) of Canadian territory; forest lands alone occupy 370 Mha.[6] Managed forests account for 230 Mha, or 62% of all forests. Four reporting zones (Boreal Shield East, Boreal Plains, Montane Cordillera and Boreal Shield West) account for 69% of managed forests.

In 2024, the net GHG balance reported for the anthropogenic component of the managed Forest Land (see section 6.3.1.2) amounted to a removal of -1.2 Mt (Table 6–1 and CRT Table 4).

The estimate for the Forest Land category includes net emissions and removals of CO_2, as well as N_2O and CH_4 emissions from slash burning and prescribed burning and drained organic forest soils. For the purposes of UNFCCC reporting, the Forest Land category is divided into Forest Land Remaining Forest Land (anthropogenic component; 160 Mha, net removal of -1.2 Mt in 2024) and Land Converted to Forest Land (0.04 Mha, net emissions of 0.02 Mt in 2024) subcategories. The Forest Land estimates for the natural component of the carbon monitoring system are reported in this chapter (see Table 6–1) but are not reported in the LULUCF total, which only reflects the anthropogenic component.

6.3.1. Forest Land Remaining Forest Land (CRT Category 4.A.1)

6.3.1.1. Category Description

As trees grow, they absorb CO_2 from the atmosphere through photosynthesis, storing some of this C in vegetation (biomass), dead organic matter (DOM) and soils. Carbon dioxide and other GHGs are returned to the atmosphere through respiration and the decay and burning of organic matter. Human interactions with the land can directly alter the magnitude and rate of these natural exchanges of GHGs over both the immediate and long term. Past land-use changes and land-use practices still affect current GHG fluxes to and from managed forests. This long-term effect is a unique characteristic of the LULUCF sector that distinguishes it from the other inventory sectors.

Forest management practices (including harvesting, silvicultural treatments and regeneration) are the primary direct human influences on emissions and removals in forests. Harvesting transfers C to HWP (see section 6.4) and produces harvest residues (branches, foliage and non-commercial species), which are left on site to decay or are burned. Clear-cut harvesting resets the stand age to 0, which changes the rate of C accumulation in biomass, as young trees accumulate little biomass in the first 30 to 40 years. The combination of GHG emissions and removals in the Forest Land category and the carbon change in the HWP pools associated with annual forest product production represents the net annual flux of carbon between managed forests and the atmosphere (Figure 6–2).

Estimated net emissions reported in the Forest Land category from the management of forests also include net fluxes from forest stands that are either of harvest origin or have recovered from natural disturbances and transfers to the HWP pool. The impact of non-anthropogenic disturbances (i.e., natural disturbances such as wildfires, insect infestations and windthrow) in the managed forest is also presented (Table 6–5).[7] Net emissions in the Forest Land category increased from 79 Mt in 1990 to 145 Mt in 2005 and have gradually returned to, and then fell below earlier levels, reaching a minimum value of 1.2 Mt of net removals in 2024. Harvest rates increased nationally from 1990, peaking in 2004, resulting in increasing emissions. The subsequent shift from increasing to decreasing emissions coincides with a sharp decline in harvest rates between 2004 and 2009 (Figure 6–2). Since 2009, harvest rates have remained relatively stable, decreasing slightly over time. As a result, emissions declined from a maximum of approximately 145 Mt CO_2 eq in 2005 to a first local minimum of about 37 Mt CO_2 eq in 2009, and this general downward trend was maintained for much of the remainder of the reporting period as areas harvested prior to the mid-2000s transitioned from net sources to net removals with the regrowth of the harvested stands. Emissions reached a new low in 2023 and 2024, reflecting reduced harvest activity due to widespread operational disruptions caused by the unusually active 2023 wildfire season. These recent minima therefore reflect both longer-term structural changes in harvest levels and age-class dynamics, as well as short-term variability linked to disturbance-driven constraints on forest management activities (Figure 6–2).

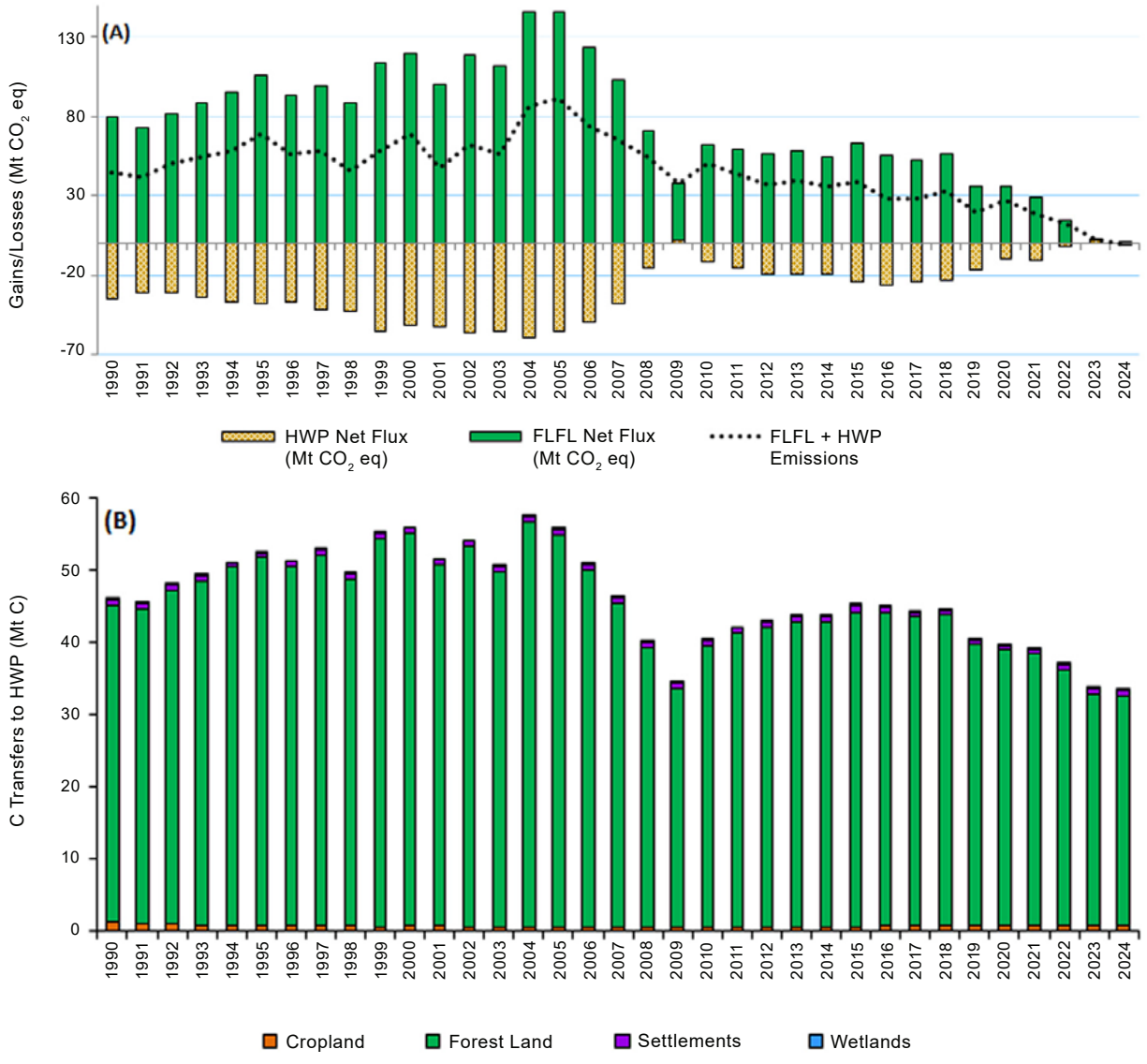
The increase in emissions that occurred prior to 2005 (Figure 6–2) is mainly due to trends in the Montane Cordillera and Boreal Plains reporting zones. In the Montane Cordillera zone, steadily increasing rates of harvest in combination with insect infestations, that occurred between 2000 and 2005, and subsequent salvage harvesting of infested stands

6 Canada's statistical data – forest inventory. Natural Resources Canada. [Accessed 2026 Jan 8]. Available online at: https://natural-resources.canada.ca/forest-forestry/state-canada-forests/much-forest-does-canada-have

7 Impacts of natural disturbances with greater than 20% tree mortality.

resulted in a shift in the average age of the forests of this region to younger age classes. Freshly harvested stands act as a net source of emissions as the DOM pool is increased on these sites and it takes time for the rate of carbon uptake in biomass[8] to recover. At the same time, low-level insect infestations increased tree mortality over large areas, resulting in increased emissions from decomposition. In the Boreal Plains Reporting Zone, increased harvest rates also resulted in a shift in the average age of forests. Parallel insect infestations and active fire seasons caused a reduction in commercially mature forest stands and, consequently, a reduction in the overall rate of C uptake for the region. The reduced C uptake and increased emissions from decomposition in these regions resulted in a decrease in removals large enough to impact the national trend. More recently, low-mortality insect infestations have impacted large areas of the Boreal Shield East and Atlantic Maritime reporting zones and, since 2010, have increased reported emissions in these regions, an impact that may continue over the next few decades.

Figure 6–2 **a) Gains and Losses of Carbon from Forest Land and HWP, and b) Annual Transfers of HWP by Contributing Land Categories**



8 Average age of the forest in this context refers to the age-class structure of the forest and carbon uptake refers to net primary production.

Table 6–5 **Area of, and Greenhouse Gas Fluxes and Carbon Transfers from, Forest Land Remaining Forest Land, Selected Years**

Subcategories	GHG	1990	2005	2019	2020	2021	2022	2023	2024
TOTAL MANAGED FOREST AREA (kha)		**230 000**	**230 000**	**230 000**	**230 000**	**230 000**	**230 000**	**230 000**	**230 000**
Areas with anthropogenic impacts		140 000	150 000	160 000	170 000	170 000	170 000	160 000	160 000
Areas with natural disturbance impacts		88 000	74 000	61 000	60 000	60 000	60 000	63 000	64 000
NET FLUX – REPORTED AND NOT REPORTED (kt CO_2 eq)[a, b]		**-45 000**	**160 000**	**170 000**	**39 000**	**320 000**	**100 000**	**1000 000**	**430 000**
Reported estimates[c]		**80 000**	**150 000**	**36 000**	**36 000**	**29 000**	**15 000**	**1 400**	**-1 200**
Anthropogenic Component, Past Forest Management Activities		270 000	320 000	190 000	180 000	170 000	160 000	140 000	130 000
Net Flux – Forest Products Transferred to HWP[d]	CO_2	160 000	200 000	140 000	140 000	140 000	130 000	120 000	120 000
Net Flux – Ecosystem	CO_2	110 000	120 000	46 000	42 000	35 000	27 000	20 000	12 000
	CH_4	200	420	250	230	240	180	140	150
	N_2O	66	200	140	130	130	110	91	94
	CO[e]	110	340	200	180	180	130	94	100
Anthropogenic Component, Mature Stands of Natural Disturbance Origin	CO_2	-190 000	-170 000	-150 000	-150 000	-140 000	-140 000	-140 000	-130 000
Emissions/removals from lands impacted by natural disturbances		**-130 000**	**8 500**	**140 000**	**2 700**	**290 000**	**89 000**	**1000 000**	**430 000**
Wildfires – direct immediate emissions[f]		26 000	51 000	130 000	12 000	260 000	79 000	870 000	320 000
	CO_2	23 000	44 000	110 000	11 000	220 000	68 000	750 000	270 000
	CH_4	2 600	5 000	13 000	1 200	25 000	7 700	85 000	31 000
	N_2O	1 000	2 000	5 000	480	10 000	3 100	34 000	12 000
Wildfires – indirect immediate CO_2 emissions[f]	CO	2 300	4 400	11 000	1 100	22 000	6 800	75 000	27 000
Post-wildfire CO_2 emissions and removals[f]	CO_2	-150 000	-98 000	-19 000	-26 000	-7 100	-10 000	56 000	71 000
Insects – emissions and removals[g]	CO_2	340	51 000	16 000	15 000	14 000	13 000	11 000	10 000
Other natural disturbances – emissions and removals[h]	CO_2	NO	NO	NO	NO	NO	NO	NO	NO

Notes:
Totals may not add up due to rounding.
NO = Not occurring
kha = kilohectare

a. Negative sign indicates removal of CO_2 from the atmosphere.
b. Net flux corresponds to the sum of the net GHG balance due to reported anthropogenic forest management activities, and emissions/removals due to natural disturbances, tracked but not reported in the CRF tables. Includes emissions/removals of CO_2 and emissions of CH_4, N_2O and CO.
c. Includes emissions/removals of CO_2 and emissions of CH_4 and N_2O, from forest stands in the anthropogenic component differentiating stands with past forest management activities from mature stands of natural disturbance origin. Not including CO emissions.
d. This transfer from forest land remaining forest land to the harvested wood products (HWP) C pool includes salvage logging after natural disturbances.
e. Indirect emissions of CO_2 from the atmospheric oxidation of CO that result from slash burning and prescribed burning activities after forest harvest are reported in CRT Table 6.
f. Immediate emissions include direct and indirect CO_2 and direct non-CO_2 emissions resulting from the immediate impact of wildfires. Post-wildfire CO_2 emissions are associated with the long-term effect of wildfires on dead and soil organic matter; they include small emissions associated with insect infestations on wildfire-impacted areas. Removals of CO_2 are associated with natural stand regeneration following wildfire.
g. Includes emissions due to insect infestations, mainly residual, and removals associated with subsequent natural stand regeneration.
h. Includes the remnant impact in emissions of Hurricane Juan on Nova Scotia forests in 2003 and removals from subsequent natural stand regeneration.

The total net flux in managed forests shown in Table 6–5 is the sum of estimates of CO_2, CH_4 and N_2O emissions and CO_2 removals affected by human activities (including CO emissions from controlled biomass burning reported as indirect CO_2), and emissions and removals that occur in areas impacted by and recovering from natural disturbances beyond the control of human intervention. When all direct and indirect emissions and removals from lands impacted by natural disturbances are included, net fluxes in managed forests (reported and not reported) amount to net removals of 48 Mt in 1990, net emissions of 150 Mt in 2005 and 398 Mt in 2024. Variations in net fluxes largely depend on the occurrence of natural disturbances in a given year (Figure 6–3) which have been increasing over the reporting period, particularly in the latter half of the time series, culminating with the unprecedented 2023 wildfire year in which emissions from wildfires surpassed all anthropogenic emissions from all Sectors in Canada.

Emissions and removals reported from the forest sector, without the natural disturbance component but also considering fluxes of carbon to the Harvested Wood Products category, demonstrate that the Canadian Forest sector acts as a net source of carbon transferred to the atmosphere and to the global waste stream as a result of short- and long-term impacts of human management (Figure 6–2).

6.3.1.2. Methodological Issues

Canada uses a Tier 3 methodology to estimate GHG emissions from, and removals by, managed forests. The country's National Forest Carbon Monitoring, Accounting and Reporting System (NFCMARS)[9] incorporates a model-based approach (Carbon Budget Model of the Canadian Forest Sector, or CBM-CFS3) (Kull et al., 2019; Kurz et al., 2009). This model integrates forest inventory data and yield curves with spatially referenced activity data on forest management and natural disturbances to estimate forest C stocks, C stock changes, and CO_2 emissions and removals. The model uses regional ecological and climate parameters to simulate C transfers between pools in the forest ecosystem as well as to the HWP pool and the atmosphere. A more detailed description of forest C modelling is provided in section A3.5.2.1.

Prior to the 2017 submission, emissions and removals reported in the Forest Land category displayed large interannual variability due to the impact of natural disturbances that masked the impacts of forest management activities. The IPCC has recognized that the issue of reporting emissions from natural disturbances in some countries is problematic and encouraged countries that use Tier 3 methodologies to work towards developing new approaches that can improve the isolation of anthropogenic impacts (IPCC, 2010). In addition, the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (hereafter referred to as the 2019 Refinement to the 2006 IPCC Guidelines; IPCC, 2019) provides examples of approaches that countries (including Canada) have used to resolve this issue. Since the 2017 submission, Canada has implemented a Tier 3 approach to isolate the effects of anthropogenic activities on managed forests. This approach involves the separate monitoring and compilation of emissions and removals from forest stands impacted by anthropogenic and natural drivers (referred to as the anthropogenic and natural disturbance components respectively). The anthropogenic component includes emissions and removals associated with (i) stands that have been directly affected by past forest management activities (e.g., clear-cutting and partial harvesting, commercial and pre-commercial thinning, and salvage logging); (ii) mature stands affected by natural disturbances causing biomass mortality of 20% or less (i.e., insect defoliation) or having greater than 20% mortality at a point during the reporting period but have recovered to their pre-disturbance biomass since; and (iii) mature stands affected by stand-replacing natural disturbances in the past that have reached a regionally-determined minimum operable age (i.e., that have reached commercial maturity and are actively monitored in forest management practice to serve the public interest). The natural disturbance component includes emissions associated with natural disturbances, such as wildfires or insect outbreaks causing more than 20% biomass mortality and the removals that occur as the stands regrow back to maturity or attain pre-disturbance biomass, respectively. To ensure transparency, all emissions and removals are presented here (Table 6–5; Figure 6–3), but reporting is based on the anthropogenic component in an effort to better capture the emissions and removals more closely linked to land management and to better inform stakeholders in the forest sector. A full accounting of natural disturbances and the C balance in managed forests can also be found in the State of Canada's Forests report (NRCan, 2024). Additional information on the estimation approach is provided in section A3.5.2.3, in Kurz et al. (2018) and Kurz et al. (2024).

Carbon stock changes in the anthropogenic component of managed forests are reported by reporting zone in CRT Table 4.A. For any given pool, C stock changes include not only exchanges of GHG with the atmosphere, but also C transfers to and from pools, for example, the transfer of C from living biomass to DOM upon stand mortality. Therefore, individual C stock changes give no indication of the net fluxes between C pools in managed forests and the atmosphere. In addition, to meet transparency reporting requirements, areas included in the natural disturbance component of managed forests are reported separately, by reporting zone, in CRT Table 4.A.

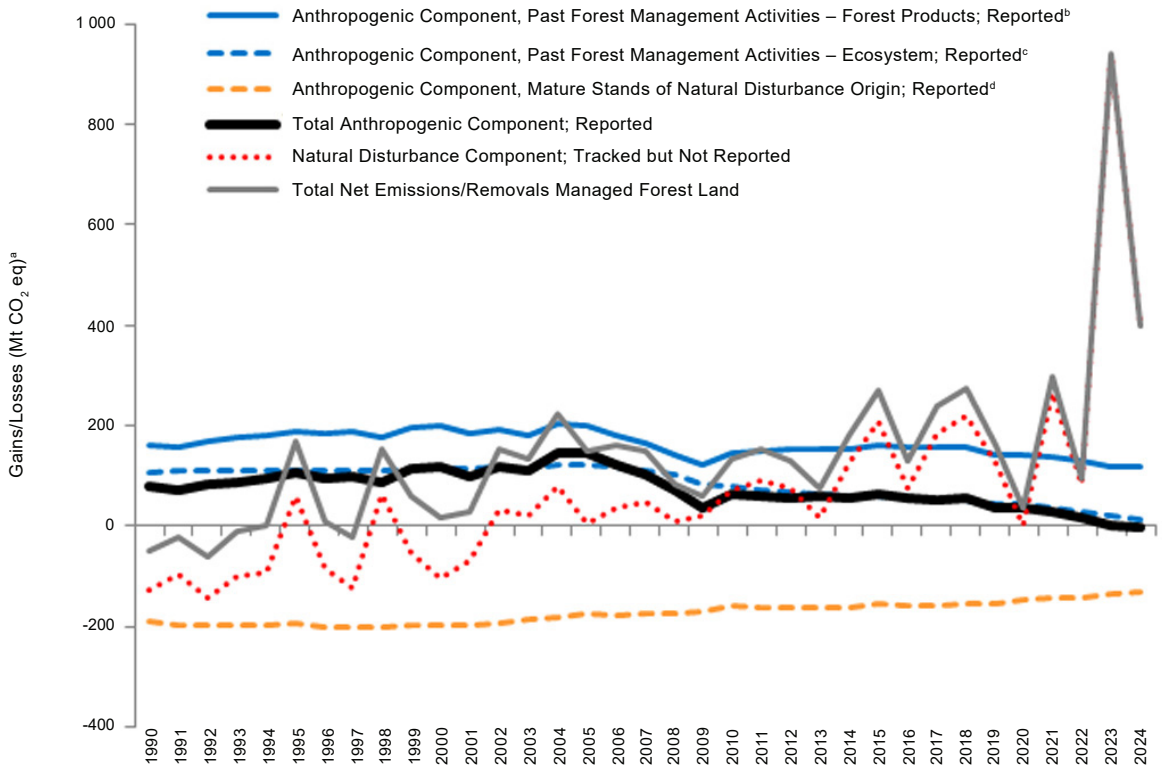
Harvesting wood from managed forests not only results in a transfer of C from the Forest Land category to the Harvested Wood Products category (Figure 6–2; Table 6–5), but also produces debris or residues that remain on-site and decompose. The fate of the C embedded in the wood transported off-site is transferred to and tracked in the HWP pool. Transfers are reported in the Forest Land category and the Harvested Wood Products category reports the change in this pool resulting from annual carbon input and annual carbon emission and disposal. In the current version of the CRT tables, transfers of wood to the HWP pool are reported in Table 4.A as additional information. The transfers are further included in the Net CO_2 Emissions/Removals columns. However, with the information provided as Additional Information, it is now possible to differentiate emissions to the atmosphere relative to transfers to the HWP pool, which was not the case in previous CRF tables. More information on Canada's approach to HWP modelling is available in section A3.5.3.

Emissions of CO_2, CH_4 and N_2O from drained organic forest soils are reported in CRT Table 4(II). They are calculated using activity data obtained from a combination of historical documents, consultations and provincial statistics, using Tier 1 emission factors from the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC, 2014). For more details, see section A3.5.2.1.

Based on calculations of direct and indirect soil N_2O emissions from net soil organic carbon (SOC) losses in stands under anthropogenic influence aggregated at the reconciliation unit (RU) level, the potential emissions from this source can be considered insignificant in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. Emissions aggregated at the RU level were approximated to range from 55 kt in 1990 to 0 kt in recent years.

9 Canada's forest carbon reporting system: https://natural-resources.canada.ca/climate-change/forest-carbon/canada-s-forest-carbon-reporting-system.

Figure 6–3 **Gains and Losses of Carbon in Forest Land Remaining Forest Land, by Component**



Notes:
a. Not including indirect CO_2
b. Transfers to HWP
c. Clear-cut and partial harvests, commercial and pre-commercial thinning, and salvage logging.
d. Stands that have reached minimum operable age (either commercial maturity or pre-disturbance biomass threshold) and are eligible to be scheduled for harvest.

6.3.1.3. Uncertainty Assessment and Time-Series Consistency

Uncertainty Assessment

Numerical techniques are used to quantify the uncertainties surrounding the CBM-CFS3 outputs (Metsaranta et al., 2017). The modelling of Canada's managed forests is not done in a single run, but in separate project runs whose outputs are subsequently assembled. For each project, 100 Monte Carlo runs are conducted using the base input data for the GHG estimates. Confidence intervals are obtained for each inventory year by randomly sampling 10 000 combinations of all the project runs for that year. Separate uncertainty estimates are produced for each GHG. In years when no substantial changes occur, such as in this submission, a Monte Carlo simulation is not performed (the most recent one was for the 2024 submission and covered the entire time series from 1990 to 2022). Instead, confidence intervals for each category in the current submission year are extrapolated.

Throughout the time series, the uncertainties associated with the annual estimates are expressed as a 95% confidence interval, bounded by the 2.5th and 97.5th percentiles of the Monte Carlo run outputs. The uncertainty range for the CO_2 estimates was 75 Mt in 1990, 95 Mt in 2005 and 82 Mt in 2024 (Table 6–6). On average, the uncertainty range was ±37 Mt of the annual median result produced by the Monte Carlo runs over the entire time series. Non-CO_2 emissions contribute little to the total uncertainty. Probability distributions for the net flux estimate are asymmetrical and skewed to the lower bound (greater sink), which is representative of the nature of the distributions of the activity data and parameters tested in the Monte Carlo analysis as expressed in the model. More information on the general approach used to conduct this analysis is provided in section A3.5.2.6, and a detailed description of methods and assumptions, as well as a discussion on the skewed nature of uncertainty distributions, can be found in Metsaranta et al. (2017).

The uncertainty associated with forestry drainage is not presented in Table 6–6. Owing to the magnitude of the emissions from this source relative to net emissions and removals from the forest sector, this source is unlikely to have an impact on the overall uncertainty estimates for the Forest Land category.

Table 6–6 **Estimates of the Net Annual CO_2, CH_4 and N_2O Fluxes in the Forest Land Remaining Forest Land Category, with 2.5th and 97.5th Percentiles, Selected Years**

Gas	Inventory Year	Net Flux (Mt)	2.5th Percentile (Mt)	% Uncertainty[a] (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
CO_2	1990	80	12	-85	87	8.8
	2005	150	88	-40	180	26
	2024	-1.9	-63	3 100	19	-1 100
CH_4	1990	0.2	0.1	-32	0.5	140
	2005	0.4	0.3	-28	0.7	81
	2024	0.1	0.0	-74	0.3	140
N_2O	1990	0.1	0.0	-38	0.2	230
	2005	0.2	0.1	-23	0.3	120
	2024	0.0	0.0	-75	0.1	210

Note:

a. Uncertainty ranges remain relatively constant throughout the time series. As a result, as the absolute value of emissions and removals decreases, the proportional error increases. Uncertainty ranges reported in section A2.3 are taken from the error associated with the proportional error for the base year 1990 and 2024. Since the proportional error for CO_2 emissions in 2024 is exceptionally large (as a result of net emissions approaching zero) Tier 1 trend uncertainty reported in A2.3 is exaggerated.

Time-Series Consistency

All estimates use consistent methodologies and data. However, the forest inventory data incorporated in the analyses were not all collected in the same year across the country. Section A3.5.2.2 explains how forest inventory data from various sources were processed to provide complete, coherent and consistent forest data for 1990 to the present.

6.3.1.4. QA/QC and Verification

Systematic and documented quality assurance / quality control (QA/QC) procedures are performed in four areas: workflow checks (manual), model checks (automated), benchmark checks (manual) and external reviews. The check results are systematically documented, and an issue-logging system identifies each issue and facilitates tracking and resolution management. Tier 2 QC checks (White and Dymond, 2008; Dymond, 2008) specifically address estimate development in the Forest Land category.

Environment and Climate Change Canada uses its own QA/QC procedures for estimates developed internally (see section 1.3, Chapter 1) and implements category-specific Tier 2 checks for estimates obtained from its partners, as well as for all estimates and activity data compiled in the LULUCF data warehouse (Blondel, 2022) and subsequently entered into the CRT Reporter software. These procedures and their outcomes are fully documented in the centralized archives.

Shaw et al. (2014) compared the C stock values predicted by the CBM-CFS3 with ground plot-based estimates of ecosystem C stocks from Canada's new National Forest Inventory (NFI). Carbon stock data sets from the NFI were entirely independent of the input data used for model simulations for each ground plot. The mean error in total ecosystem stocks (representing the comparison between model predictions and ground-plot measurements) was 1%, while the biases in the above-ground biomass, deadwood, litter and mineral soil C pools were 7.5% (4.3 t/ha), -30.8% (-4.5 t/ha), 9.9% (5 t/ha) and 8.4% (8.1 t/ha), respectively; the contribution of the soil pool was the largest in absolute value. The errors in the above-ground biomass and deadwood pools compared favourably to the standards proposed in the IPCC's Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC, 2003) for these pools (8% and 30% respectively). These results point to important pool-, region- and species-specific variations that require further study.

Following Shaw et al. (2014), a national-scale, data-driven calibration study of soil and DOM C modelling parameters was conducted (Hararuk et al. 2017), using a more comprehensive database of upland forest soil C observations (Shaw et al. 2018). The improved calibration of DOM-related parameters – including base decay rates and their sensitivity to temperature, proportions of C released to the atmosphere, root turnover and snag fall rates – resulted in faster C cycling in woody debris (deadwood) and the soil organic layer (litter), as well as more distinct C dynamics in hardwood and softwood dominated stands. These calibrated parameters were fully implemented in the current submission, partially addressing the above-mentioned biases by reducing the overestimation of deadwood and soil carbon stocks relative to National Forest Inventory (NFI) measurements. At the national level, this resulted in a downward revision of estimated total forest carbon stocks, almost entirely attributable to shorter residence times of carbon in deadwood and litter pools and partially offset by increases in soil carbon pools (Fisher et al. 2025). Regional responses varied: while deadwood stocks declined across all regions, litter and soil pools exhibited deviations from the national pattern, particularly in colder northern ecozones. These differences reflect interactions between hardwood–softwood composition and temperature sensitivity of decay rates, especially in mineral soil pools. A comprehensive uncertainty analysis is currently underway to better characterize remaining biases and to inform further methodological refinements.

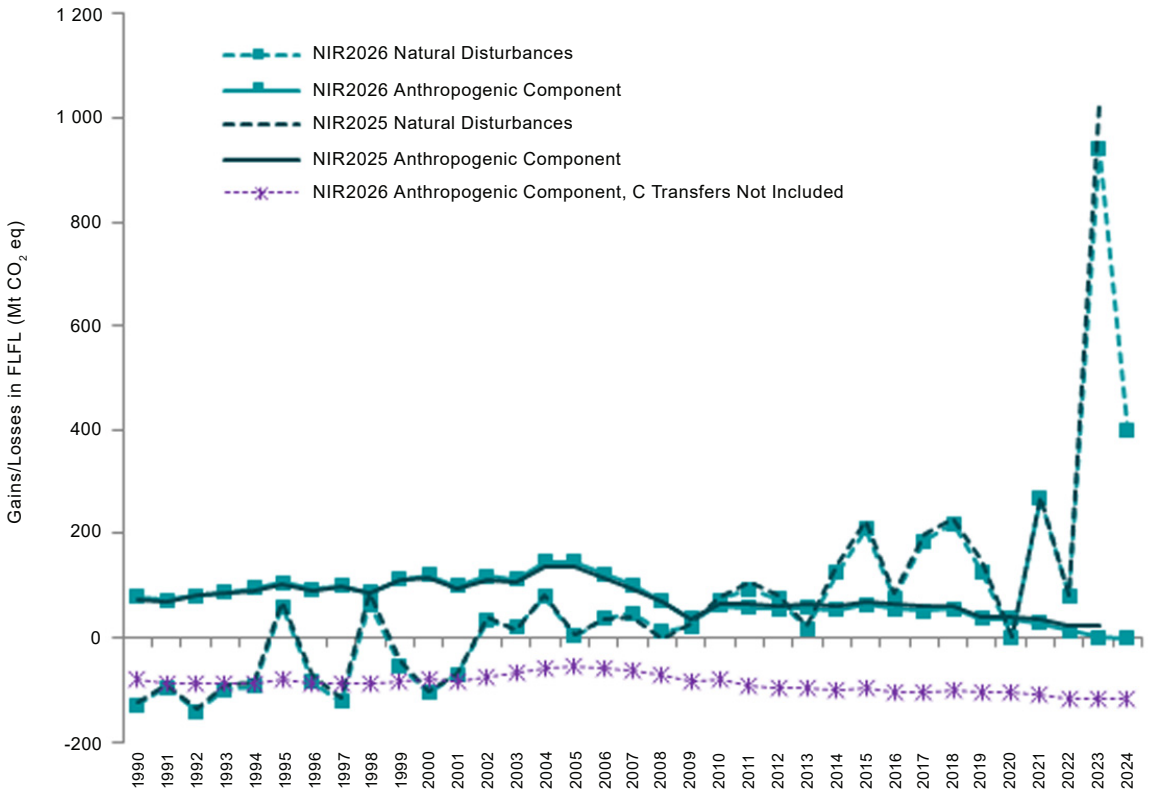
Additional analyses have been conducted at the site-scale, comparing hybrid biometric-model estimates derived using a combination of tree-ring observations and the CBM-CFS3 against eddy covariance derived estimates (e.g., Metsaranta et al. 2018; 2021), and at provincial scales (e.g., Hagemann et al. 2010; Heffner et al. 2021) to compare estimates against

provincial forestry plot data. In general, like Shaw et al. (2014), these studies demonstrated that there is good agreement between estimates for some C stocks such as live biomass, and that the most gain in model performance would be obtained from improvements to how DOM dynamics are represented. Those studies also suggest further exploration of spatial variations driven by species composition, soil types, microbial activities and bryophyte abundance. As part of quality assurance (QA) efforts, the approach used in the 2017 National Inventory Report (NIR) for estimating anthropogenic emissions and removals was reviewed by an international panel of forest scientists convened by ECCC in October 2016. The panel found that the new approach effectively isolates anthropogenic emissions and removals due to forest management from the impacts of natural disturbances. The panel also stated that the criterion used to classify stands impacted by insect infestations as being under anthropogenic or natural influence was justifiable. However, it recommended that the threshold used to differentiate anthropogenic from natural emissions and removals after stand-replacing natural disturbances should be regionally specific to incorporate variations in forest ecology. Changes were implemented in the 2018 submission and provincial forest experts reviewed and approved the revised approach.

6.3.1.5. Recalculations

Recalculations in the Forest Land category resulted from two significant methodological changes this year (Fisher et al., 2025): (i) the implementation of an improved set of dead organic matter (DOM) and soil carbon parameters in the CBM-CFS3, and; (ii) updates to forest management activity data, including minor revisions for 2020 to 2022 and a major downward correction to the 2023 conventional harvest targets. Combined with other minor updates, these changes resulted in upward revisions to emissions in the early part of the time series and downward revisions in more recent years. Net recalculations in key reporting years include revisions of +6.2 Mt CO_2 eq in 1990, +10 Mt CO_2 eq in 2005, and −22 Mt CO_2 eq in 2023 (Figure 6–4).

Figure 6–4 **Recalculations in the Natural Disturbance Component and Anthropogenic Component of Forest Land Remaining Forest Land**



6.3.1.6. Planned Improvements

Studies have been developed to explore the role of human actions and management on fire regimes, the relationship between trends in emissions and removals and key indicators of human management such as harvest rates and conservation areas as well as analyses of the consistency of carbon recovery intervals in forest landscapes with evolving age-class structures. Upon completion of these studies, revisions will be made to Canada's anthropogenic partitioning protocols.

During the period of this analysis, continual improvements will be implemented (i) updates to baseline inputs (data, processes and parameters, e.g., refinements to fire activity data) refinements to parameters in the CBM-CFS3 modelling framework; as well as (ii) science improvements such as refinements to wildfire emission estimates through variable burn intensity. Longer-term plans also include trend uncertainty and sensitivity analyses, and an examination of how various components contribute to the asymmetrical distribution of uncertainty estimates around net fluxes as well as a gradual integration of increasing spatially explicit data and estimates in the modelling framework.

Additional details on planned improvements for Forest Land are outlined in Chapter 8, section 8.3.1 and Table 8–5, and further information may be found in the Improvement Plan for Forest and Harvested Wood Products Greenhouse Gas Estimates.[10]

6.3.2. Land Converted to Forest Land (CRT Category 4.A.2)

6.3.2.1. Category Description

This category includes all land converted to forest land by direct human activities. This does not include reforestation after harvesting or abandoned farmland where natural regeneration has been allowed to occur. More precisely, the category refers to the active establishment of forest on land where the previous land use was not forest (typically, abandoned farmland).

The total cumulative area reported in the Land Converted to Forest Land category declined from 170 kha in 1990 to 31 kha in 2024. Given that activity data after 2008 are only for Ontario and recent afforestation activities starting in 2021 (see section 6.3.2.2), the trend mainly reflects the gradual transfer of lands afforested more than 20 years ago to the Forest Land Remaining Forest Land category. Nearly 86% of all conversions of farmland to forest land in the last 20 years occurred in Eastern Canada (Atlantic Maritime, Mixedwood Plains and Boreal Shield East reporting zones), with 8% in the Prairie provinces (Boreal Shield West, Boreal Plains and Sub-humid Prairies reporting zones) and the remaining 5% in the most westerly ecozones (Pacific Maritime and Montane Cordillera reporting zones).

Net removals declined throughout the period from -1.0 Mt in 1990, and transitioned to net emissions of 0.02 Mt in 2024. Net C accumulation largely occurred in living biomass. Soil C sequestration was negligible and is expected to remain so because this category is restricted to plantations younger than 20 years. For the same reason and considering the relatively small net increase in planted trees in the early years, it is important to emphasize that the category is not expected to contribute significantly to the net GHG balance in the Forest Land category. When these trends are being considered, it must also be noted that the data used in this analysis are not comprehensive.

6.3.2.2. Methodological Issues

Under the Government of Canada's Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative, afforestation records for 1990–2002 were collected and compiled (NRCan, 2005a). In that period, softwood plantations, especially spruce and pine, accounted for 90% of the area planted. Activities from 1970 to 1989 and 2003 to 2008 were estimated based on activity rates observed in the FAACS data, supplemented by data from the Forest 2020 Plantation Demonstration Assessment carried out by NRCan in the mid-2000s (NRCan, 2005b). Recent federal afforestation program data were sourced from Natural Resources Canada (NRCan). In addition, since the 2022 submission, the estimates reported in this category include the effect of afforestation activity data for Ontario from 2007 to 2019 obtained through a data-sharing agreement with Forests Ontario providing access to its database of tree planting activities.

Since 2021, estimates for afforestation activities in Canada have been prepared using a methodology that initializes ecosystem carbon stocks based on origin land-use categories and defines post-planting carbon dynamics according to planted forest cover types (see section A3.5.2.4; Hafer et al., 2022).

GHG emissions and removals on land newly converted to forest land were estimated using the CBM-CFS3, as described in section A3.5.2.1. However, the biomass losses from croplands during the conversion year are estimated using historical yields, harvest index relationship and root-shoot ratio (see section A3.5.4.2). It was assumed that ecosystems would generally accumulate soil C at a slow rate. The limited time frame of this analysis and the magnitude of the activity relative to other land use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

10 Canada's Improvement Plan for Forest and Harvested Wood Products Greenhouse Gas Estimates: https://data-donnees.az.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/E-LULUCF/?lang=en

6.3.2.3. Uncertainty Assessment and Time-Series Consistency

Significant challenges remain in estimating the uncertainty for this category due to the lack of a consistent national system for tracking afforestation and because a Monte Carlo simulation cannot currently be run using the model data input structure for this category. Given these limitations, initial uncertainty estimates were developed based on expert judgement. It was assumed that the 95% confidence intervals for this category could be estimated at 10% smaller or 200% larger than the reported value.

6.3.2.4. QA/QC and Verification

Tier 2 QC checks (Dymond, 2008) specifically address estimate development in the Forest Land category. Environment and Climate Change Canada, while maintaining its own QA/QC procedures for internally developed estimates (see section 1.3, Chapter 1), has implemented specific procedures for estimates obtained from its data partners, as well as for all estimates and activity data from the LULUCF data warehouse (Blondel, 2022) subsequently entered into the CRT Reporter software.

6.3.2.5. Recalculations

Recalculations occurred due to (i) the refinements made to carbon in biomass in Cropland, and (ii) revisions made to the afforestation activity data and their impacts on the residual emissions. This change caused downward recalculations of -87 kt in 1990, -63 kt in 2005 and -2.1 kt in 2023.

6.3.2.6. Planned Improvements

Although access to information on afforestation activity remains limited, continued efforts are underway to obtain more data for recent years from provincial and territorial resource management agencies. Uncertainty estimates will be further refined as more information becomes available.

6.4. Harvested Wood Products (CRT Category 4.G)

6.4.1. Category Description

Gains and losses from the Harvested Wood Products category are reported using the Simple Decay Approach described in the annex to Volume 4, Chapter 12, Section 12A.3.2, 2019 Refinement of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (hereafter referred to as the 2019 Refinement of the 2006 IPCC Guidelines; IPCC, 2019). The simple decay approach is similar to the Production Approach, tracking all fluxes of carbon associated with HWP from the Forest to HWP pools and to the end of its useful life, but differs by including bioenergy products and wood waste products that result from wood extracted from the forest. Wood harvested from the forest is reported as a carbon leaving the forest ecosystem and subsequently entering harvest wood products (more details provided in section A3.5.3).

Gains and losses associated with this category result from the use and disposal of HWP manufactured from wood obtained from industrial roundwood harvesting on forest land, residential firewood harvesting in forests and other wooded lands, and forest conversion activities in Canada and subsequently consumed either in Canada or abroad. Products disposed of at the end of their useful life are transferred to the waste stream in the country where the wood product was used. Due to the large proportion of Canadian wood that is exported, we are not able to accurately track the fate of that carbon.

Fluxes of carbon in this source are influenced by the balance between new harvest inputs (including short-lived products and wood waste) and the decay of longer-lived wood products from historical harvests. The HWP category has primarily acted as a carbon store throughout the time series with increasing storage of carbon reaching a maximum net removal in 2004 (-61 Mt CO_2 eq), coinciding with peak harvest rates. However, the category was reported as a net source of emissions in 2009 and 2023 when the decaying HWP pool outweighed new C inputs resulting in the loss of 1.0 and 0.7 Mt CO_2 eq, respectively from the HWP pool. In 2024, the HWP pool increased by -0.6 Mt CO_2 eq, a significant decline in annual carbon storage compared to the storage of 57 Mt CO_2 eq and 39 Mt CO_2 eq in 2005 and 1990 respectively (Table 6–7). This trend reflects the legacy effect of delayed carbon losses from historical harvest inputs plus decreases in new carbon stored as HWP that is resulting from lower recent harvest levels.

For the entire reporting period, carbon in biomass transferred from the forest is reported as a carbon loss from the Forest ecosystem (dotted line in Figure 6–5), which was the value reported for submissions prior to the implementation of the HWP model in 2015. The carbon that is transferred from the Forest ecosystem to the HWP pool creates a pool of carbon that is stored in products in use. The net difference between transfers into and the transfers out of the HWP carbon pool, from either product disposal or emission through combustion as bioenergy (bars in Figure 6–5), are representative of the reported flux according to the simple decay method as defined in the 2019 Refinement of the 2006 IPCC Guidelines (IPCC, 2019).

Table 6–7 **Carbon Stocks in the Harvested Wood Products Pool and Losses Resulting from Their Use and Disposal**

Source Subcategories / Commodities	Land Category	1990	2005	2019	2020	2021	2022	2023	2024
Carbon Stocks and Fluxes (kt C)[a]									
Inputs		**46 000**	**56 000**	**40 000**	**40 000**	**39 000**	**37 000**	**34 000**	**33 000**
Conventional harvest[b]	Forest Land	40 000	51 000	36 000	35 000	35 000	33 000	30 000	30 000
Forest conversion[b]	Cropland	1 100	430	630	700	700	690	650	650
	Wetlands	2.8	5.6	7.7	8.9	19.0	9.4	-	-
	Settlements	670	690	620	570	590	570	610	560
Residential firewood[c]	Forest Land	4 100	3 100	3 200	2 800	2 500	2 700	2 500	2 300
	Cropland	230	130	150	140	140	140	140	140
	Settlements	82	83	84	84	84	84	84	84
Exports		19 000	31 000	20 000	18 000	18 000	16 000	15 000	15 000
Net stocks[d]		330 000	520 000	610 000	610 000	610 000	610 000	610 000	610 000
Carbon Flux – Domestic Consumption from harvest		**24 000**	**20 000**	**19 000**	**20 000**	**20 000**	**20 000**	**18 000**	**18 000**
Solid wood – sawnwood		1 500	2 100	2 700	2 700	2 800	2 800	2 800	2 800
Solid wood – wood panels		730	890	1 200	1 200	1 200	1 200	1 200	1 200
Other solid wood products		250	520	610	610	610	610	620	620
Pulp and paper market		2 300	210	820	760	700	650	610	570
Residential firewood and industrial fuelwood		14 000	16 000	13 000	13 000	13 000	14 000	12 000	12 000
Mill residue[e]		5 000	450	320	1 400	810	970	530	530
Carbon Flux – Worldwide from Canadian harvest		**12 000**	**20 000**	**17 000**	**17 000**	**16 000**	**16 000**	**16 000**	**15 000**
Solid wood – sawnwood		2 700	4 400	5 300	5 300	5 400	5 400	5 400	5 400
Solid wood – wood panels		210	1 200	1 700	1 700	1 700	1 700	1 700	1 700
Other solid wood products		14	14	18	18	18	19	19	19
Pulp and paper market		8 500	14 000	9 600	9 300	8 900	8 500	8 000	7 600
Mill residue[e]		120	580	510	550	550	550	490	490
Net Flux (kt CO_2)		**-39 000**	**-57 000**	**-18 000**	**-10 000**	**-11 000**	**-3 100**	**640**	**- 720**

Notes:

a. Totals may not add up due to rounding.

b. Carbon (C) estimate provided by the CBM-CFS3 model in the wood biomass resultsing from forest harvest (including salvage logging after natural disturbances on forest land) and from forest conversion activities in Canada and that would be reported as C losses in CRT Table 4.A under the Forest Land Remaining Forest Land category and in tables 4.B, 4.D and 4.D under subcategories related to forest conversion, if using the instant oxidation approach for HWP.

c. Includes the C in residential firewood harvested from forest, agricultural woody biomass and urban trees, and assumed to be burned in the year of harvest. This C would be reported as C losses in CRT tables 4.A under Forest Land Remaining Forest Land, 4.B under Cropland Remaining Cropland, and 4.E under Settlements Remaining Settlements, if using the instant oxidation approach for HWP.

d. Represents the quantity of C in the HWP pool at the end of the reporting year. Because inputs to the model consider the harvests since 1900, net stocks over the reporting period may include C harvested before 1990.

e. Assumed to be disposed of in the year of harvest.

These differences represent the annual net increase and decrease of C storage in the HWP pool. With the exceptions of 2009 and 2023, annual carbon inputs to HWP pools have consistently outweighed outputs; however, this trend is currently leveling out, with the change in cumulative stocks in products approaching zero in recent years. In total, 610 Mt C have been transferred and stored in the HWP pool, of which approximately 300 Mt C were added during the reporting period.

Harvested Wood Products gains and losses are inextricably linked to the emissions/removals reported in the Forest Land category: the sum of net emissions/removals reported in the Forest Land category and emissions reported in the Harvested Wood Products category provides an estimate of total net emissions/removals reported from managed forests (Figure 6–2).

6.4.2. Methodological Issues

A country-specific model, applying the IPCC simple-decay approach, the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP),[11] is used to monitor and quantify the fate of C that has been exported from Forest Land from the point of forest harvest, forest conversion or firewood collection from Forests, Cropland or Settlement areas. The model tracks HWP sub-pools and C flows between sub-pools throughout the life cycle of wood products (e.g., manufacturing, use, trade and disposal).

The simple decay approach (see section 12A.3.2 in IPCC, 2019) excludes HWP imports and includes all HWP exports.[12] The approach quantifies all carbon exports from Land categories, including products that do not undergo storage, such as domestic bioenergy products. Carbon storage in short- and long-lived products is treated in the same way as in the Production Approach with losses calculated based on the half-lives of products entering the pool. The carbon loss either from the disposal of short- and long-lived products and the combustion of bioenergy products are reported as CO_2 in the HWP source category and CH_4 and N_2O emissions from HWP combustion or decomposition are reported in the Energy and

11 Canada's forest carbon reporting system: https://natural-resources.canada.ca/climate-change/forest-carbon/canada-s-forest-carbon-reporting-system

12 Currently statistics on bioenergy exports are not available, bioenergy currently modelled is domestic.

Waste sectors in the country of their use or disposal in accordance with the 2006 IPCC Guidelines (IPCC, 2006; more details provided in section A3.5.3) in the country of their disposal. For HWP consumed and disposed of in Canada, CH_4 emissions were reported under the Waste sector, and emissions from methane recovery for energy purposes were included under the Energy sector, in accordance with the IPCC 2006 Guidelines (IPCC, 2006; Chapter 12, section 12.1).

The HWP model uses carbon transferred from harvest as inputs. These inputs (Table 6–7) include (i) the annual mass of C transferred to forest products that result from conventional, contemporary[13] and residential firewood harvesting on Forest Land and a relatively small amount from lands converted from forest to cropland, wetlands (hydroelectric reservoirs) and settlements (around 2.7% of all inputs in any year) transferred from the CBM-CFS3 model (see section 6.3.1.2); and (ii) an additional annual quantity of C from woody biomass harvested from cropland and from urban trees on land in the Settlements category and used for residential bioenergy (Table 6–7). Harvest data since 1990 were generated by Canada's country-specific forest ecosystem carbon dynamics model CBM-CFS3 and were available spatially by reconciliation units (RU) (see section 6.3.1.2). Historical harvests between 1941 and 1989 were at the aggregated national level from Statistics Canada and were used to backcast for the period between 1900 and 1940.

Data on annual volumes of residential firewood and industrial fuelwood are provided by the Energy sector (see section A3.1.4.1.4.). Residential firewood data were obtained from surveys of residential wood use for the years 1997, 2003, 2007, 2015, 2017 and 2019 (Statistics Canada 1997, 2003, 2007, 2015, 2017, 2019); and pellet and manufactured log consumption data were collected from surveys for the years 1996, 2006, 2012, 2017 and 2019 (Canadian Facts, 1997; TNS, 2006; TNS, 2012; Statistics Canada, 2017, 2019). Data on firewood consumption in the territories come from fuelwood and firewood harvest statistics in the National Forestry Database,[14] and data on industrial fuelwood come from the annual Report on Energy Supply and Demand in Canada (RESD). More information on the estimation methodology, data sources and parameters used in the model can be found in sections 3.1 and A3.5.3.

Activity data, annual estimates of C inputs, stock changes in the HWP pool and the resulting net emissions for each commodity are reported in CRT Table 4.G. In accordance with the Simple Decay Approach, the following assumptions were made in reporting HWP-related data in this table:

- **Column C (Gains)**: corresponds to C inputs associated with C transferred from any wood-producing land category (e.g., Forest Land) to the HWP pools used domestically and exported; these C inputs would represent C transfers to the HWP pool, reported in Column U of tables 4.A, 4.B, 4.D and 4.E.
- **Column D (Losses)**: corresponds to C losses using decay Equation 12.1 in Volume 4, Chapter 12, of the 2006 IPCC Guidelines (IPCC, 2006), for HWP with longer half-lives and from the annual combustion of firewood and the oxidation of milling waste.
- **Column F (Annual change in stocks)**: calculated as the net interannual change in stocks in the HWP pool; the total annual values of these net stocks are reported in Table 6–7.
- **Column G (Net gains/losses from HWP in use, CO_2)**: values reported in this column correspond to the CO_2 emissions associated with the carbon change in the HWP pool calculated as 44/12 × (the annual carbon domestic harvest – the annual release of carbon at the end of its useful life from HWP that came from wood harvested in the reporting country, including wood that is exported but excluding imports).

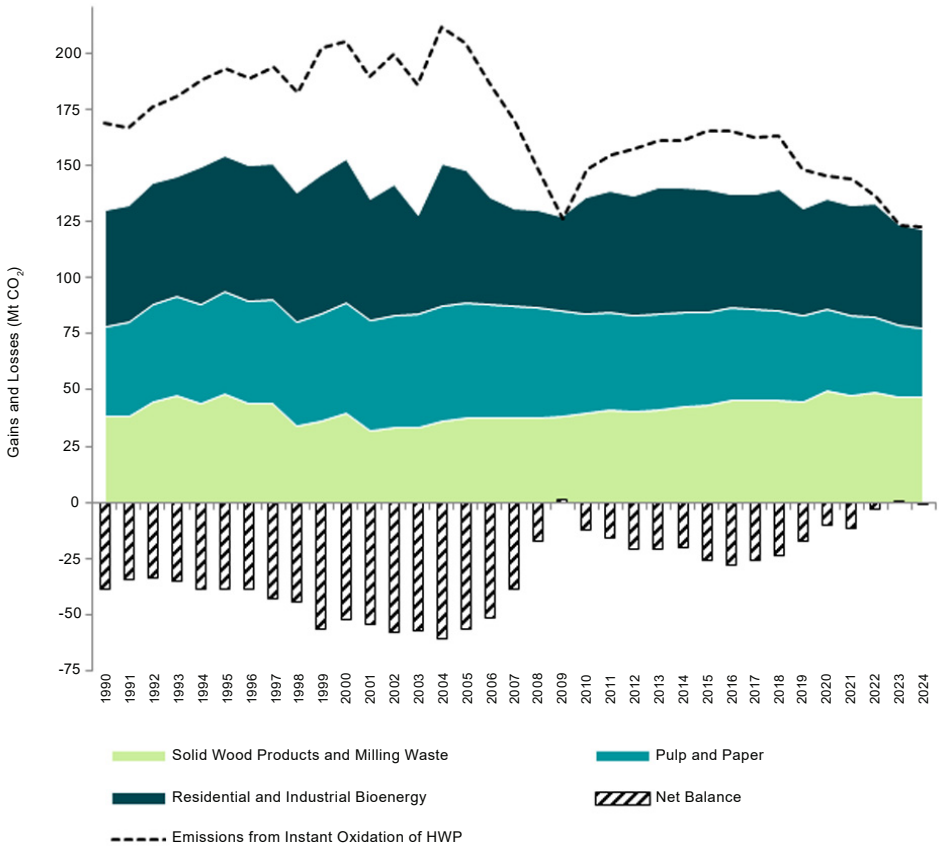
6.4.3. Uncertainty Assessment and Time-Series Consistency

In the assessment of the uncertainty associated with the Harvested Wood Products category, model parameters are varied during Monte Carlo simulations. In addition, 100 HWP inputs are derived from the CBM-CFS3 (ecosystem) uncertainty analyses. These simulations are used to estimate the combined uncertainty associated with the two estimation systems (i.e., CBM-CFS3 and NFCMARS-HWP) for all C harvested since 1990 (Table 6–8). Additional parameters were used in the Monte Carlo analysis including the uncertainty distributions for historical inputs (pre-1990 harvest), contemporary inputs (harvests since 1990) and five allocation parameters related to bioenergy. Best practices for treatment of uncertainty for the new reporting approach is still under evaluation. In the current submission, confidence intervals are built around estimates of changes in carbon in HWP pools associated with conventional harvest and forest conversion. Confidence intervals are still considered to be accurate, however, the symmetry of the interval around the mean may be biased. More details are provided in section A3.5.3.

13 Contemporary harvesting refers to harvest activities that occurred since 1990.

14 National Forestry Database, available online at https://open.canada.ca/data/en/dataset/011ff922-fb26-4edc-9474-f10acf410dbc.

Figure 6–5 **Gains and Losses from the Harvested Wood Products Pool Using the Simple Decay Approach**



Notes:
The net balance is the difference between the C transferred to the HWP pool and gross flux from the HWP pool, the value reported in the CRT tables representing the net flux to and from the HWP pool.
This data series represents the carbon transferred annually from the forest and other land into the HWP C pool in units of CO_2. It includes salvage logging after natural disturbances in forests.

6.4.4. QA/QC and Verification

Environment and Climate Change Canada, while maintaining its own QA/QC procedures for internally developed estimates (see section 1.3, Chapter 1), has implemented specific procedures for estimates obtained from its data partners, as well as for all estimates and activity data compiled in the LULUCF data warehouse (Blondel, 2022) and subsequently entered into the CRT Reporter software.

6.4.5. Recalculations

Recalculations occurred in the Harvested Wood Products category, due to (i) updated HWP model parameters based on the latest Food and Agriculture Organization (FAO) statistics on Canadian forest products;[15] (ii) updated HWP commodity conversion parameters; (iii) updated waste incineration activity data; and (iv) updated residential bioenergy activity data and emission factors (see section 6.9.5).

The combined effect of these methodological and activity data changes resulted in small downward recalculations in total fluxes reported in this category early in the time series and upward recalculations later in the time series. Recalculations in key reporting years resulted in a downward revision in carbon storage in HWP of -0.15 Mt CO_2 eq in 1990 and upward revisions to carbon storage of 0.02 Mt CO_2 eq in 2005 and 5.8 Mt CO_2 eq in 2023.

15 FAOSTAT Forestry Production and Trade: https://www.fao.org/faostat/en/#data/FO, and FAOSTAT Forestry Trade Flows: https://www.fao.org/faostat/en/#data/FT

Table 6–8 **Estimates of CO_2 Gains and Losses from Harvested Wood Products, with 2.5th and 97.5th Percentiles, Selected Years**

Inventory Year	Source of C inputs	Gains/Losses (Mt CO_2)	2.5th Percentile (Mt)	% Uncertainty (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
1990	Forest conversion – since 1990	-3.9	-3.0	-22	-4.3	12
	Conventional harvest – since 1990	-88	-116	31	-95	8
	Historical harvest – before 1990	53	41	-24	67	25
2005	Forest conversion – since 1990	-1.4	-1.3	-4.0	-1.8	33
	Conventional harvest – since 1990	-71	-94	32	-75	5.8
	Historical harvest – before 1990	15	12	-24	20	33
2024	Forest conversion – since 1990	-0.9	-1.0	13	-1.9	111.6
	Conventional harvest – since 1990	-10	-20	110.6	-17	80.6
	Historical harvest – before 1990	10	7.7	-23	11	9

6.4.6. Planned Improvements

Research is in progress to improve the regional differentiation of HWP production and trade ensuring that the provincial/territorial summaries accurately reflect regional conditions and further work is aimed at the characterization of the biomass feedstocks used as fuel in the industry sector.

More details are provided in section 6.3.1.6 and in Chapter 8, section 8.3.1 and Table 8–5.

6.5. Cropland (CRT Category 4.B)

Cropland covers approximately 46 Mha of Canada's territory. In 2024, the net GHG balance in the Cropland category amounted to net removals of 3.6 Mt (Table 6–1). For UNFCCC reporting purposes, the Cropland category is divided into Cropland Remaining Cropland (net removals of 10 Mt in 2024) and Land (i.e., either forest or grassland) Converted to Cropland (net emissions of 6.5 Mt in 2024). The estimates of Land Converted to Cropland include net emissions and removals of CO_2, as well as N_2O and CH_4 emissions.

6.5.1. Cropland Remaining Cropland (CRT Category 4.B.1)

6.5.1.1. Category Description

Cultivated agricultural land in Canada includes field crops, summerfallow, hayfields, and tame or seeded pastures, mainly located in the nine southernmost reporting zones. About 83% of Canada's cropland can be found in the interior plains of Western Canada, made up of the Semi-arid Prairies, Sub-humid Prairies and Boreal Plains reporting zones, while another 12% is in the Mixedwood Plains reporting zone of Eastern Canada.

The Cropland Remaining Cropland subcategory includes CO_2 emissions/removals from mineral soils; CO_2 emissions from the cultivation of organic soils; and CO_2 emissions/removals resulting from changes in woody biomass associated with specialty crops, trees and shrubs, and land not fulfilling the definition of Forest Land (Figure 6–6). An enhanced Tier 2 approach is used to estimate CO_2 emissions and removals in mineral soils, impacted by changes in tillage practices and perennial/annual crop conversion on an area basis. Since the 2022 submission, the IPCC Tier 2 Steady State approach (IPCC, 2019; Thiagarajan et al., 2022) is used to estimate the impact of crop productivity and subsequent crop residue C input on soil C storage. As a result, the explicit inclusion of area-based summerfallow factors is eliminated as a separate driver of changes in cropland soil C. Estimates of CO_2 removals associated with increases in C inputs to soils from reductions in summerfallow are based exclusively on changes in crop production to avoid double counting since regional estimates of production changes inherently include the reduction in summerfallow. In addition, a country-specific method using manure-induced C retention factors has been developed for estimating soil C storage as influenced by the application of manure to soils under annual crop production (Liang et al., 2021).

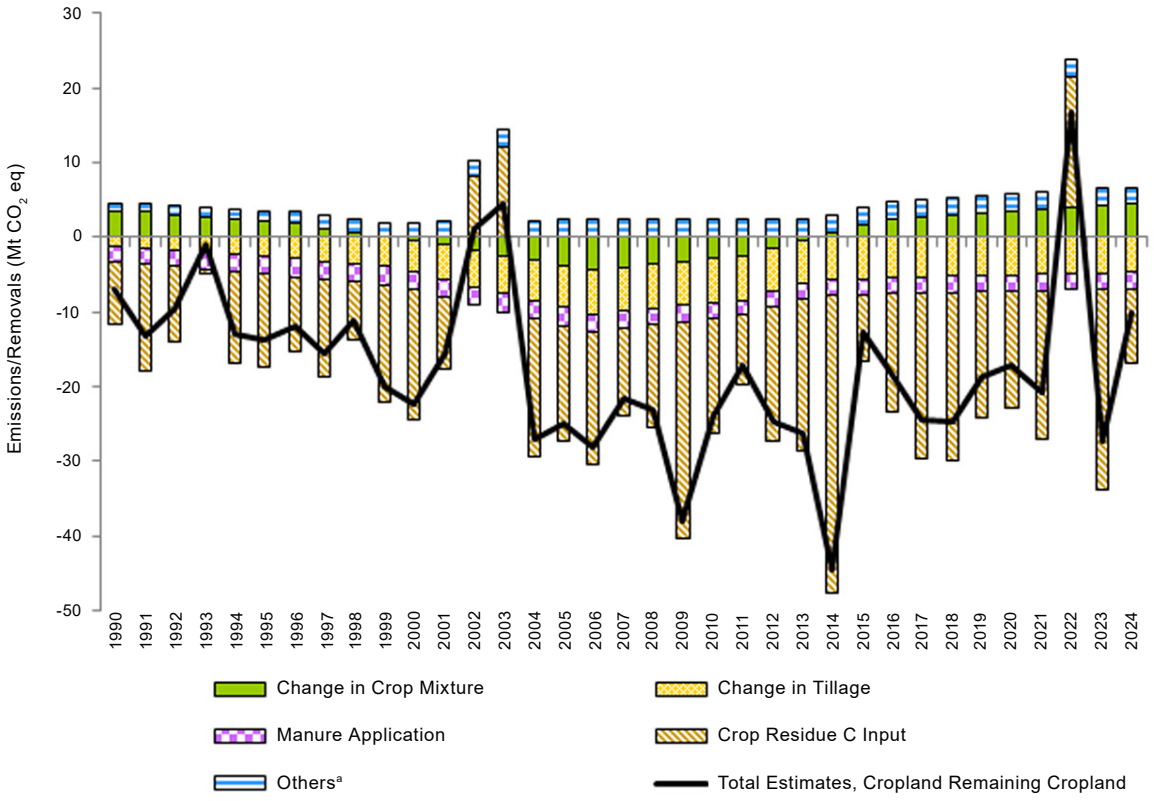
6.5.1.1.1. CO_2 Emissions from, and Removals by, Mineral Soils

The vast majority of cropland (nearly 100%) occurs on mineral soils. The amount of organic C retained in these soils is a function of crop production and the rate of SOC decomposition. Cultivation and management practices can lead to an increase or decrease in the organic C stored in soils. This change in SOC results in CO_2 emissions to or removal from the atmosphere.

In 1990, changes to mineral soil management represented net CO_2 removals of 8 Mt (Table 6–9). CO_2 removals by soil increased to 27 Mt in 2005 and 12 Mt in 2024. Since 1990, on average, the yields of major field crops increased by 6.9% for barley, 55% for canola, 35% for corn, 4% for soybean and 26% for spring wheat. However, crop yields fluctuated by year, impacting C inputs to soils from crop residues, resulting in fluctuations in net removals of CO_2 by soils of 8 Mt in 1990, 15 Mt in 2005, and 10 Mt in 2024. Interannual variability tends to be high throughout the time series, reflecting weather-related impacts on crop production.

Conservation tillage increased significantly, from 11 Mha in 1990 to 29 Mha in 2024, and this trend results in CO_2 removals by soil of 1.3 Mt in 1990, 5.6 Mt in 2005 and then leveling off to 4.7 Mt in 2024 (Table 6–9; Campbell et al., 1996; Janzen et al., 1998; McConkey et al., 2003). Furthermore, the proportion of perennial crops relative to annual crops increased between 1990 and 2006, also observed in the net change in crop mixtures, which resulted in net emissions of 3.5 Mt in 1990, net removals of 3.8 Mt in 2005 and net emissions of 4.5 Mt in 2024. Since 2006, however, the proportion of annual crops in the crop mixture has increased, while the rate of adoption of conservation tillage has declined. Manure application on annual cropland contributed to relatively constant CO_2 removals by soils varying from 2.1 Mt to 2.5 Mt annually, reflecting changes in beef cattle, swine and poultry populations. As a result of these combined changes in management practices, since 2006, net removals by mineral soils have increased in most years, mainly driven by the decrease in the proportion of perennial crops in the crop mixture and fluctuations in crop yield and crop residue C input.

Figure 6–6 **Emissions and Removals Related to Cropland Remaining Cropland**



Note:
a. "Others" include emissions/removals associated with perennial woody crops, harvest of woody biomass, and cultivation of histosols, and residual emissions from historic land conversion to cropland.

Table 6–9 **Baseline and Recent-Year Emissions and Removals Associated with Various Land Management Changes in the Cropland Remaining Cropland Category**

Categories	Land Management Change (LMC)	Emissions/Removals (kt CO_2 eq)[a]							
		1990	2005	2019	2020	2021	2022	2023	2024
TOTAL CROPLAND REMAINING CROPLAND		**-7 000**	**-25 000**	**-19 000**	**-17 000**	**-21 000**	**17 000**	**-27 000**	**-10 000**
Cultivation of histosols		**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**	**1 100**
Perennial woody crops		**-1000**	**41**	**-10**	**20**	**16**	**15**	**-65**	**-110**
Woody biomass transferred to HWP		**840**	**490**	**540**	**530**	**520**	**530**	**520**	**520**
Total mineral soils		**-8 000**	**-27 000**	**-20 000**	**-19 000**	**-22 000**	**15 000**	**-29 000**	**-12 000**
Crop mixture changes	Increase in perennial crops	-3 600	-12 000	-11 000	-11 000	-11 000	-11 000	-11 000	-11 000
	Increase in annual crops	7 100	8 500	15 000	15 000	15 000	15 000	16 000	16 000
Tillage changes	Conventional to reduced	- 870	-1 000	-650	-630	-600	-590	-580	-560
	Conventional to no-till	-420	-3 700	-3 500	-3 500	-3 500	-3 400	-3 400	-3 300
	Other[b]	-0.5	-860	- 920	- 900	- 870	-850	-830	-800
Crop residue C input		-8 300	-15 000	-17 000	-16 000	-20 000	17 000	-27 000	-10 000
Manure application		-2 100	-2 500	-2 200	-2 200	-2 200	-2 100	-2 100	-2 100
Land conversion – residual emissions[c]		110	680	700	700	700	700	700	700

Notes:
a. A negative sign indicates the removal of CO_2 from the atmosphere.
b. Includes a shift from reduced to no-till as well as other changes in tillage with relatively less significant impacts on emissions/removals, namely: reduced to conventional, no-till to conventional, and no-till to reduced
c. Net residual CO_2 emissions from the conversion of forest land and grassland to cropland occurring more than 20 years prior to the inventory year, including emissions from the decay of woody biomass and DOM.

6.5.1.2. Methodological Issues

According to the 2006 IPCC Guidelines (IPCC, 2006), changes in SOC are driven by changes in soil management practices. When no change in management has occurred, it is assumed that mineral soils are neither sequestering nor losing C.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management practices on SOC, selecting the key management practices and management changes likely to cause changes in soil C stocks and on which activity data (time series of management practices) from the *Census of Agriculture* (COA) were available. Several management practices are known to increase SOC in cultivated cropland, including reduced tillage intensity, intensification of cropping systems, adoption of yield-promoting practices, and re-establishment of perennial vegetation (Janzen et al., 1997; Bruce et al., 1999). Other land management changes (LMCs), such as manure application and increased crop productivity, are also known to have positive impacts on SOC. Data on rates of annual biomass production can be determined from the yield estimates produced to estimate N_2O emissions from crop residues (Thiagarajan et al., 2018), as can data on C input in manure. Estimates of CO_2 changes in mineral soils were derived from the following LMCs:

- changes in the proportion of annual and perennial crops
- changes in tillage practices
- changes in crop productivity/crop residue C input
- manure application

Carbon emissions and removals were estimated by applying a combination of area-based and country-specific C emission and removal factors multiplied by the relevant area of land that underwent the management change (for changes in tillage practices and perennial/annual crop mixtures), and country-specific C factors based on changes in rates of crop residue C inputs multiplied by the estimated area of crop production. Soil C removals resulting from manure application were estimated using manure-induced C retention factors, making use of manure production rates consistent with the data developed for estimating N_2O emissions in Chapter 5. Calculations were performed at the scale of Soil Landscapes of Canada (SLC) polygons (see section A3.5.1). The C emission/removal factors represent the rate of SOC change per year and per unit area of land that underwent a land management change.

The impact of LMCs on SOC varies with the initial conditions. Therefore, to obtain the most accurate estimates of soil C stock changes, the cumulative effects of the long-term management history of each piece of land or farm field should be considered. This inventory relies mainly on the COA for the estimated area of LMCs (i.e., changes in tillage and crop mixtures), which are not spatially explicit. The area of LMCs was determined individually in the 3475 SLC polygons where agricultural activities occur, each one with an agricultural area between roughly 1000 and 1 000 000 ha. This is the finest resolution possible for activity data linked to an ecological land stratum. The COA provides information on the area of each practice in each census year, so only the net area of change for each land management practice can be estimated. Estimates of these LMCs are as close to the gross area of LMCs as is feasible for regional or national analyses.

The validity of the COA-based LMC estimates relies on two key assumptions: the additivity and the reversibility of area-based C factors. Additivity assumes that the combined effects of different LMCs or of LMCs at different times would be the same as the sum of the effect of each individual LMC. Reversibility is the assumption that the C effects of an LMC in one direction (e.g., converting annual crops to perennial crops) are the opposite of the C effects of the LMC in the opposite direction (e.g., converting perennial crops to annual crops).

The various C factors associated with each specific area-based tillage practice and perennial/annual crop mixture in space and time were derived using the CENTURY model (Version 4.0), by comparing the output from scenarios with and without the management change in question.

Crop productivity has continued to increase in Canada, likely due to higher fertilization rates and improvements in crop genetics (Fan et al., 2019). The 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019) provides a Tier 2 Steady State approach for estimating the change in SOC storage as impacted by crop productivity. This method was applied using crop biomass input data consistent with estimates of crop residue nitrogen (N) used to estimate nitrous oxide emissions in Chapter 5.

A country-specific method using a manure-induced C retention factor (Liang et al., 2020) was developed to estimate the soil C sink resulting from manure application to cropland soils. Estimates of SOC change were limited to the application of manure on annual cropping systems. SOC changes from applications of manure on perennial cropping systems were not included due to a lack of empirical data on this impact.

A more detailed description of the methodologies used for determining C factors and other key parameters can be found in section A3.5.4.1.

6.5.1.3. Uncertainty Assessment and Time-Series Consistency

Uncertainty was estimated analytically using a Tier 1 approach. The uncertainties associated with estimates of CO_2 emissions and removals were assessed by taking account of the uncertainties surrounding the area of management changes (i.e., changes in tillage practices and annual/perennial crop mixtures), and the associated C factors (McConkey et al., 2007).

The uncertainty associated with the area of a given management practice in an ecodistrict was found to vary inversely with the relative proportion of that practice regarding the total area of agricultural land in that ecodistrict. The relative uncertainty associated with the area of a management practice (expressed as the standard deviation for an assumed normal population) decreased from 10% to 1.25% of the area as the relative area of that practice increased (McConkey et al., 2007).

The uncertainties associated with C change factors for tillage and annual/perennial crop mixtures were attributed to two main sources: (i) the process uncertainty inherent in C change due to inaccuracies in predicting C change even when the management practice is defined perfectly; and (ii) the situational uncertainty in C change due to variations in the location or timing of the management practice. Further details on estimating processes and situational uncertainties can be found in section A3.5.4.1. Uncertainty estimates associated with emissions/removals of CO_2 from mineral soils were developed by McConkey et al. (2007), who reported uncertainty values of ±19% for the level and ±27% for the trend. These uncertainty estimates have not been updated since the 2011 annual submission. Changes in agricultural activity data due to the incorporation of earth-observation data may have modified uncertainty estimates slightly.

A formal uncertainty analysis has not yet been carried out for the estimates of cropland C change associated with changes in crop yield. Interannual variability is high throughout the time series, mainly reflecting weather-related impacts on crop production, especially drought in the Canadian prairies. Similarly, a formal uncertainty analysis has not been conducted for the estimates of cropland C change from manure application, though uncertainty estimates associated with field measurements of manure-induced C retention are available.

Consistency in the CO_2 estimates is ensured through the use of the same methodology for the entire time series of estimates.

6.5.1.4. QA/QC and Verification

Tier 1 QC checks implemented by AAFC specifically address estimate development in the Cropland Remaining Cropland subcategory. Environment and Climate Change Canada, while maintaining its own QA/QC procedures for internally developed estimates (see section 1.3, Chapter 1), has implemented additional QC checks for estimates obtained from its partners as well as for all estimates and activity data from its LULUCF data warehouse (Blondel, 2022) subsequently entered the CRT Reporter software. In addition, activity data, methodologies, and changes have been documented and archived in paper and electronic form.

In February 2009, Canada convened an international team of scientists and experts from Denmark, France, Japan, Sweden, the Russian Federation, and the United States to conduct a QA assessment of its methods. Some limitations in the current system were found regarding activity data, which could possibly create some bias in the current C stock change estimates. In particular, the lack of a complete and consistent set of land-use data and issues with the concept and application of pseudo-rotations were cited.

Carbon change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). The comparison showed that empirical data on changes in SOC, in response to no-till seeding, were highly variable, particularly in Eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. Liang et al. (2020) compiled soil C stock change data under conventional, reduced and no-till practices on agricultural soils in Canada, and reported that climate, soil texture, and management duration are the main drivers of soil C change in no-till systems. The analysis suggested that estimates of tillage impacts could be improved through the addition of more recent and more comprehensive data. For the change from annual to perennial cropping, the mean empirical factor was 0.59 Mg C ha^{-1} yr^{-1}, which compares favourably with the range of 0.46–0.56 Mg C ha^{-1} yr^{-1} in the modelled factors in western Canadian soil zones (VandenBygaart et al., 2008). For Eastern Canada, only two empirical change factors were available, but they fell within the range of the modelled values (0.60–1.07 Mg C ha^{-1} yr^{-1} empirical versus 0.74–0.77 Mg C ha^{-1} yr^{-1} modelled).

Manure-induced C retention represents the average fraction of C input from various manures that is retained in the soil. A country-specific method using manure-induced C retention was developed by analyzing ten long-term studies on manure application on Canadian soils under a wide range of climatic and soil conditions across the country (Liang et al., 2021).

Several soil C models of varying complexities (i.e., the Rothamsted carbon model [RothC], Introductory Carbon Balance Model [ICBM], and the Campbell model) that can use measured crop yields as C inputs in simulations were tested in the national C assessment analysis. These models were also used for simulations of soil C storage with varying degrees of success against field observations (Thiagarajan et al., 2022). These models' estimates of national soil C change varied significantly. For comparability purposes among developed countries, the IPCC Tier 2 Steady State approach (IPCC, 2019) is used for estimating the change in soil C storage as impacted by crop productivity and crop residue C input. The results of this approach were observed to be roughly equivalent to the mean of the other models.

As part of QA and continuous improvement efforts, methodologies for estimating soil C storage, as impacted by changes in crop productivity / crop residue C input and manure application on annual cropland soils, were reviewed by a panel of researchers and scientists from ECCC and AAFC in summer 2021. The panel found that the proposed methods were an improvement over the previous reporting methodologies in addressing clear methodological deficiencies and that the modifications further address, in part, issues identified in the 2009 international review. A review of the estimation procedures used for C inputs added to the soil from crop residues revealed that a quality control procedure inadvertently replaced some C inputs with mean values. A correction was made to remove this procedure in this inventory edition to address the discrepancies in C inputs from crop residues.

6.5.1.5. Recalculations

Recalculation occurred due to corrections to the calculation of carbon returned to soil as crop residue on an annual basis, across the time series. A procedure that was put in place to identify and refine outliers in the spatial carbon distribution was identified to introduce a bias to the quantity of carbon returned to soils. This procedure was removed from the data treatment process. There were also minor modifications to the spatial distribution of yield in the Cropland SOC modelling input database. As a result of these modifications, emissions were revised upwards by 0.65 Mt in 1990, 0.49 Mt in 2005, and downward by 0.12 Mt in 2023.

6.5.1.6. Planned Improvements

An integrated modelling approach is planned to simulate the change in soil C storage as impacted by crop productivity, tillage practices and crop mixtures. The model parameters will be adapted to Canadian conditions through Bayesian optimization. Currently, multiple models are being assessed, including the IPCC Tier 2 Steady State approach. In addition, a complete formal analysis and calculation of uncertainty including that associated with tillage practices, annual/perennial crop mixtures, crop productivity and crop residue C input and manure application are also planned in the medium term, within three to five years.

More details are provided in Chapter 8, Table 8–5.

6.5.1.7. CO_2 Emissions from the Cultivation of Organic Soils

6.5.1.7.1. Category Description

In Canada, the cultivation of organic soils is defined as the conversion of organic soils to annual crop production, normally accompanied by artificial drainage, cultivation and liming. Organic soils used for agricultural production in Canada include peaty-phase gleysols, fibrisols over 60-cm thick, and mesisols and humisols over 40-cm thick (Soil Classification Working Group, 1998).

6.5.1.7.2. Methodological Issues

Emissions from the cultivation of organic soils were calculated by multiplying the total area of cultivated histosols by the default emission factor of 7.9 Mg C ha^{-1} yr^{-1} for cropland, and 5.7 Mg C ha^{-1} yr^{-1} for grassland (IPCC, 2014).

The COA does not provide information on the area of cultivated histosols, and area estimates were based on the expert opinion of soil and crop specialists across Canada (Liang et al., 2004). The estimated total area of cultivated organic soils in Canada (constant for the period from 1990 to 2024) was 16 kha for annual crops and 33 kha for perennial crops. Nearly 90% of cultivated histosols are in the Boreal Shield East, Mixedwood Plains and Boreal Plains reporting zones.

6.5.1.7.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties surrounding the area estimates for cultivated histosols and the emission factor. The uncertainty associated with the 95% confidence limit for the area estimate of cultivated histosols was assessed at ±50% (Hutchinson et al., 2007). The uncertainty associated with the 95% confidence limit for the default emission factor is estimated at ±90% (IPCC, 2014). The overall mean and uncertainties associated with this source of emissions were estimated to be 1.1 ± 0.3 Mt for the level uncertainty and 0 ± 0.13 Mt for the trend uncertainty (McConkey et al., 2007).

The same methodology and emission factors were used for the entire time series of emission estimates.

6.5.1.7.4. QA/QC and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies, and changes to methodologies have been documented and archived in paper and electronic form.

The same methodology and emission factors were used for the entire time series of emission estimates.

6.5.1.7.5. Recalculations

Minor revisions were made to the area under the organic soils. These recalculations increased removals by 11 kt in 1990, 2005 and 2023.

6.5.1.7.6. Planned Improvements

No improvements are currently planned for this category.

6.5.1.8. CO_2 Emissions from and Removals by Woody Biomass

6.5.1.8.1. Category Description

Estimated emissions from and removals by woody biomass in this category include those by trees and shrubs growing on agricultural land as well as by perennial woody crops such as vineyards, fruit orchards and Christmas trees. A portion of the tree biomass lost in cropland is transferred to the HWP pool to meet residential bioenergy requirements. Therefore, this C transfer is now reported as emissions in the Cropland Remaining Cropland category and transferred to the Harvested Wood Products category. For more details, see section 6.4 and section A3.5.4.1. Accordingly, the net emissions remained unchanged.

Under the definitional framework adopted in Canada for LULUCF reporting, abandoned cropland is still included in the Cropland category until there is evidence of a new land use. However, there is little information on the dynamics of cropland abandonment or re-cultivation. Owing to these data limitations, only vineyards, fruit orchards, Christmas trees, and trees and shrubs are considered in changes in woody biomass and abandoned and re-cultivated cropland are not included in this category.

Net CO_2 fluxes from woody biomass on agricultural land reported in the Cropland Remaining Cropland category, including the transfers to the HWP pool, amounted to net removals of 0.16 Mt in 1990, net emissions of 0.53 Mt in 2005, and net emissions of 0.42 Mt in 2024. The emissions associated with woody biomass, transferred to the HWP pool and used for residential bioenergy, accounted for 0.84 Mt, 0.49 Mt and 0.52 Mt of the total firewood emissions reported under the Harvested Wood Products category in 1990, 2005 and 2024, respectively.

6.5.1.8.2. Methodological Issues

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yield. Vineyards and fruit trees are pruned annually, and old plants are replaced on a rotating basis for disease prevention or stock improvement purposes or to introduce new varieties. For all three of these crops, it is assumed that, because of rotational practices and sustained yield requirements, a uniform age-class distribution is generally found. Hence, there would be no net increase or decrease in biomass C in existing operations, since losses of C from harvest or replacement would be balanced by gains from new plant growth. Therefore, the approach used was limited to detecting changes in the areas occupied by vineyards, fruit orchards, and Christmas tree plantations and estimating the corresponding C stock changes in total biomass. More information on the assumptions and parameters involved can be found in section A3.5.4.1.

Woody biomass in the Cropland category also includes perennial trees and shrubs in farmyards, shelterbelts and hedgerows. The method tracks the woody volume losses from clearing and gains from planting and annual growth, using earth observation-based monitoring and ecozone-specific growth parameters. More information on the assumptions and parameters is provided in section A3.5.4.1.

6.5.1.8.3. Uncertainty Assessment and Time-Series Consistency

When the loss of an area occupied by perennial woody crops occurs, all the C in the woody biomass is assumed to be immediately released. In addition, it is assumed that the uncertainty associated with the C losses equals the uncertainty associated with the mass of woody biomass C. The default uncertainty of ±75% (i.e., 95% confidence limits) for woody biomass in the Cropland category from the 2006 IPCC Guidelines (IPCC, 2006) was used for vineyards, fruit orchards and Christmas trees.

If a loss occurs in the area of fruit trees, vineyards or Christmas trees and this area is believed to have been converted to annual crops, a perennial-to-annual crop land conversion is assumed, with an associated uncertainty contributing to the overall uncertainty in C stock change. For a gain in fruit trees, vineyards or Christmas trees, the uncertainty associated with the annual C change is assumed to be the default value of ±75% (i.e., 95% confidence limits; IPCC, 2006).

The overall means and uncertainties associated with emissions or removals of CO_2 from vineyards, fruit orchards and Christmas trees were estimated to be 2 ± 0.2 kt for the level uncertainty and -29 ± 42 kt for the trend uncertainty (McConkey et al., 2007). The overall mean and uncertainty associated with removals of CO_2 from trees and shrubs is described in Huffman et al. (2015a) and is estimated to be -440 ± 180 kt for the annual estimate. Since removals resulting from the growth of trees and shrubs represent the biggest contribution to the overall removal/emission estimates, these two land cover types drive the uncertainty in the woody biomass subcategory, which is estimated to average 41% for the level uncertainty. More information on the method and factors considered in determining the uncertainty associated with C stock changes in trees and shrubs can be found in Huffman et al. (2015a).

The same methodology was used for the entire time series of emission estimates.

6.5.1.8.4. QA/QC and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies have been documented and archived in paper and electronic form.

6.5.1.8.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

6.5.1.8.6. Planned Improvements

Methodologies are being developed to improve the classification and automated quantification of changes in areas of trees and shrubs in Canada's agricultural regions. More details are provided in Chapter 8, Table 8–5.

6.5.2. Land Converted to Cropland (CRT Category 4.B.2)

This category includes the conversion of forest land and agricultural grassland to cropland. More than 99% of the total annual emissions estimated and reported in this category are in the Forest Land Converted to Cropland subcategory, with total annual emissions decreasing from 12 Mt in 1990 to 6.5 Mt in 2024. Emissions in the Grassland Converted to Cropland subcategory are relatively small.

6.5.2.1. Forest Land Converted to Cropland (CRT Category 4.B.2.a)

6.5.2.1.1. Category Description

The clearing of forest land for agricultural use remains an ongoing and growing practice in Canada, accounting for 55% of forest area conversion in 2024. In 1990, emissions from Forest Land conversion were 12 Mt (66% of area), declined to a minimum of 3.4 Mt (31% of area) in 2010 and have since increased to 6.5 Mt (55% of area). The cumulative area reported under the Forest Land Converted to Cropland subcategory in CRT Table 4.B amounted to 1300 kha during the 20 years prior to 1990, 600 kha during the 20 years prior to 2005, and 440 kha during the 20 years prior to 2024. The methods used to determine the area converted annually are the same as those used for all other types of forest conversion and are outlined in section 6.9. In 2024, immediate emissions from the conversion of forest to cropland totalled 4.2 Mt, while residual emissions from events that occurred in the last 20 years totalled 2.5 Mt.

6.5.2.1.2. Methodological Issues

Dead Organic Matter and Biomass Pools

Approximately 90% of emissions originate from the biomass and DOM pools during and after conversion, with the remainder attributed to the soil pool. The same modelling environment is used for estimating these emissions as for the Forest Land Remaining Forest Land subcategory. A general description of this modelling environment is provided in section 6.3.1.2. For more information, see section A3.5.4.3.

Soils

Emissions from soils in this category include net C stock changes resulting from the actual conversion, a very small net source of CO_2 due to the change in management practices in the 20 years following conversion, and the N_2O emissions from the decay of soil organic matter. Emissions/removals reported in the Forest Land Converted to Cropland subcategory also include those resulting from changes in land management practices, crop production, and manure application on this land. Soil emissions were calculated by multiplying the total area of conversion by the empirically derived emission factor which incorporates modelling-based SOC dynamics (see section A3.5.4.3). The pattern of SOC changes that occur after the conversion of forest land to cropland clearly differs in Eastern and Western Canada.

Eastern Canada

All agricultural land in the eastern part of the country was forested before its conversion to agriculture. Many comparisons of forest SOC with SOC in adjacent agricultural land in Eastern Canada—either in the scientific literature or the Canadian Soil Information System—show a mean C loss of 20% at depths to approximately 20–40 cm (see section A3.5.4.3). The average N change was -5.2%, equivalent to a loss of approximately 0.4 Mg N ha^{-1}. For those comparisons in which both N and C losses were determined, the corresponding C loss was 19.9 Mg C ha^{-1}. Therefore, it was assumed that N loss was a constant 2% of C loss.

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics involved in the conversion of forest land to cropland in Eastern Canada. More details on the methodologies used to determine the maximal C loss and associated rate constant involved in the conversion of forest land can be found in section A3.5.4.3. A Tier 2 methodology is used to estimate the removals from cropland biomass C stocks using historical data of crop yields, harvest index and root-shoot ratio in croplands. More details on the methodologies are available in section A3.5.4.2. As in the case of direct N_2O emissions from agricultural soils (see Agriculture sector, Chapter 5), an IPCC Tier 2 method (IPCC, 2006) is used to estimate N_2O emissions from the conversion of forest land to cropland, by multiplying the amount of C loss by the fraction of N loss per unit of C and by an emission factor (EF_Base). EF_Base was determined for each ecodistrict based on topographic and climate conditions (see Annex 3.4).

Western Canada

Much of the current agricultural land in Western Canada (the Prairies, as well as the Peace River region of British Columbia) was formerly native grassland. Therefore, in the West, forest land that has been converted to cropland consists primarily of forests on the fringe of former grassland areas.

The Canadian Soil Information System represents the best available source of SOC data for agricultural areas and areas managed for forest harvesting. On average, these data suggest that no loss of SOC occurs from forest conversion and that, in the long term, the balance between C input and SOC mineralization under agriculture remains similar to what it was under forest. It is important to recognize that, along the northern fringe of western Canadian agricultural lands, where most forest conversion occurs, the land is marginal for arable agriculture, and pasture and forage crops are the dominant management practices. As a result, in this region, the conversion of forest land to cropland managed exclusively for seeded pastures and hayfields was assumed to result in no long-term losses of SOC.

The C loss from forest conversion in Western Canada results from the loss of above- and below-ground tree biomass and the loss or decay of other above- and below-ground coarse woody DOM present at the time of forest conversion. The C gains occur in croplands after the conversion of forest to croplands from biomass using a Tier 2 methodology (see section A3.5.4). The average N change in Western Canada for sites at least 50 years after the breaking of the land for cultivation was +52% (see Annex 3.5), reflecting the substantial added N in agricultural systems compared with managed forests. However, when the uncertainty associated with the actual C-N dynamics of forest conversion is recognized, the conversion of forest land to cropland in Western Canada can be assumed not to be a source of N_2O.

6.5.2.1.3. Uncertainty Assessment and Time-Series Consistency

Greenhouse gas fluxes in the Forest Land Converted to Cropland subcategory result from a combination of (i) logging and burning, producing immediate emissions from biomass and DOM; (ii) organic matter decay and subsequent CO_2 emissions in the DOM pool; and (iii) net C losses from SOC. Immediate CO_2 emissions always refer to the area converted in the inventory year; residual emissions, while also occurring on land converted during the inventory year, mostly come from land converted over the last 20 years. Non-CO_2 emissions are produced exclusively by burning and occur during the conversion process.

Immediate and residual CO_2 emissions from the biomass and DOM pools represent the largest components in this category and contribute the most to the category uncertainty (Table 6–10). In all cases, uncertainty values are presented as the 95% confidence interval around the median (biomass and DOM pools) or mean (soil pool) value of the estimates.

Uncertainty estimates were derived independently for the biomass and DOM pools and soil organic matter using this estimation approach. The uncertainty associated with the activity data was incorporated in all analyses (see section 6.9.3 for more details).

The fate of biomass and DOM, when forest conversion occurs, and the ensuing emissions are modelled using the same framework used in the Forest Land category. Consequently, the corresponding uncertainty estimates were also developed under this framework, using the same Monte Carlo runs used to generate uncertainty estimates for the Forest Land category. For a description of the general approach, see section 6.3.1.3. More information can be found in section A3.5.4.3.

The uncertainty associated with the net CO_2 flux from the soil pool was estimated analytically (McConkey et al., 2007); for more information on the general approach used in this analysis, see section A3.5.4.3.

6.5.2.1.4. QA/QC and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines (IPCC, 2006). AAFC, which derived the estimates of SOC changes, also performed external quality checks. The activity data, methodologies, and changes to methodologies have been documented and archived in paper and electronic form.

6.5.2.1.5. Recalculations

Recalculations in Forest Land to Cropland resulted from two methodological changes this year: (i) the implementation of an improved set of dead organic matter (DOM) and soil carbon parameters in the CBM-CFS3 (see section 6.3 for details), and (ii) the introduction of a new mapping period from 2018 to 2023, which shows an increase in forest conversion to agriculture in recent years. The parameter improvements led to downward revisions of emissions of 0.72 Mt in 1990 and 0.33 Mt in 2005, while the updated mapping resulted in an upward revision of 1.2 Mt in 2023.

Table 6–10 **Uncertainty Associated with the Components of CO_2 and Non-CO_2 Emissions from Forest Land Converted to Cropland for the 2024 Inventory Year**

Emission Components	Emissions (kt CO_2 eq)	Uncertainty (kt CO_2 eq)
Immediate CO_2 emissions	3 965	±1 156
Residual CO_2 emissions from the DOM pool[a]	2 274	±579
Residual CO_2 emissions from the soil pool	228	±142
CH_4 emissions	182	±84
N_2O emissions	77	±25

Note:
a. DOM = dead organic matter

6.5.2.1.6. Planned Improvements

The planned improvements described in section 6.9 will also affect this category. The modelled soil C change factors will be validated against a meta-analysis of published soil C change factors for forest land conversion to cropland. More details are provided in Chapter 8, Table 8–5.

6.5.2.2. Grassland Converted to Cropland (CRT Category 4.B.2.b)

6.5.2.2.1. Category Description

The conversion of native grassland to cropland occurs in the Canadian Prairies and generally results in losses of SOC and soil organic N, and emissions of CO_2 and N_2O to the atmosphere.

6.5.2.2.2. Methodological Issues

Several studies on changes in SOC and soil organic N in grassland converted to cropland have been carried out in the Brown, Dark Brown and Black soil zones of the Canadian Prairies. The average SOC loss was 22%, and the corresponding average change in soil organic N was 0.06 kg N lost per kg C (see section A3.5.4.2).

Emissions from C stocks in biomass of grasslands are estimated using a Tier 1 methodology following the 2006 IPCC Guidelines (IPCC, 2006). A Tier 2 methodology is used to estimate the removals from cropland biomass C stocks using historical data of crop yields, harvest index and root-shoot ratio in croplands. More details on the methodologies are available in section A3.5.4.2. Emissions/removals reported in the Grassland Converted to Cropland subcategory include residual emissions from the loss of SOC due to the land-use change and are affected by changes in land management practices. The CENTURY model (Version 4.0) is used to estimate SOC dynamics in the conversion of grassland to cropland on Brown and Dark Brown Chernozemic soils. More details on the methodologies used to determine the maximal C loss and rate constant associated with the breaking of grassland can be found in section A3.5.4.2.

Emissions of N_2O in the Grassland Converted to Cropland subcategory were estimated in a similar way to those in the Forest Land Converted to Cropland subcategory, by using a Tier 2 methodology (IPCC, 2006) which involves multiplying the amount of C loss by the fraction of N loss per unit of C by a base emission factor (EF_Base). The value of EF_Base is determined for each ecodistrict based on climate and topographic characteristics (see section A3.4.3).

6.5.2.2.3. Uncertainty Assessment and Time-Series Consistency

Although the conversion from agricultural grassland to cropland can and does take place, the opposite—the conversion from cropland to grassland—does not occur due to the definitional framework used for managed lands (see section 6.2). Therefore, the uncertainty surrounding the absolute value of the area of this conversion cannot be greater than the uncertainty surrounding the area of cropland or grassland. Consequently, the uncertainty associated with the area of conversion was considered equivalent to that associated with the area of either cropland or grassland in each ecodistrict, whichever is lower. The uncertainty associated with the SOC change was estimated in the same way as in the Forest Land Converted to Cropland subcategory. The overall mean and uncertainty associated with emissions due to SOC losses in the Grassland Converted to Cropland subcategory were estimated to be 27 ± 13 kt for the level uncertainty and -260 ± 120 kt for the trend uncertainty.

The same methodology and emission factors were used for the entire time series of emission estimates.

6.5.2.2.4. QA/QC and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines (IPCC, 2006). The activity data, methodologies and changes to methodologies have been documented and archived in paper and electronic form.

6.5.2.2.5. Recalculations

Recalculations were performed to address the corrections made to the crop residue C returned to the soil on an annual basis, for the whole time series. These modifications resulted in an upward recalculation of 3 kt in 1990 (8%), 2 kt in 2005 (10%) and 1 kt in 2023 (2.4%).

6.5.2.2.6. Planned Improvements

Canada plans to validate the modelled soil C change factors with measured and published soil C change factors for grassland conversion based on literature analysis. More details are provided in Chapter 8, Table 8–5.

6.6. Grassland (CRT Category 4.C)

Grassland used for agriculture is defined under the Canadian LULUCF framework as pasture or rangeland on which the only agricultural land management activity is the grazing of domestic livestock. It occurs only in geographical areas where the grassland would not naturally transition to forest if abandoned—the natural shortgrass prairie region in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. Agricultural grassland is found in three reporting zones: Semi-arid Prairies (7.0 Mha), Montane Cordillera (0.2 Mha) and Pacific Maritime (0.3 kha). As with the Cropland category, the change in management triggers a change in soil C stocks (IPCC, 2006). Very little information is available on management practices for Canadian agricultural grassland, and it is unknown whether the soil quality of grazed land is improving or degrading. Therefore, Canada reports emissions in the Grassland Remaining Grassland subcategory using an IPCC Tier 1 method (IPCC, 2006), assuming that no changes in management practices have occurred since 1990. Under the current definitional framework, which is explained in section 6.2, the conversion of land to grassland in the Land Converted to Grassland subcategory is reported as "not occurring" (Table 6–4).

6.6.1. Grassland Remaining Grassland (CRT Category 4.C.1)

6.6.1.1. Category Description

In Canada, fires sometimes occur on managed grasslands in the form of prescribed burns to control invasive plants and stimulate the growth of native species, or are caused by lightning, accidental ignition, or military training exercises. The burning of managed grasslands is a net source of CH_4, CO, NO_x and N_2O emissions (IPCC, 2006).

Emissions associated with the burning of managed grassland are reported in CRT Table 4(V), they have remained relatively small and stable at around 1 kt per year over the reported period.

6.6.1.2. Methodological Issues

Emissions of CH_4 and N_2O from the burning of managed agricultural grassland were estimated using an IPCC Tier 1 method (IPCC, 2006), considering the area burned, fuel load and combustion efficiency for each burning event. Emission factors (2.7 g CH_4 kg^{-1} dry matter burned, and 0.07 g N_2O kg^{-1} dry matter burned) were taken from the 2006 IPCC Guidelines (IPCC, 2006).

Activity data from 1990 to 2012 on the area, fuel load and combustion efficiency of each burning event on managed agricultural grassland were collected through consultations (Bailey and Liang, 2013). The activity data on the burning of managed agricultural grassland from 2013 to 2015 were updated in the 2018 submission.

6.6.1.3. Uncertainty Assessment and Time-Series Consistency

The uncertainties associated with emissions from this source are due to the uncertainties surrounding the area estimates, average fuel loads per hectare and combustion efficiency, along with the emission factors. The uncertainty associated with the 95% confidence intervals for burned materials is estimated at ±50%, based on expert judgment. The uncertainty associated with the 95% confidence intervals for the default emission factors is ±40% for CH_4 and ±48% for N_2O (IPCC, 2006). The overall uncertainties estimated for this source of emissions using error propagation were ±64% for CH_4 and ±69% for N_2O, respectively.

The same methodology and emission factors were used for the entire time series of emission estimates.

6.6.1.4. QA/QC and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with 2006 IPCC Guidelines (IPCC, 2006). The activity data and methodologies have been documented and archived in paper and electronic form.

6.6.1.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

6.6.1.6. Planned Improvements

No improvements are currently planned for this category.

6.7. Wetlands (CRT Category 4.D)

Wetlands cover about 14% of Canada's land mass (ECCC, 2016). In Canada, a wetland is defined as land that is saturated with water long enough to promote anaerobic processes. Wetland indicators include poorly drained soils, hydrophytic vegetation and various kinds of biological activity that are adapted to a wet environment. In other words, a wetland is any land area that can hold water long enough to let wetland plants and soils develop. To provide a standardized framework for these areas, the Canadian Wetland Classification System divides wetlands into five broad categories: bogs, fens, marshes, swamps and shallow water (National Wetlands Working Group, 1997).

For this report, the Wetlands category is restricted to wetlands that do not fall into the Forest Land, Cropland or Grassland categories. This follows the land categories as defined in the 2006 IPCC Guidelines (IPCC, 2006). Currently, no national estimate exists for the total area of these wetlands in Canada, due to their small, fragmented, and often remote nature, which makes comprehensive mapping challenging.

Managed wetlands are defined as those in which human intervention has directly altered the water table and, consequently, the dynamics of GHG emissions and removals. In this inventory, they include: (i) peatlands drained for peat extraction, (ii) flooded lands (i.e., reservoirs), and (iii) resource extraction (i.e., mining activities in Alberta's Oil Sands Region). While the 2006 IPCC Guidelines, the 2013 Wetland Supplement, and the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2006; 2014; 2019) provide explicit methods for calculating GHG emissions and removals from peat extraction and flooded lands, they do not specifically address estimation methods for wetland management associated with resource extraction, which represents a unique Canadian context. Therefore, a domestic methodology was developed, following the generic framework of the IPCC 2006 Guidelines (IPCC, 2006), to estimate GHG emissions and removals from wetlands affected by resource extraction. For UNFCCC reporting purposes, the Wetlands category is divided into Wetlands Remaining Wetlands and Land Converted to Wetlands.

In 2024, the net GHG balance in the Wetlands category amounted to net emissions of 5.4 Mt (Figure 6–7). Emissions are primarily associated with flooded lands, which accounts for 71% of annual totals, while peat extraction and resource extraction activities contribute smaller shares. Overall, total annual emissions in Wetlands have decreased over time, from 10.1 Mt in 1990 to 5.4 Mt in 2024, reflecting largely from the reductions in reservoir creation and the stabilization of reservoir emissions. The recalculations in emissions for this category amount to 5.0 Mt in 1990, 4.3 Mt in 2005 and 2.9 Mt in 2023. Recalculations for specific managed wetland types—peat extraction, flooded lands and resource extraction—are presented in the subsections below.

6.7.1. Wetlands Remaining Wetlands (CRT Category 4.D.1)

This category includes managed wetlands, including peat extraction sites, flooded lands >20 years old (i.e., reservoirs) and non-forested wetlands disturbed during resource extraction activities. Emissions and removals from this category encompass CO_2, CH_4, and N_2O pathways governed by hydrology, substrate type (organic vs. mineral), vegetation, and management practices. Canada's reporting follows the 2013 IPCC Wetlands Supplement and the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2014; 2019), with further details provided in section A3.5.6. The net GHG balance for Wetlands Remaining Wetlands in 2024 was 4.8 Mt (Figure 6–7).

6.7.1.1. Peat Extraction Remaining Peat Extraction (CRT Category 4.D.1.a)

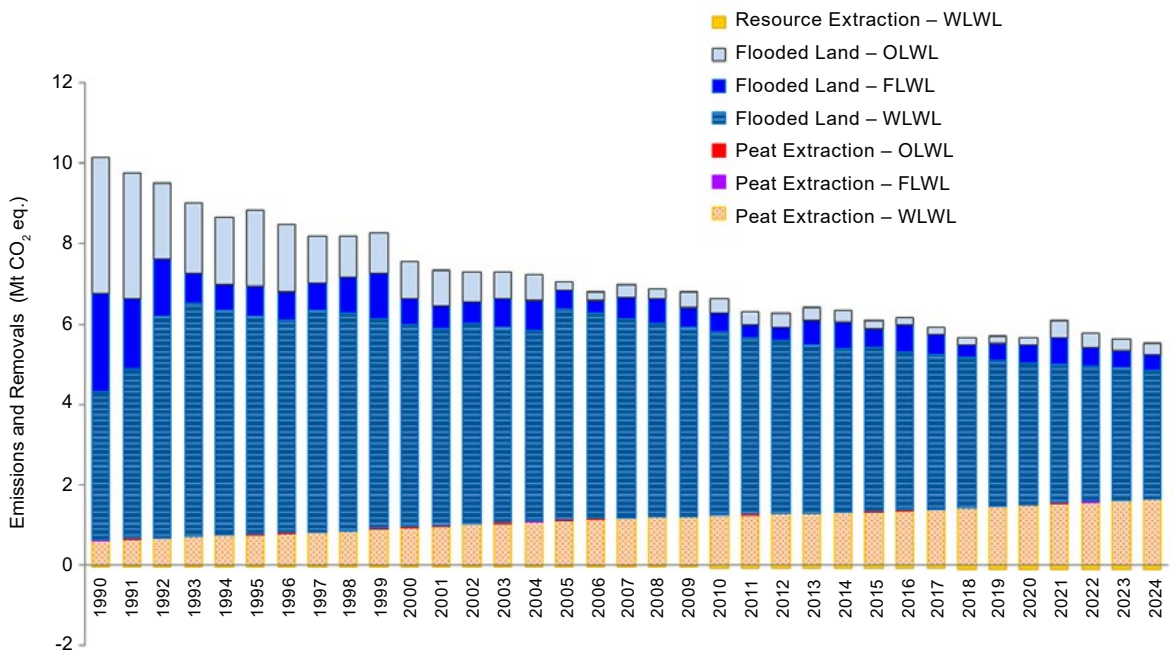
6.7.1.1.1. Category Description

Canada has about 114 million hectares of peatlands, but only 38 thousand hectares have been historically drained for peat extraction. Of these, around 21 thousand hectares are under active management, 6 thousand hectares are abandoned and unrestored, and 11 thousand hectares have been restored or naturally regenerated. Currently, peat extraction is concentrated in New Brunswick, Quebec, Alberta, and Manitoba, primarily serving the horticultural sector. Emissions from peat extraction have increased over time due to expanded drainage areas and the decay of previously harvested peat. Annual peat carbon removed off-site increased from 200 tonnes in 1990 to 440 tonnes in 2024, while associated emissions rose from 0.6 Mt in 1990 to 1.6 Mt in 2024. Restoration efforts have reduced overall emissions, compared to if these same sites remained drained or unrestored, but continue to be a net source of emissions as they transition from net sources to net sinks (see section A3.5.6.1).

6.7.1.1.2. Methodological Issues

While Canada's GHG estimates for wetlands are derived from activity-based datasets (e.g., site-level peat extraction records), the resulting emissions are aggregated and reported across 18 reporting zones to maintain consistency with the national spatial framework (see section A3.5.1). Estimates follow a Tier 2 approach, consistent with the 2006 IPCC Guidelines and the 2013 IPCC Wetlands Supplement (IPCC, 2006; 2014), using methods specific to Canadian peatland management.

Figure 6–7 **Emission and removal estimates of Wetland Remaining Wetland and Land Converted to Wetland**



Tier 2 emission factors are derived from research on Canadian-specific management practices (see section A3.5.6.1) and include on-site CO_2, CH_4, and N_2O emissions from drained and restored peatlands, as well as off-site CO_2 from waterborne carbon losses and the decay of extracted peat. Peat extraction areas for key years (1990, 2007, 2013, 2022) were determined using an earth observation-based mapping approach and classified into management subcategories: active extraction, unrestored, naturally regenerated, rewetted, and actively restored using the Moss Layer Transfer Technique (MLTT) (see section A3.5.6.1). National peat production statistics were used to estimate annual peat removal. Converted areas are reported in CRT Table 4.D for the first year after conversion and under Peat Extraction Remaining Peat Extraction thereafter, with emissions recorded in CRT Table 4.D.1.a.

6.7.1.1.3. Uncertainty Assessment and Time-Series Consistency

Uncertainty in peat extraction estimates arises from several factors, beginning with limitations in mapping peatland extent and condition, which affect area estimates and management subcategorization. A consistent time series from 1990 to 2024 is maintained, with back-casting applied when methods or activity data are updated to ensure continuity of the time series (see section A3.5.6.1). Additional uncertainty stems from soil carbon parameters in peatlands, particularly under changing water table conditions. Although a formal uncertainty assessment has not yet been conducted, key contributors include the estimated extent of converted areas based on mapping, emission factors for various categories of decommissioned sites (e.g., rewetted and restored), and variations in the moisture content of extracted peat.

6.7.1.1.4. QA/QC and Verification

Industry and academic experts, including members of the Canadian Sphagnum Peat Moss Association and the Peatland Ecology Research Group, provided critical support for the establishment of quality control procedures for the Peat Extraction category. Experts also validated mapping estimates and reviewed country-specific emission factors to ensure accuracy of the methodologies put in place. Additional cross-checks included internal consistency tests, spatial reconciliation with other land categories, and documentation of assumptions in section A3.5.6.1 and Table A6.5–11. General QA/QC procedures outlined in section 1.4 of Chapter 1 are applied.

6.7.1.1.5. Recalculations

Minor revisions were made to activity data in 2023 from updated peat production statistics. These recalculations increased emissions by 5 kt in 2005 and 15 kt in 2023.

6.7.1.1.6. Planned Improvements

Planned improvements for the Peat Extraction category include using remote sensing to improve estimates of peatland extent and condition and to enhancing knowledge of CH_4 and CO_2 emissions through new field measurements and validation. Additional work will focus on updating activity data as sites are developed or restored and exploring methods to better assess peatland recovery after extraction, supported by monitoring data. More details are provided in Chapter 8, Table 8–5.

6.7.1.2. Flooded Land Remaining Flooded Land (CRT Category 4.D.1.b)

6.7.1.2.1. Category Description

The Flooded Land Remaining Flooded Land category refers constructed reservoirs (e.g., for hydroelectric power, flood control, irrigation, water supply) that have been in place for more than 20 years. In Canada, these flooded lands cover about 5.7 million hectares in 2024. In accordance with the 2006 IPCC Guidelines (IPCC, 2006), these areas transition to this category after a 20-year threshold to reflect their long-term stabilized status, having previously been reported in the Land Converted to Flooded Land category.

The vast majority of these flooded lands were created during the mid-20th century expansion of Canada's hydroelectric capacity, and continue to support energy production, water management, and regional flood control efforts. Emissions from these systems have generally ranged between 3 and 6 Mt since 1990, primarily driven by carbon dioxide (CO_2) and methane (CH_4) released from decomposing organic matter, but have recently trended downward to 3.2 Mt in 2024.

This decline indicates that most Canadian reservoirs have are beyond their initial high-emission phase. While CH_4 emissions persist due to ongoing anaerobic processes, these systems are transitioning toward a more stable state as the legacy carbon pools from the original flooding events are depleted.

6.7.1.2.2. Methodological Issues

While Canada's GHG estimates for wetlands are derived from activity-based datasets (e.g., individual reservoir records), the resulting emissions are aggregated and reported across 18 reporting zones to maintain consistency with the national spatial framework (see section 3.5.1). Estimates follow a Tier 2 approach, consistent with the 2006 IPCC Guidelines, the 2013 Wetland Supplement, and the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2006; 2014; 2019), using methods specific to reservoirs management.

The CO_2 and CH_4 emissions from the surface of reservoirs are estimated using a country-specific Tier 2 approach based on Canadian research and modeled fluxes (see section A3.5.6.2 and Table A6.5–9). This approach is used instead of the IPCC default assumption of instant oxidation of biomass carbon in the year of flooding (IPCC, 2006), as this default does not accurately represent real biogeochemical processes observed in Canadian systems. Emissions are reported in CRT Table 4.D for 20 years after flooding to avoid double counting dissolved organic carbon losses. Emissions are calculated for reservoirs flooded between 1832 and 2024. For each reservoir, the proportion of pre-flooding forest area determines allocation between Forest Land Converted to Flooded Land and Other Land Converted to Flooded Land. Fluctuations in reported areas reflect the transition of reservoirs from "converted" (<20 years) to "remaining" (>20 years), not changes in flooding rates. For Flooded Land Remaining Flooded Land, annual CO_2 and CH_4 emissions from reservoirs more than 20 years are estimated following methodologies outlined in section A3.5.6.2.

6.7.1.2.3. Uncertainty Assessment and Time-Series Consistency

Uncertainty in estimates for large reservoirs classified as Flooded Land Remaining Flooded Land arises from several factors. Variability in CH_4 emission factors due to differences in trophic state and temperature is a major contributor, along with reliance on proxy reservoirs where emission data are missing in the G-res model (Prairie et al., 2017) and seasonal changes in water extent. Additional uncertainty stems from limitations in mapping wetland extent and condition, which affect activity data, and from current methodologies that do not fully track dissolved organic carbon (DOC) across land categories. A consistent time series from 1990 to 2024 is maintained, and an overall uncertainty for Flooded Land is estimated using a standard error propagation approach (see section A3.5.6.2), ranging from ±15% in 1990 to ±23% in 2024.

6.7.1.2.4. QA/QC and Verification

Quality control for Flooded Land involves collaboration with academic institutions and hydroelectric companies to ensure accuracy and transparency. Reservoir and constructed waterbody area estimates are validated using geospatial datasets and historical hydroelectric records. Emission estimates are reviewed by experts from these organizations, who provided technical input on mapping accuracy, emission factors, and decay functions to maintain scientific robustness.

Additional QA/QC measures include internal consistency checks, spatial reconciliation with other land categories, and documentation of assumptions in section A3.5.6.2 and Table A6.5–9. General QA/QC procedures outlined in section 1.4 of Chapter 1 are applied.

6.7.1.2.5. Recalculations

Recalculations in this category were due to updated activity data as well as an updated flooded land model that incorporates Canadian specific emission factors from the G-res modeling framework (see section A3.5.6.2). An additional 150 reservoirs, including hydroelectric, flood control, irrigation, and water supply reservoirs, were added to the inventory, increasing the reported reservoir area by 4.7 million hectares. All reservoirs were mapped using Sentinel satellite imagery over a 10-year period to capture seasonal fluctuations and permanent water coverage. Canada updated its approach for flooded land areas by adopting the IPCC default 20-year transition period, replacing the previous 10-year period. This change ensures the areas transition from the conversion category into Flooded Land Remaining Flooded Land category.

Country-specific emission factors for CO_2 and CH_4 were developed using the G-res model, adapted for Canadian conditions with inputs from public datasets and expert knowledge. This approach accounts for reservoir age, climate zone, morphometry, and organic carbon inputs, and applies decay functions that reflect contrasting emission trajectories: CO_2 declines rapidly after impoundment, while CH_4 decreases more gradually due to persistent anaerobic decomposition.

Emissions are now tracked for 100 years after flooding (previously for 10 years), with CO_2 reported for the first 100 years and CH_4 treated as a continuing source beyond that period. Both gases are reported under Land Converted to Wetlands for the first 20 years and under Wetlands Remaining Wetlands thereafter. Methodological updates also introduced methane reporting, which was previously not estimated, recognizing that CH_4 emissions persist indefinitely while CO_2 emissions decline to baseline after 100 years.

These improvements resulted in an upward recalculation of emissions in the Flooded Land Remaining Flooded Land by 3.1 Mt in 1990, 4.2 Mt in 2005, and 2.5 Mt in 2023.

6.7.1.2.6. Planned Improvements

Improvements to the Flooded Land category is focused on refining spatial datasets to better capture flooded areas and supporting emission validation with targeted field measurements. More details are provided in Chapter 8, Table 8–5.

6.7.1.3. Other Wetlands Remaining Other Wetlands (CRT Category 4.D.1.c) – Resource Extraction

6.7.1.3.1. Category Description

Since 1884, approximately 36 thousand hectares of non-forested peatlands have been impacted by resource extraction activities in Alberta's Oil Sands Region. Of this total, 21 thousand hectares have been converted to the Settlements category representing disturbances such as surface mines, roads, wells and other conversions (see section 6.8.2.3.1).

The remaining 15 thousand hectares consist of peatlands disturbed by oil and gas exploration activities (e.g., seismic lines). Because these areas continue to function as a wetland, they remain within the Wetlands category and are reported under Other Wetlands Remaining Other Wetlands. Estimates for this category represent minor net removals from these managed wetlands, which have increased from 0.02 Mt in 1990 to 0.09 Mt in 2024. The increasing removals of this category reflect the expansion of the area of impacted wetlands over time.

6.7.1.3.2. Methodological Issues

Activity data for estimates of emissions resulting from wetland disturbance during resource extraction in Alberta's Oil Sands Region are compiled using the Human Footprint Inventory (HFI; ABMI, 2022 version) and the Alberta Merged Wetland Inventory (AMWI; Government of Alberta, 2025) to identify impacted wetland areas. To ensure spatial consistency and avoid double-counting, forested wetlands are excluded from this analysis using the SCANFI canopy-cover mapping to delineate forest extent (Guindon et al., 2024). For more detail, refer to A3.5.6.3.

Estimates for this category were developed using a Tier 2 approach adapted from Tier 3 modelling of wetland disturbance. The method was developed using the Canadian Model for Peatlands (CaMP; Bona et al., 2020), a modelling framework that tracks carbon growth, turnover, and decay across vegetation, litter, and organic soil layers. By applying disturbance matrices parameterized with regional empirical data, the CaMP simulated the fate of carbon pools for oil and gas extraction and exploration activities.

Because the CaMP outputs summarize total net ecosystem exchange, results from the model are not partitioned into separate carbon pools (i.e., biomass, DOM, soil). Instead, all stock changes are reported in the organic soil pool in CRT Table 4.E and in CRT Table 4.D reflecting that the majority of emissions results from the disturbance of the peat layer. An exception to this reporting logic is the historical practice of burning biomass (e.g., peat piles, woody biomass) which are reported separately in CRT Table 4(IV).

6.7.1.3.3. Uncertainty Assessment and Time-Series Consistency

Uncertainty in estimates of emissions resulting from wetland disturbance during resource extraction arises from several factors. Limitations in mapping wetland extent and condition affect activity data across all subcategories, and current LULUCF methodologies do not fully track the fate of dissolved organic carbon (DOC), making allocation to the correct land category challenging. A consistent time series from 1990 to 2024 is maintained.

The uncertainty for resource extraction, is driven primarily by wetland extent mapping and soil carbon parameters in peatlands, particularly under changing water table conditions. Uncertainty for resource extraction in the Alberta's oil sand region was estimated using a simplified Monte Carlo approach, described in section A3.5.6.3. The uncertainty ranges from 57% to 140%, driven mainly by variability in wetland extent among regional map products.

6.7.1.3.4. QA/QC and Verification

Quality control for resource extraction involves a comprehensive review of modelling assumptions, emission factors, and spatial activity data representing industrial disturbances. Expert consultations were conducted (see section A3.5.6.3), and NRCan and Alberta provincial geospatial and wetland experts participated in refining assumptions, selecting appropriate datasets, and integrating feedback. The methodology was also presented at national scientific conferences to obtain external input and ensure transparency.

Additional QA/QC measures include internal consistency checks, spatial reconciliation with other land categories, and documentation of assumptions in section A3.5.6.3 and Table A6.5–10. General QA/QC procedures outlined in section 1.4 of Chapter 1 are applied.

6.7.1.3.5. Recalculations

Resource extraction was introduced is a new reporting category under wetlands, capturing emissions from non-forested peatlands disturbed by oil and gas development. This addition contributed as a removal of 16 kt CO_2 eq in 1990, 35 kt CO_2 eq in 2005, and 95 kt CO_2 eq in 2023 to the Wetlands Remaining Wetlands category total. The inclusion of this category improves completeness and transparency in Canada's GHG inventory by accounting for industrial disturbances previously unreported under wetlands.

6.7.1.3.6. Planned Improvements

Planned work for resource extraction include accounting for CH_4 emissions from saturated wetland soils and integrating forested wetlands by refining deforestation estimates, which currently classify forested wetlands as upland. More details are provided in Chapter 8, Table 8–5.

6.7.2. Land Converted to Wetlands (CRT Category 4.D.2)

This category covers land-use changes where areas are converted to wetlands and reported under Land Converted to Wetlands for the first 20 years following conversion. It includes conversions of Forest Land to Wetlands, primarily by flooding or peat extraction, as well as conversions of Other Land to Flooded Land, where the flooded area was not previously forested.

Recalculations for this category reflect updates to emission factors, refinements to activity data, and integration of new spatial layers (documented with rationale in Chapter 8 and Annex 3.5). All impacted time-series have been adjusted to maintain comparability. These changes resulted in an upwards recalculation of emissions by 100 kt in 1990, 0.24 kt in 2005, and 290 kt in 2023 for Forest Land Converted to Wetlands, and 1.8 Mt, 0.15 Mt, and 0.21 Mt for Other Land Converted to Wetlands.

6.7.2.1. Forest Land Converted to Peat Extraction (CRT Category 4.D.2.a.i)

6.7.2.1.1. Category Description

This subcategory covers areas where forest land is converted to managed peat extraction sites, typically through drainage, clearing, and infrastructure development (e.g., haul roads, ditches, processing pads). At conversion, living biomass is reduced (harvested or cleared), and soil hydrology altered, initiating changes in soil carbon stocks and GHG fluxes. Consistent with IPCC guidance, emissions and removals during the first 20 years after conversion are reported under Land Converted to Wetlands; thereafter, these areas transition to Wetlands Remaining Wetlands. Additional details are provided in section 6.7.1.1.1.

6.7.2.1.2. Methodological Issues

While Canada's GHG estimates for wetlands are derived from activity-based datasets (e.g., site-level peat extraction records), the resulting emissions are aggregated and reported across 18 reporting zones to avoid double-counting across land categories (see section A3.5.1). Estimates follow a Tier 2 approach, consistent with the 2006 IPCC Guidelines and the 2013 IPCC Wetlands Supplement (IPCC, 2006; 2014), using methods specific to Canadian peatland management.

Tier 2 emission factors are derived from research on Canadian-specific management practices (see section A3.5.6.1). When forest land is converted to peat extraction, this involves changes in soil carbon stocks resulting from both tree removal and drainage within newly established extraction sites. Additional methodological details can be found in section 6.7.1.1.2. Harvested forest biomass is allocated to harvested wood products (HWP) as outlined in sections A3.5.2 and A3.5.3.

6.7.2.1.3. Uncertainty Assessment and Time-Series Consistency

For the uncertainty associated to the Forest Land Converted to Peat Extraction subcategory, refer to section 6.9 on Forest Conversion. Further details on the uncertainty associated with the Tier 2 estimation methodologies are provided in sections 6.7.1.1.3 and A3.5.6.2.

6.7.2.1.4. QA/QC and Verification

General QA/QC procedures outlined in section 1.4 of Chapter 1 apply to this category, along with specific checks described in section 6.9 (Forest Conversion), and section 6.7.1 (Wetlands Remaining Wetlands). Cross-checks include verifying land-use change data for consistency with national forest and wetland inventories and ensuring spatial alignment with geospatial datasets. Additional QA/QC and Verification can be found in section 6.7.1.1.4. Assumptions and emission factors are documented in section A3.5.6.1 and Table A6.5–8.

6.7.2.1.5. Recalculations

Minor revisions were made to activity data in 2023 from updated peat production statistics. These recalculations decreased Forest Land Converted to Peat Extraction emissions by <1 kt in 1990 and 2005, and 1.4 kt in 2023.

6.7.2.1.6. Planned Improvements

Future work will focus on implementing improvements described in section 6.9 (Forest Conversion).

6.7.2.2. Forest Land Converted to Flooded Land (CRT Category 4.D.2.b.i)

6.7.2.2.1. Category Description

Forest Land Converted to Flooded Land refers to areas where forest ecosystems have been permanently inundated due to the creation of reservoirs for hydroelectric power, flood control, irrigation, or water supply. This conversion typically involves the removal of forest vegetation followed by flooding, leading to significant changes in carbon dynamics, primarily from the decomposition of submerged biomass and soil organic matter. In Canada, most conversions occurred during the mid-20th century as part of large-scale hydroelectric development projects. These areas are reported under this category for the first 20 years following flooding, reflecting the initial period of elevated greenhouse gas emissions from decomposing organic material. Emissions are dominated by CO_2 and CH_4 released from submerged biomass and soils, with the highest fluxes occurring shortly after inundation and gradually declining as decomposition stabilizes. Emissions for Forest Land Converted to Flooded Land were 2.7 Mt in 1990, 2.7 Mt in 2005 and 2.0 Mt in 2024.

6.7.2.2.2. Methodological Issues

For Flooded Lands, Canada applies two distinct methodologies. When forest clearing occurs prior to flooding, carbon stock changes in non-flooded pools are estimated using the CBM-CFS3 model, consistent with other forest conversion events. Emissions from burning non-flooded biomass debris are reported in CRT Table 4(V), while emissions from the decay of remaining residues are reported in CRT Table 4.D for up to 20 years after clearing. After this period, emissions transition to the Flooded Land Remaining Flooded Land subcategory.

When standing forests are flooded without prior clearing, emissions from reservoir surfaces and other constructed waterbodies are estimated using a country-specific Tier 2 approach based on measured CO_2 fluxes (see section A3.5.6.2), rather than the default assumption in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) that all biomass carbon is immediately oxidized. This approach reflects the slower decomposition of trees and soils under anaerobic conditions observed in practice. Canada's methodology distinguishes emissions from forest clearing, which are estimated in the same way as other forest conversion activities, from emissions from flooded standing forest, which are separately accounted for through measured fluxes.

Emissions are reported in CRT Table 4.D for 20 years after flooding to avoid double counting dissolved organic carbon losses (see section 6.7.1.2.2). Time since conversion is tracked so that emissions are reported under Land Converted to Wetlands for the first 20 years post-flooding, and under Wetlands Remaining Wetlands thereafter, consistent with IPCC (2006) guidance on category reporting.

6.7.2.2.3. Uncertainty Assessment and Time-Series Consistency

For the uncertainty associated to the Forest Land Converted to Flooded Land, refer to section 6.9 on Forest Conversion. Further details on the uncertainty associated with the Tier 2 estimation methodologies are provided in sections 6.7.1.2.3 and A3.5.6.2.

6.7.2.2.4. QA/QC and Verification

General QA/QC procedures outlined in section 1.4 of Chapter 1 apply to this category, along with specific checks described in section 6.9 (Forest Conversion), and in section 6.7.1.2.4. Cross-checks include verifying land-use change data for consistency with national forest and wetland inventories and ensuring spatial alignment with geospatial datasets. Assumptions and emission factors are documented in section A3.5.6.2 and Table A6.5–9.

6.7.2.2.5. Recalculations

Recalculations in this category reflect updated activity data and the implementation of an enhanced flooded land emission model that incorporates Canada-specific emission factors derived from the G-res modeling framework (see section 6.7.1.2.5). Methodological changes are outlined in section A3.5.6.2. Additional recalculations were also applied to the forest conversion category (see section 6.7) to account for revisions related to forest clearing.

These improvements resulted in an upward recalculation in Forest Land Converted to Flooded Land emissions of 100 kt in 1990, 0.1 kt in 2005, and 290 kt in 2023.

6.7.2.2.6. Planned Improvements

Future work will focus on implementing the improvements outlined in section 6.9 (Forest Conversion). Planned updates for emissions from flooded standing forest include updated emission factors and activity data, as detailed in Chapter 8 (Table 8–5).

6.7.2.3. Other Land Converted to Peat Extraction (CRT Category 4.D.2.a.v)

6.7.2.3.1. Category Description

This subcategory includes conversions from Other Land (e.g., non-forest, non-agricultural areas) to Wetlands for peat extraction activities. Associated emissions and removals account for biomass losses at the time of conversion, changes in soil carbon stocks on organic substrates, and methane (CH_4) emissions where applicable, in accordance with IPCC guidance for peatland management (IPCC, 2006).

6.7.2.3.2. Methodological Issues

Conversions are reconciled with the 18-zone spatial framework to avoid double-counting across land categories and to ensure consistent treatment of disturbances and management overlays. Emissions and carbon stock changes from these conversions follow consistent methodological principles, with activity-specific methods applied for the Peat Extraction category.

When other land is cleared and converted to peat extraction, changes in soil carbon stocks are assessed in the newly established extraction fields, accounting for the impacts of biomass removal and drainage. Additional methodological issues can be found in section 6.7.1.1.2.

6.7.2.3.3. Uncertainty Assessment and Time-Series Consistency

Further details on the uncertainty associated with the Tier 2 estimation methodologies are provided in Annex 3.5 section A3.5.6.2 and section 6.7.1.1.3 in this Chapter.

6.7.2.3.4. QA/QC and Verification

General QA/QC procedures outlined in section 1.4 of Chapter 1 apply to this category. Cross-checks include verifying land-use change data for consistency with national forest and wetland inventories and ensuring spatial alignment with geospatial datasets. Additional QA/QC and verification can be found in section 6.7.1.1.4. Assumptions and emission factors are documented in section A3.5.6.1.

6.7.2.3.5. Recalculations

Minor revisions were made to activity data in 2023 from updated peat production statistics. These recalculations increased Other Land Converted to Peat Extraction emissions by <1 kt in 1990 and 2005, and 7.3 kt in 2023.

6.7.2.3.6. Planned Improvements

Future work will focus on implementing improvements described in section 6.7.1.1.6.

6.7.2.4. Other Land Converted to Flooded Land (CRT Category 4.D.2.b.v)

6.7.2.4.1. Category Description

This subcategory refers to areas where non-forest, non-agricultural lands have been permanently inundated due to the creation of reservoirs for hydroelectric power, flood control, irrigation, or water supply. These conversions typically involve flooding of previously unmanaged or sparsely vegetated land, resulting in changes to carbon dynamics, including decomposition of any existing biomass and soil organic matter. In Canada, the vast majority of these flooded lands were created during the mid-20th century as part of large-scale hydroelectric development projects. Emissions during the first 20 years following flooding are reported under this category, reflecting the initial period of elevated greenhouse gas emissions from decomposing organic material. Emissions are primarily CO_2 and CH_4 released from soils and any residual biomass, with fluxes highest shortly after inundation and declining over time as decomposition stabilizes.

6.7.2.4.2. Methodological Issues

When non-forest land is flooded, Canada does not assume immediate oxidation of organic carbon. Instead, emissions from reservoir surfaces are estimated using a country-specific Tier 2 approach based on measured CO_2 fluxes (see section A3.5.6.2), replacing the IPCC default assumption of instant carbon oxidation at the time of flooding (IPCC, 2006). This approach reflects the slower decomposition of organic matter under anaerobic conditions observed in practice. Emissions are reported in CRT Table 4.D for 20 years after flooding to avoid double counting dissolved organic carbon losses. Additional methodological details are provided in section 6.7.1.2.2.

Time since conversion is tracked so that emissions are reported under Land Converted to Wetlands for the first 20 years post-flooding, and under Wetlands Remaining Wetlands thereafter. Canada's methodology improves representation of carbon dynamics compared to the 2006 IPCC Guidelines default (IPCC, 2006), which assumes all organic carbon is emitted immediately after flooding.

6.7.2.4.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty assessment for this category follows the same approach as described in section 6.7.1.1.3, using the standard error propagation method outlined in section A3.5.6.2. Uncertainty is primarily driven by the use of proxy emission factors for some reservoirs and variability in seasonal water extents. Overall uncertainty for this subcategory ranges between ±15% in 1990 and ±23% in 2024.

6.7.2.4.4. QA/QC and Verification

QA/QC procedures for this category follow the same approach as described for Wetlands Remaining Wetlands and outlined in section 6.7.1.1.4. This includes internal consistency checks, spatial reconciliation with other land-use categories, and documentation of assumptions and methodologies in the Annexes. General QA/QC procedures in section 1.4 of Chapter 1 also apply.

6.7.2.4.5. Recalculations

Recalculations in this category reflect updated activity data and the implementation of an enhanced flooded land emission model that incorporates Canada-specific emission factors derived from the G-res modeling framework (see section 6.7.1.2.5). Methodological changes are outlined in section A3.5.6.2. The improvements resulted in an upward recalculations of emissions by 1.8 Mt in 1990, 0.15 Mt in 2005, and 0.20 Mt in 2023 for Other Land Converted to Flooded Land.

6.7.2.4.6. Planned Improvements

Planned work for resource extraction will include accounting for CH_4 emissions from saturated wetland soils and integrating forested wetlands by refining deforestation estimates, which currently classify forested wetlands as upland. Continuous improvements will focus on the development of knowledge and updated activity data, particularly on the extent of wetland and forested wetland classification. Future work will aim to develop estimates for reclaimed and restored sites, as well as to expand the methodology beyond the Alberta oil sands region to cover industrial disturbances to wetlands nationally.

More details are provided in Chapter 8, Table 8–5.

6.8. Settlements (CRT Category 4.E)

The Settlements category is diverse and includes all roads and transportation infrastructure; rights-of-way for power transmission and pipeline corridors; residential, recreational, commercial and industrial land in urban and rural settings; and land used for non-renewable resource extraction (e.g., oil and gas, mining).

For this inventory, the Settlements category is divided into the Settlements Remaining Settlements (urban trees and resource extraction) and Land Converted to Settlements subcategories. Estimates involve several types of land conversion reported in different subcategories: forest land (Forest Land Converted to Settlements), non-forest land in the Canadian North (Grassland Converted to Settlements), and wetlands in the Oil Sands Region of Alberta (Wetlands to Settlements). In 2024, the 0.58 Mha of land in the Land Converted to Settlements subcategory accounted for emissions of 8.3 Mt while the growth of urban trees removed 4.0 Mt.

6.8.1. Settlements Remaining Settlements (CRT Category 4.E.1)

6.8.1.1. Category Description

This category includes carbon stock changes associated with urban tree biomass in Canada, and residual emissions remaining after the 20-year post-conversion period for wetlands converted to settlements because of resource extraction activities.

Urban Trees

Estimates of CO_2 removals due to tree growth in other Settlement subcategories outside of urban areas are not included. Total annual removals from urban trees were relatively stable throughout the time series, averaging 4.0 Mt per year. Estimates are reported for nine of the southernmost reporting zones, where major urban centres are located. The largest removals in 2024 occurred in the Mixedwood Plains (1.4 Mt) and Pacific Maritime (1.4 Mt) reporting zones, which together accounted for 72% of total removals. Firewood attributed to urban tree biomass, transferred to the HWP pool, and used for residential bioenergy accounted for 0.3 Mt per year of the total firewood emissions reported under the Harvested Wood Products category.

Resource Extraction

Residual emissions from wetland converted to settlements in Alberta's Oil Sands Region (see section 6.8.2.3) are relatively small but show an increasing trend over the time series, from negligible levels in 1990 (2 kt) to 94 kt in 2024.

6.8.1.2. Methodological Issues

Urban Trees

Removals of CO_2 by urban trees were estimated using a Tier 2A crown cover area method from the 2006 IPCC Guidelines (IPCC, 2006). Urban tree crown (UTC) cover estimates for 1990 and 2012 were developed for a significant portion of the total urban area using a point-based sampling approach. Sample points were interpreted manually, from digital aerial photos or high-resolution satellite imagery, and classified in two broad categories: tree crown or non-tree crown. The total crown cover area was then estimated using the UTC and total urban area estimates for each time period. The estimated total crown cover area was then multiplied by a crown cover area-based growth rate (CRW, as defined in Chapter 8, Volume 4 of IPCC 2006) specific to each RU to yield an annual gross sequestration rate; net sequestration was estimated by applying a factor to the gross value. The values of C storage and sequestration in urban trees for 18 RUs (see Table A6.5–11) were derived as described in Steenberg et al. (2023). Growth and sequestration rates were applied to the 18 RUs confirming that estimates of UTC cover area and the sequestration rate are the main drivers of overall removal estimates. A more detailed description of this estimation methodology can be found in section A3.5.7.1.

Resource Extraction

Activity data were derived from the Human Footprint Inventory (HFI; 2022 version) developed by the Alberta Biodiversity Monitoring Institute (ABMI, 2025). To ensure spatial consistency and avoid double-counting, forested wetlands are excluded from this analysis using the SCANFI canopy-cover mapping to delineate forest extent (Guidon et al., 2024).

This methodology uses Tier 2 factors (Table A6.5–10) developed from the Canadian Model for Peatlands (CaMP; Bona et al. 2020) to estimate residual emissions from peatlands affected by resource extraction in the Oil Sands Region. Time since conversion is tracked so that emissions are reported under Wetland Converted to Settlement for the first 20 years post-disturbance, and under Settlement Remaining Settlement thereafter. See section 6.8.2.1.1 for more details.

6.8.1.3. Uncertainty Assessment and Time-Series Consistency

Urban Trees

The uncertainty surrounding the UTC estimates was assessed based on the standard error associated with the sampling approach (0.2% for the national UTC estimate). Standard errors for the UTC estimates were low, given the very large number of sampling points used. The uncertainty associated with the total urban area was estimated to be 15% in 1990 and 10% in 2012. The uncertainty surrounding national-scale gross C sequestration (33%) was estimated using a Monte Carlo analysis for each RU based on the urban tree data collected in the field in Canada. The total uncertainty associated with the estimates of the net CO_2 sequestration of urban trees is 38% for 1990 and 2012. Section A3.5.7.1 provides more information. The same methodology and coefficients were used for the entire time series of emission estimates.

Resource Extraction

The uncertainty for the residual emissions from resource extraction in Alberta's Oil Sands Region was estimated using the simplified Monte Carlo analysis described in section A3.5.6.3. For this subcategory, the uncertainty ranges between 55% to 91%, depending on the year, driven mainly by variation in the estimated wetland extent given that different regional wetland map products vary widely.

6.8.1.4. QA/QC and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures implemented in Canada's GHG inventory, which also apply to this category.

Urban Trees

For urban trees, estimates of the regional UTC values used were compared with the published UTC values for Canadian cities estimated from point-based sampling. In most cases, the UTC estimates corresponded closely to the published values, with an overall coefficient of determination (R2) of 0.90 derived from the linear regression analysis. In addition, at a national scale, UTC estimates were compared to those derived using a potential natural vegetation approach (IPCC, 2006) and, when weighted based on urban area, were within 2%.

Resource Extraction

For Resource Extraction, QC activities include review of modelling assumptions, emission factors, and spatial activity data representing industrial disturbances. Expert consultations were conducted (see section A3.5.6.3), and NRCan and Alberta provincial geospatial and wetland experts participated in refining assumptions, selecting appropriate datasets, and integrating feedback. The methodology was also presented at national scientific conferences to obtain external input.

6.8.1.5. Recalculations

Urban Trees

No recalculations occurred for this category for the current inventory edition.

Resource Extraction

Minor recalculations occurred due to the inclusion of resource extraction estimates. These changes resulted in an upward recalculation of emissions by 2 kt in 1990, 36 kt in 2005, and 84 kt in 2023.

6.8.1.6. Planned Improvements

Urban Trees

For urban trees, further work will be undertaken to update the methodology, activity data estimates, and the coefficients used to estimate gross and net removals. Planned updates include the sampling of digital aerial photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas are planned around the 2005, 2015 and 2020.

Resource Extraction

Planned work for resource extraction will include accounting for CH_4 emissions from saturated wetland soils and integrating forested wetlands into the wetland disturbance area by identifying the quantity of current deforestation activity, which misclassify forested wetlands as upland forest. Continuous improvements will focus on the development of knowledge and updated activity data, particularly on the extent of wetland and forested wetland classification. Future work will aim to develop estimates for reclaimed and restored sites, as well as to expand the methodology beyond the Alberta oil sands region to cover industrial disturbances to wetlands nationally.

More details are provided in Chapter 8, Table 8–5.

6.8.2. Land Converted to Settlements (CRT Category 4.E.2)

In 2024, emissions in the Land Converted to Settlements subcategory totalled 8.3 Mt. While several land categories, including forest land, could potentially be converted to settlements, the current data available are insufficient to quantify the areas of, or associated emissions from, all types of land-use change. Significant efforts have been invested in quantifying the areas converted from forest to settlements, as this was the leading forest conversion from 1998 until 2016. On average, from 1990 to 2024, a total of 21 kha of forest land was converted annually to settlements, predominantly in the Boreal Plains, Boreal Shield East, Atlantic Maritime, Mixedwood Plains, and Montane Cordillera reporting zones. Forest land conversion accounts for nearly 95% of emissions reported in this category. A consistent methodology was developed for all forest conversion and is outlined in section 6.9 and section A3.5.2.7.

The remainder of this section covers the conversion of non-forest land to settlements, which includes land-use changes in the Canadian North reported under the Grassland Converted to Settlements subcategory, land conversion in the agricultural regions of Canada reported under the Cropland Converted to Settlements subcategory, and land conversion associated with resource extraction in the Alberta's Oil Sands Region reported mainly under the Wetlands Converted to Settlements subcategory with some residual emissions also reported in Settlements Remaining Settlements subcategory as well. In 2024, non-forest land conversion accounts for 5% of emissions reported in this category.

6.8.2.1. Cropland Converted to Settlements (CRT Category 4.E.2.2)

6.8.2.1.1. Category Description

Urban and industrial expansion for resource extraction purposes has been the main driver of the conversion of cropland to settlements in Canada. On average, from 1990 to 2000 and 2000 to 2010, 18 kha and 11 kha of cropland were converted annually to settlements, predominantly in the Mixedwood Plains, Subhumid Prairies, and Atlantic Maritime reporting zones. Emissions are not estimated at this point but are part of the improvement plans for this category.

6.8.2.1.2. Methodological Issues

Areas of cropland converted to settlements were estimated from land-use maps from 1990, 2000 and 2010 by Huffman et al. (2015b) using the methods described in section A3.5.7.2. Annual conversion rates were estimated by calculating the total areas of land converted between these three years and dividing them by the time range, assuming a constant conversion rate from year to year. Annual conversion rates were extrapolated using a constant conversion rate after 2010.

6.8.2.1.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty surrounding the area of land-use changes was quantified using 457 points in five main census metropolitan areas (CMAs) (i.e., Toronto, Hamilton, Oshawa, Montreal and Edmonton), which account for over 45% of the total conversion area. The overall accuracy in detecting areas of true change was above 80% and concurs with the values found by Huffman et al. (2015b) on the accuracy of each individual land-use map.

6.8.2.1.4. QA/QC and Verification

Polygons from the 2011 census were used to define the boundary of each CMA, and Landsat imagery from the Global Land Survey data (provided with ArcGIS Online) was obtained for each area for 1990, 2000 and 2010.[16] Over 200 points were used to verify land cover / land-use change for each time period, using visual interpretation. The points were defined using stratified random sampling, with 50% of points in areas with a change from cropland to settlements and 50% in areas with no changes, separated by a minimum distance of 1 km, to avoid statistical bias.

6.8.2.1.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

16 Landsat Time Enabled Imagery – Canada: https://hub.arcgis.com/maps/9a239fbe2952436a80d3cff95cab34bc/about

6.8.2.1.6. Planned Improvements

Future efforts to develop estimates for this category will focus on estimating emissions and removals associated with the areas of change.

More details are provided in Chapter 8, Table 8–5.

6.8.2.2. Grassland Converted to Settlements (CRT Category 4.E.2.c)

6.8.2.2.1. Category Description

This specific methodology does not refer to traditional grasslands occurring on the Prairies or Montane Cordillera reporting zones, but instead refers to land-use change that is occurring on the Taiga and Tundra, north of the unmanaged forest regions of Canada. Resource development is the dominant driver of land-use change in Canada's Arctic and subarctic regions. In 2024, the conversion of grassland to settlements in the Canadian North accounted for emissions of 140 kt, up from 125 kt in 1990. The major source of emissions in this category over the time series is the conversion of grassland to settlements in the Taiga Shield East, Taiga Plains and Boreal Cordillera zones (reporting zones 4, 13 and 16).

6.8.2.2.2. Methodological Issues

An accurate estimation of direct human impacts in Northern Canada requires that activities be geographically located and that the vegetation present prior to conversion is known—a significant challenge, considering that the area of interest extends over 560 Mha and intersects with 11 reporting zones (1, 2, 3, 4, 5, 8, 10, 13, 16, 17 and 18) (see Figure 6–1). Land-use change areas were estimated using mapping derived from image interpretation for the years 1990, 2000, 2010, and 2020, as described in section A3.5.7.3.

Biomass carbon stocks were obtained from expert consultations held from 2020 to 2021 and are based on primary literature including field sampling and remote sensing, as well as expert understanding of the relationship between climate and plant productivity in northern environments, as described in section A3.5.7.3. Emission estimates are limited to C stock changes in pre-conversion above-ground biomass and below-ground biomass.

Due to the complex interactions between development practices and permafrost, it is not currently possible to accurately quantify emissions from soil disturbance in this region. Expert consultations (Lapointe E., 2022) determined that additional research was required to provide measurements of emissions and removals associated with the diverse practices that occur when development occurs in Canada's north that can then inform methodological development.

6.8.2.2.3. Uncertainty Assessment and Time-Series Consistency

An error propagation approach described in section A3.5.7.3 was used to estimate uncertainty for this category. The uncertainty estimate for this category ranges between 15% to 66% for the different reporting zones, due to the variability of vegetation over this vast area and the allocation of widths assigned to human disturbances mapped as linear features in the activity data.

6.8.2.2.4. QA/QC and Verification

Section 1.4 of Chapter 1 describes the general QA/QC procedures implemented in Canada's GHG inventory, which also apply to this category.

6.8.2.2.5. Recalculations

No recalculations occurred for this category for the current inventory edition.

6.8.2.2.6. Planned Improvements

Future efforts to improve estimates in this category will focus on compiling Canadian science to estimate emissions from the soil pool, as well as improving estimates for biomass where regrowth might occur following the initial disturbance.

More details are provided in Chapter 8, Table 8–5.

6.8.2.3. Wetlands Converted to Settlements (CRT Category 4.E.2.d) – Resource Extraction

6.8.2.3.1. Category Description

This subcategory includes approximately 21 thousand hectares of non-forested Wetlands that have been converted to Settlements by resource extraction activities in Alberta's Oil Sands Region. Relevant activities include open surface mines, in situ wells, and associated infrastructure such as pipelines, access roads, and tailing ponds.

Residual emissions are tracked under this subcategory for the first 20 years following the conversion. After 20 years, the land and residual emissions transition to the Settlements Remaining Settlements category (see section 6.8.1 for greater detail). Emissions in this category have been steadily increasing from 65 kt in 1990 to 310 kt in 2024, peaking in 2020 at 375 kt.

An additional 10 thousand hectares consists of peatlands disturbed by oil and gas exploration activities (e.g., seismic lines). However, as these areas continue to function as a wetland, they remain within the Wetlands category and are reported under Other Wetlands Remaining Other Wetlands (see section 6.7.1), rather than being classified as a conversion to Settlements.

6.8.2.3.2. Methodological Issues

Activity data for resource extraction in Alberta's Oil Sands Region are compiled using the Human Footprint Inventory (HFI; ABMI, 2022 version) and the Alberta Merged Wetland Inventory (AMWI; Government of Alberta, 2025) to identify impacted wetland areas. Time since conversion is tracked so that emissions are reported under Wetland Converted to Settlement for the first 20 years post-disturbance, and under Settlement Remaining Settlement thereafter (see section 6.8.1.1). To ensure spatial consistency and avoid double-counting, forested wetlands are excluded from this analysis using the SCANFI canopy-cover mapping to delineate forest extent (Guindon et al., 2024). For more detail, refer to section A3.5.6.3.

Estimates for this category were developed using a Tier 2 approach. As outlined in section 6.7.1.3.2, emission factors were derived from the Canadian Model for Peatlands (CaMP; Bona et al., 2020), a Tier 3 modeling framework that tracks carbon growth, turnover, and decay across vegetation, litter, and organic soil layers. By applying disturbance matrices parameterized with regional empirical data, the CaMP simulated the fate of carbon pools for oil and gas extraction and exploration activities.

Because the CaMP outputs summarize total net ecosystem exchange, results from the model are not partitioned into separate carbon pools (i.e., biomass, DOM, soil). Instead, all stock changes are reported in the organic soil pool in CRT Table 4.E and in CRT Table 4.D reflecting that the majority of emissions results from the disturbance of the peat layer. An exception to this reporting logic is the historical practice of burning biomass (e.g., peat piles, woody biomass) which are reported separately in CRT Table 4(IV).

6.8.2.3.3. Uncertainty Assessment and Time-Series Consistency

A simplified Monte Carlo analysis, described in section A3.5.6.3, was used to estimate uncertainty for this category. Estimated uncertainties range from 55% to 67% for CO_2, 40% to 97% for CH_4 and 0% to 93% for N_2O, depending on the year. These high uncertainties are primarily driven by variation in the estimated wetland extent, as different regional wetland map products vary widely.

6.8.2.3.4. QA/QC and Verification

Section 1.4 of Chapter 1 describes the general QA/QC procedures implemented in Canada's GHG inventory, which also apply to this category.

QA/QC activities include review of modelling assumptions, emission factors, and spatial activity data representing industrial disturbances. Expert consultations were conducted (see section A3.5.6.3), and NRCan and Alberta provincial geospatial and wetland experts participated in refining assumptions, identifying authoritative datasets, and integrating feedback. The methodology was also presented at national scientific conferences to obtain external input.

6.8.2.3.5. Recalculations

Recalculations were due to the introduction of a methodology to estimate emissions associated with resource extraction leading to the conversion of Wetlands to Settlements. As a result, emissions were revised upward by 65 kt in 1990, 180 kt in 2005, and 330 kt in 2023.

6.8.2.3.6. Planned Improvements

Planned work for resource extraction will include accounting for CH_4 emissions from saturated wetland soils and integrating forested wetlands by refining deforestation estimates, which currently classify forested wetlands as upland. Continuous improvements will focus on the development of knowledge and updated activity data, particularly on the extent of wetland and forested wetland classification. Future work will aim to develop estimates for reclaimed and restored sites, as well as to expand the methodology beyond the Alberta oil sands region to cover industrial disturbances to wetlands nationally.

More details are provided in Chapter 8, Table 8–5.

6.9. Forest Conversion

6.9.1. Category Description

Forest conversion is not a reporting category, since it overlaps with the Cropland Remaining Cropland, Land Converted to Cropland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Land Converted to Settlements and Harvested Wood Products categories. This section will briefly discuss the methodological issues specific to this type of land-use change and outline the general approach taken in estimating its extent, location and impact. A consistent approach was used for all types of forest conversion, minimizing omissions and overlaps, while maintaining spatial consistency as much as possible.

In 2024, the conversion of forest land to other land uses, specifically cropland, wetlands (peat extraction, and flooded lands [reservoirs]), and settlements, resulted in combined immediate and residual emissions of 19 Mt, down from 27 Mt in 1990. This decline was driven by a 5.2 Mt decrease in immediate and residual emissions from forest conversion to cropland, a 2.5 Mt decrease in emissions from forest conversion to wetlands (reservoirs), and a decrease of 0.78 Mt in immediate and residual emissions from forest conversion to settlements. Note that these values include residual emissions for historical conversions that have transitioned to the "land remaining" categories (e.g., Cropland Remaining Cropland and Wetlands Remaining Wetlands categories) after the 20-year threshold.

Additionally, there are Carbon transfers associated with HWP originating from forest conversion activities since 1990. While total transfers are reported in the respective source categories, the net change in carbon storage is reported in the HWP category as a net storage of CO_2 in CRT Table 4.G. These transfers amounted to the net annual increase in the carbon stored in HWP of 0.9 Mt in 2024, down from 3.9 Mt in 1990 (see section 6.4).

Care should be taken in distinguishing annual forest conversion rates (64 kha in 1990 and 54 kha in 2024) from the total area of forest land converted to other land uses, as reported in the CRT tables for each inventory year. The values in the CRT tables encompass all forest land conversion for 20 years, including the current inventory year, and are therefore significantly higher than the annual rates of forest conversion to other land uses.

It is also important to note that the immediate emissions from forest conversion, which occur at the time of the conversion event, are a fraction of the total emissions produced from current and previous forest conversion activities reported in any inventory year. In 2024, immediate emissions (7.3 Mt) represented 39% of the total reported land emissions due to forest conversion events; the balance is accounted for by residual emissions due to prior events. Decay rates for DOM are such that residual emissions continue beyond 20 years, after which they are reported as part of the C stock changes in the Cropland Remaining Cropland and Wetlands Remaining Wetlands categories.

The primary drivers of forest conversion are agricultural expansion and resource extraction, accounting for 44% and 27% of the cumulative area of forest converted since 1990, respectively. While annual rates of forest conversion to cropland decreased steadily from 42 kha to 12 kha in 1990 and 2010, this trend has since reversed. Annual conversion rates have gradually increased to approximately 30 kha since 2020 —reaching the levels observed in the 1990s—primarily driven by agricultural expansion in the Boreal Plains, Sub-humid Prairies and Mixedwood Plains zones (Figure 6–8).

As this trend continues, agricultural expansion is accounting for a greater proportion of forest conversion emissions in Canada. In 2024, agricultural expansion was responsible for approximately 55% of the total land area converted annually, demonstrating the impact of agricultural expansion on this category in recent years.

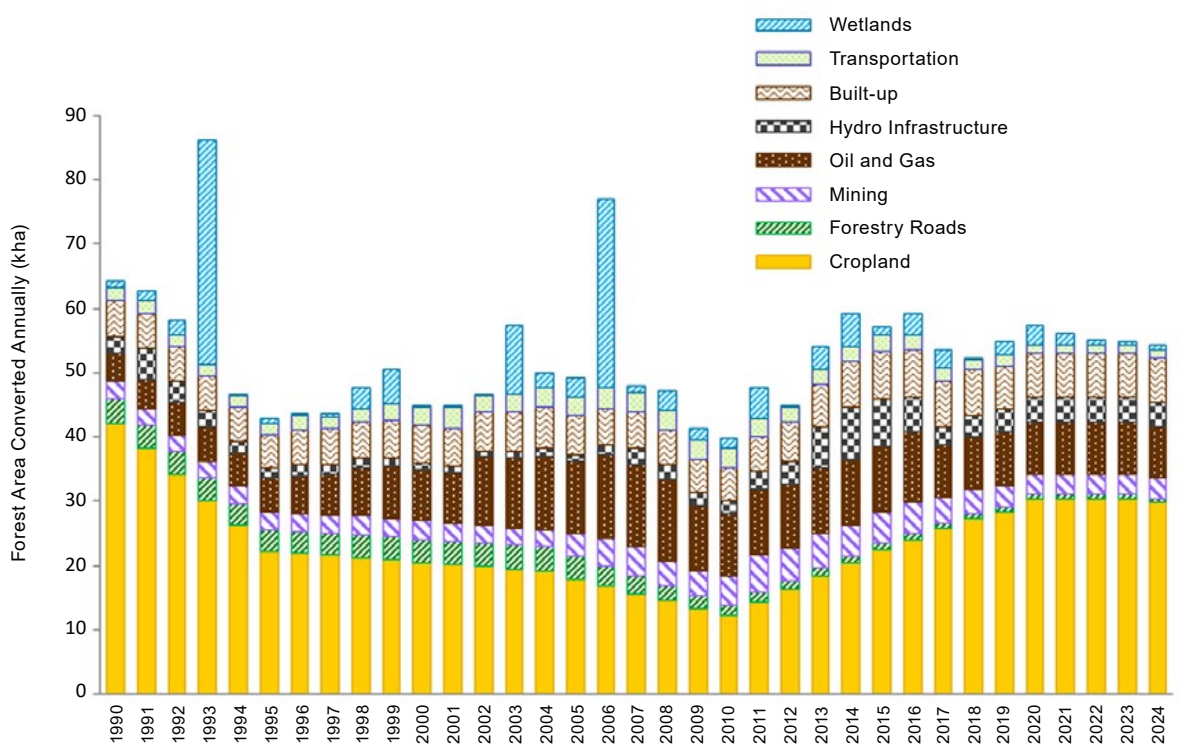
Annual rates of conversion of forest land to settlements – which include forestry roads, mining, oil and gas, hydro infrastructure, transportation, and built-up lands, including urban expansion – fluctuated significantly over the reporting period. From 21 kha in 1990, rates peaked at 31 kha in 2007 and 34 kha in 2014, before falling back to 24 kha in 2024 (Figure 6–8).

Between 1998 and 2016, the conversion of land to settlements was the primary driver of forest conversion in Canada, accounting on average for 56% of the total area converted annually. This pattern reflects trends in resource development (e.g., forestry roads, hydro infrastructure, mining, oil and gas, and transportation), especially in the Boreal Plains region, which reached an annual peak rate of 15 kha in the years 2006, 2007 and 2008. Forest conversion for resource development in this region has decreased since then but still contributes to 22% of the total forest area lost nationally in 2024.

The occasional impoundment of large reservoirs (e.g., La Forge 1 in 1993 and Eastmain 1 in 2006) represent episodic significant forest conversion events (Figure 6–8). For example, in 1993 the greatest areas of forest conversion were attributed to the Wetlands category. However, because much of the pre-conversion C stocks are flooded rather than cleared or burned, these episodic events may not release commensurate quantities of greenhouse gases.

Forest conversion affects both managed and unmanaged forests. Losses of unmanaged forests occur mainly in reporting zones 4 (Taiga Shield East) and 5 (Boreal Shield East) and are caused mostly by reservoir impoundment. They also occur to a lesser extent in reporting zones 9 (Boreal Shield West) and 8 (Hudson Plains).

Figure 6–8 **Annual Area of Forest Converted by End Land Use**



6.9.2. Methodological Issues

The conversion of forest to other land categories has occurred at high rates in the past and is still a prevalent practice in Canada. It is driven by a variety of circumstances across the country, including policy and regulatory frameworks, market forces and resource endowment. The economic activities causing forest losses are diverse and result in heterogeneous spatial and temporal patterns of forest conversion, which have been systematically documented in recent decades. The challenge has been to develop an approach that incorporates a variety of information sources to capture the various forest conversion patterns across the Canadian landscape, while maintaining a consistent approach to minimize omissions and overlap.

The approach adopted for estimating forest areas converted to other uses is based on three main information sources: (i) systematic or representative sampling of remote sensing imagery; (ii) records; and (iii) expert judgment (Dyk et al., 2011, 2015). The core method involves mapping forest conversion by sampling remotely sensed Landsat images from circa 1975, 1990, 2000, 2008, 2013, 2018 and 2023, defining time periods as 1975 to 1990, 1990 to 2000, 2000 to 2008, 2008 to 2013, 2013 to 2018, and 2018 to 2023. For implementation purposes, all permanent forest removal wider than 20 m from tree base to tree base and at least 1 ha in area was considered forest conversion. This convention was adopted as a guide to consistently label linear patterns in the landscape. The other main information sources consisted of databases or other documentation on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs. When the remote sensing sample was insufficient, expert opinion was called upon to resolve differences between records and remote sensing information and apparent discrepancies in area estimates. A more detailed description of the approach and data sources used is provided in section A3.5.2.7.

All estimates of emissions from biomass and DOM pools due to forest conversion were generated using the CBM-CFS3 model (see section 6.3.1.2), except when forests were flooded without prior clearing or were cleared for peat extraction (see section 6.7 and section A3.5.6). Emissions from the soil pool were estimated using different modelling frameworks, except for the Land Converted to Settlements subcategory, for which CBM-CFS3 decay rates were used. Consequently, methods are generally consistent with those used in the Forest Land Remaining Forest Land subcategory. Section A3.5.2.1 summarizes the estimation procedures.

6.9.3. Uncertainty Assessment and Time-Series Consistency

The estimate of the total forest area converted annually in Canada is associated with an overall uncertainty estimate of ±30% (Leckie, 2011), with the 95% confidence interval for the true value of this annual area between 45 kha and 83 kha in 1990, and between 38 kha and 71 kha in 2024. Care should be taken not to apply the 30% range to the cumulative area reported in the CRT tables for forest land converted to another land category over the last 20 years. Section A3.5.2.7 describes the main sources of uncertainty associated with the area estimates derived from remote sensing.

6.9.4. QA/QC and Verification

General QA/QC procedures are implemented in this category as outlined in section 1.4 of Chapter 1. In addition, detailed Tier 2 QA/QC procedures were carried out during estimate development, involving documented QC of imagery interpretation, field validation, cross-calculations, and the detailed examination of results (Dyk et al., 2011, 2015). The calculations, use of records data, and expert judgment are traceable through the compilation system and have been documented. More information is available in section A3.5.2.7.

Environment and Climate Change Canada, while maintaining its own QA/QC procedures for internally developed estimates (see section 1.3, Chapter 1), has implemented specific procedures for estimates obtained from its data partners, as well as for all estimates and activity data from the LULUCF data warehouse (Blondel, 2022) subsequently entered with CRT Reporter software.

6.9.5. Recalculations

Recalculations that occurred in the Forest Conversion resulted from three methodological changes this year: (i) the implementation of an improved set of dead organic matter (DOM) and soil carbon parameters in the CBM-CFS3 (see section 6.3), (ii) the completion of a new mapping period from 2018 to 2023, which revised forest conversion rates across the land use categories in recent years and; (iii) the implementation of an enhanced flooded land emission model and updated reservoir activity data. These changes resulted in upward revisions to the entire time series, with 2.5 Mt in 1990, 2.9 Mt in 2005, and 2.0 Mt in 2023 in key reporting years.

Recalculations in key reporting years resulted in revisions in carbon storage in HWP of +91 kt in 1990, -116 kt in 2005 and -212 kt in 2023.

6.9.6. Planned Improvements

The development of new mapping data, parameters and processes for forest conversion is part of the continuous improvements to the LULUCF estimates. In the long-term, improvements include the revision of the 1970 to 2010 deforestation activity data, which will lead to improved estimates for earlier time periods.

More details are provided in Chapter 8, section 8.3.1 and Table 8–5.

WASTE (CRT SECTOR 5)

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7.1. Overview

The Waste sector in Canada includes emissions from the treatment and disposal of wastes, including Landfills, Composting and Biological Treatment of Solid Waste, Incineration and Open Burning of Waste, and Wastewater Treatment and Discharge.

7.1.1. Emissions Summary

Greenhouse gas (GHG) sources included in the Waste sector are methane (CH_4) from Landfills; CH_4 and nitrous oxide (N_2O) from the Biological Treatment of Solid Waste; carbon dioxide (CO_2), CH_4 and N_2O from Incineration and Open Burning of Waste; and CO_2, CH_4 and N_2O from Wastewater Treatment and Discharge.

In 2024, greenhouse gas emissions from the Waste sector accounted for 22.5 Mt of total national emissions, compared with 23.5 Mt for 2005, a decrease of 0.96 Mt or 4.1% (Table 7–1). The emissions from this sector represented 3.5% of total Canadian GHG emissions in 1990, 3.1% in 2005 and 3.3% in 2024.

The primary contributor to the Waste sector emissions was Municipal Solid Waste Landfills, which in 2024 accounted for 18.4 Mt CO_2 eq or 82% of the Waste sector emissions (Table 7–1).

CO_2 emissions attributable to waste that is of non-fossil biological (biogenic) origin are included in the inventory as carbon stock exchanges in the Agriculture Forestry and Land Use Change (AFOLU) sector (IPCC 2006, Volume 5, Chapter 1). As such, CO_2 emissions originating from materials of biogenic origin are only reported in the Waste sector as a memo item. CH_4 emissions from waste products utilized for energy production (such as burning landfill gas or biogas for heat or electricity) are reported under the Energy sector of the inventory and are omitted from the Waste sector.

Table 7–1 **Overview of GHG Emissions from the Waste Sector, Selected Years**

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2005	2019	2020	2021	2022	2023	2024
Waste	**21 300**	**23 500**	**23 000**	**23 000**	**23 200**	**23 100**	**23 000**	**22 500**
Landfills (5.A)								
Municipal Solid Waste Landfills	18 100	19 600	18 900	19 000	19 200	19 100	18 900	18 400
Industrial Wood Waste Landfills	906	1 040	790	772	753	735	719	703
Biological Treatment of Solid Waste (5.B)	**149**	**328**	**505**	**511**	**604**	**605**	**605**	**609**
Incineration and Open Burning of Waste (5.C)	**290**	**349**	**173**	**158**	**150**	**170**	**160**	**147**
Wastewatter Treatment and Discharge (5.D)								
Municipal Wastewater Treatment and Discharge	1 430	1 740	2 180	2 200	2 180	2 260	2 320	2 390
Industrial Wastewater Treatment and Discharge	407	414	411	368	354	277	235	231

Note: Totals may not add up due to rounding.

There were methodological changes in the Landfills (5.A), Biological Treatment of Waste (CRT 5.B), Incineration and Open Burning of Waste (5.C) and Municipal Wastewater Treatment and Discharge (CRT 5.D) subsectors. The changes in GHG emissions resulting from method revisions and recalculations from updated activity data are provided in Table 7–2. Detailed descriptions of the method change and the activity data updates are provided in the recalculation section for each source category in this chapter and in Chapter 8.

Table 7–2 **Summary of Recalculations for the Waste Sector, Selected Years**

Sector		GHG Emissions (kt CO_2 eq)							
		1990	2005	2018	2019	2020	2021	2022	2023
Landfills (5.A)									
Previous Submission (2024 NIR)		19 100	20 800	20 100	20 200	19 700	19 600	19 700	19 700
Current Submission (2025 NIR)		19 000	20 700	19 700	19 700	19 800	19 900	19 800	19 600
Change in Emissions	(kt)	-126	-103	-373	-479	73	301	83	-56
	(%)	-1%	0%	-2%	-2%	0%	2%	0%	0%
Biological Treatment of Solid Waste (5.B)									
Previous Submission (2024 NIR)		81	243	376	379	384	504	504	503
Current Submission (2025 NIR)		149	328	500	505	511	604	605	605
Change in Emissions	(kt)	0.0	84.2	124.0	126.0	127.0	99.8	101.0	103.0
	(%)	0%	35%	33%	33%	33%	20%	20%	20%
Incineration and Open Burning of Waste (5.C)									
Previous Submission (2024 NIR)		262	345	170	169	154	145	166	156
Current Submission (2025 NIR)		290	349	175	173	158	150	170	160
Change in Emissions	(kt)	28.0	4.2	4.9	4.4	4.6	4.4	4.5	4.5
	(%)	11%	1%	3%	3%	3%	3%	3%	3%
Wastewater Treatment and Discharge (5.D)									
Previous Submission (2024 NIR)		1 900	2 220	2 690	2 650	2 630	2 600	2 600	2 630
Current Submission (2025 NIR)		1 830	2 150	2 630	2 590	2 570	2 530	2 530	2 560
Change in Emissions	(kt)	-67.5	-65.1	-60	-60	-65	-68	-69	-69
	(%)	-4%	-3%	-2%	-2%	-2%	-3%	-3%	-3%

Note: Totals may not add up due to rounding.

7.2. Municipal Solid Waste Landfills (CRT Category 5.A.1)

7.2.1. Category Description

The Landfills emissions category is comprised of Municipal Solid Waste (MSW) landfills and industrial wood waste landfills. MSW encompasses waste from the Residential sector, the Industrial, Commercial and Institutional (ICI) sector and the Construction and Demolition (C&D) sector, as well as landfilled sewage sludge. Most waste landfilled in Canada is part of the MSW category. By contrast, industrial wood waste (i.e., waste from sawmill operations, pulp and paper production and other forest industry processes) is often deposited in small landfills at or near the originating facility. Because of the unique waste composition (i.e., wood and wood industry residuals) and distinct locations and practices of wood waste landfills, emissions from industrial wood waste are reported as a separate category from MSW Landfills (section 7.3).

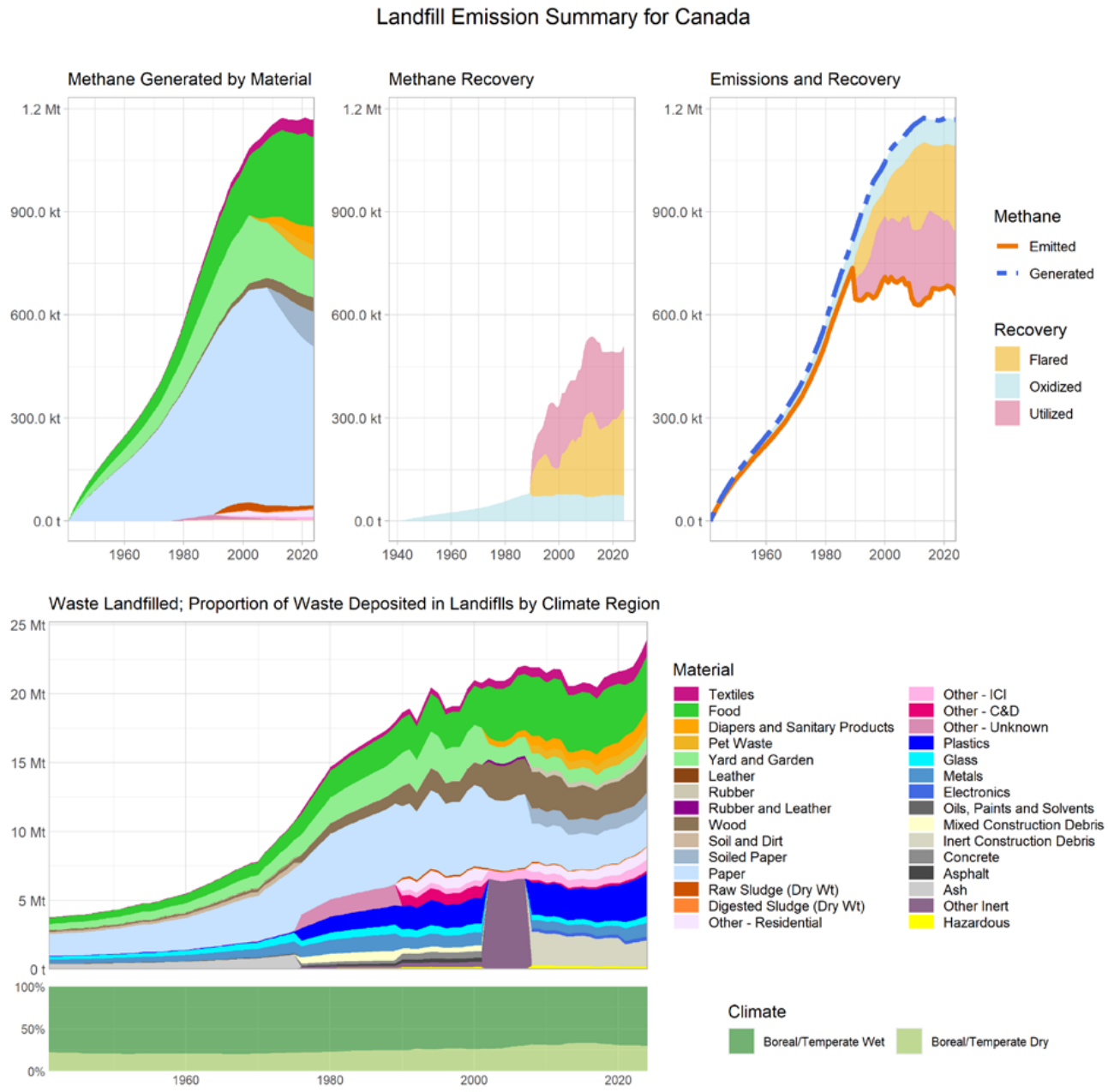
In Canada, most MSW disposal occurs in managed municipal landfills. Few, if any, unmanaged waste disposal sites exist in Canada. The disposal of MSW is regulated by provinces and territories but is typically managed by municipal or regional authorities. While regulations vary across the country, common regulatory requirements include use landfill cover and installation of landfill gas capture at larger sites. Furthermore, many provinces are implementing, or already have in place, specific waste reduction targets, such as organic bans on landfilled waste, or per capita waste generation goals.

MSW landfills are the dominant contributor of emissions from the Waste sector. This category accounts for approximately 82% of the Waste sector emissions (Table 7–1). Emissions from waste disposal are generated by the anaerobic decomposition of buried organic waste in the landfill. While CO_2 is also produced, it is of biogenic origin and is therefore not reported as part of the total emissions of the Waste sector. Emissions of N_2O are considered negligible.

The primary factors influencing emissions from MSW landfills include the amount of waste landfilled and methane recovery practices (Figure 7–1). Quantities of waste landfilled have steadily increased over time as a result of population growth and changes in per capita waste generation, from less than 5 Mt of waste landfilled per year before 1960 to approximately 20 Mt/year in 1990, and have remained relatively stable since the early 2000s at approximately 25 Mt/year. Methane recovery has

increased since the early 1990s, from approximately 130 kt CH_4 recovered (flared and utilized) in 1990 to approximately 330 kt CH_4 recovered in 2005, and has remained consistently around 450 kt CH_4/year recovered from 2010 onward. Waste composition is another factor influencing emissions, with changes in the overall composition of waste influencing the overall methane generation potential and decay rates. For example, the changing waste composition and contribution of each material type to methane generated in landfills can be seen in Figure 7–1.

Figure 7–1 **Municipal Solid Waste Landfilled, Methane Generated (by Source Material), Recovered and Emitted**



7.2.2. Methodological Issues

Landfill emissions in Canada are estimated using the first-order decay methodology from the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), with parameters from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019). The same methodology, but with different parameters, is used for MSW landfills and Industrial Wood Waste landfills (discussed in section 7.3.2). Emissions from landfills are modelled as one generic landfill for waste disposed in each climate zone (Boreal/Temperate Wet and Dry), for each Province and Territory.

Landfill gas, which is composed mainly of CH_4 and CO_2, is produced by the anaerobic decomposition of organic wastes. The decomposition process typically begins after waste has been in a landfill for 10 to 50 days. Although the majority of the CH_4 and CO_2 gases are generated within 20 years of landfilling, emissions can continue for 100 years or more (Levelton, 1991).

A consistent source of data on the amount of waste landfilled over time is not currently available. Instead, the total amount of waste disposed (landfilled, exported and incinerated) in each province forms the basis of the emission calculations. Data are available on the amount of waste exported and incinerated and so are used to derive the amount of waste landfilled.

Several factors contribute to the generation of gases within a landfill. The key factors are the degree to which a landfill is anaerobic, the waste composition (specifically, the carbon content and degradability) and the moisture (which is the primary factor limiting decay rates). While there are several other factors affecting CH_4 generation in landfills, such as pH and nutrient availability, they are not considered to be as important as moisture and waste composition and are not represented in the IPCC first order decay model.

Not all CH_4 generated within a landfill will be released into the atmosphere. From the CH_4 generated in a landfill, some may be captured through landfill gas capture technology, and some may be oxidized in landfill covers. Landfill gas capture on managed landfill sites is an increasingly popular activity in Canada. CH_4 from landfill gas can be used to generate electricity or heat or can be flared to reduce the GHG potential of emitted gases. Oxidation of CH_4 into CO_2 by methanotrophic bacteria in landfill covers is accounted for by applying an oxidation factor to the emissions estimated to be generated in the landfill, after landfill gas capture is accounted for. Every province/territory in Canada requires managed landfills of a certain size to have daily cover material in place to bury waste. There are also annual cover requirements, as well as more robust cover material for closed landfills.

7.2.3. Uncertainty Assessment and Time-Series Consistency

The level of uncertainty associated with CH_4 emissions from MSW Landfills was estimated to be ±76% for CH_4 based on defaults available in the IPCC 2006 Guidelines (IPCC, 2006).

Time-series consistency is ensured through the use of consistent methods and activity data (type and sources) for all inventory years. Where necessary, time-series gaps in activity data are imputed with interpolated or extrapolated values, with consideration taken for details such as start of facility operations, collection system installation dates are considered. See Annex 3.6 for further details of activity data preparation.

7.2.4. QA/QC and Verification

The annual quality control process involves verifying that all activity data and methodological updates have been incorporated into the model. Expected changes in emission estimates from individual methodological updates and regular data updates were compared against the total actual changes in emissions to verify that all recalculations have been incorporated correctly. Time-series trends of activity data and emission estimates were reviewed to identify any unexpected changes in emissions at the regional and national level. Standard quality assurance checks were completed, such as confirming that records for all years and regions had been included in final estimates and that national totals matched the sum of regional totals.

7.2.5. Recalculations

New landfill gas recovery data and landfill waste disposal data were acquired from a voluntary survey of landfill operators, conducted by Environment and Climate Change Canada (ECCC). The updated data replaces previously extrapolated values, and on occasion includes revisions to previously held landfill gas collection estimates and site-specific disposal data. The updates to methane recovery impact net emission estimates, which are calculated based on modelled methane production minus the total recovery by province and territory. The latest long-term climate data and site-specific disposal data were used to update estimates of proportions of waste landfilled by climate zone (wet, dry) for each province and territory, with notable changes for Ontario (from 7% dry climate to 3% dry climate) and Alberta (from 100% dry climate to 99% in dry climate). New waste characterization (composition) data and recompilation of recent (2016-present) composition have resulted in some updates to emissions in recent years.

7.2.6. Planned Improvements

Opportunities for incorporating more refined data on amounts and types of waste landfilled in provinces and territories are being investigated. Increased collaboration with provincial and other regional authorities may result in higher quality data that can be integrated directly into the waste model or used to verify current estimates. Work is underway to incorporate site-level estimates and emissions modelling.

7.3. Industrial Wood Waste Landfills (Included in CRT Category 5.A.1)

7.3.1. Category Description

Industrial Wood Waste Landfills are privately owned and operated to manage waste from the forest industry produced at sawmills and pulp and paper mills. These landfills are used to dispose of surplus wood residue, including sawdust, wood shavings, bark, ash and wastewater treatment residuals. Wood waste disposed of in Canada originates from two primary sources; the solid wood industry (e.g., sawmills) and the pulp and paper industry (e.g., paper manufacturing). Increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes has limited the quantities of solid wood waste being disposed in industrial wood waste landfills, as residual wood is being processed as a value-added product (e.g., wood pellets for residential and commercial pellet stoves and furnaces, and hardboard, fibreboard and particleboard).

Wood waste landfills typically incorporate grading, cover use and water management, and as such are considered as managed waste sites. Industrial wood waste disposal accounts for 4.3% (0.91 Mt CO_2 eq) of the emissions from waste in 1990, 4.4% (1.0 Mt) in 2005, and 3.1% (0.70 Mt) in 2024.

7.3.2. Methodological Issues

As noted previously, the increasing demand for waste recovery and waste-to-energy applications in recent years has reduced the solid wood residuals to negligible amounts. Waste residuals are therefore specified as zero for the solid wood industry from 2010 onwards. In contrast, the available data indicates that landfilling of waste from pulp and paper facilities is continuing. There are limited data available on the amount of waste sent to industrial wood waste landfill sites, and, as such, interpolation between data points is necessary. Based on the available information, and given that methane production rates from decomposition of wood waste is typically less than methane generated at MSW landfills, it is assumed that no landfill gas recovery occurs at wood waste landfills. See Annex 3.6 for further details of activity data preparation and model methodology.

7.3.3. Uncertainty Assessment and Time-Series Consistency

The level of uncertainty associated with CH_4 emissions from MSW landfills and wood waste landfills combined was estimated to be in the range of ± 76% for CH_4. Time-series consistency is ensured through the use of consistent methods and activity data (type and sources) for all inventory years. Where necessary, time-series gaps in activity data are imputed with interpolated or extrapolated values.

7.3.4. QA/QC and Verification

The quality control process consisted of verification in the input data to the model to ensure that all activity data updates were made and that they were in alignment with the original data source. Recalculated estimation values were compared to the previous submission to check for consistency and identify any unsupported significant changes that may point to errors. The emissions time series has been reviewed (numerically and visually) to evaluate trends in the estimates.

7.3.5. Recalculations

Whereas previously the historical pulp and paper residuals were estimated based on data sources that covered a period from 1981 until present (and assumed constant for the pre-1981 period), new data sources were identified that provide information on the historical amount of pulp and paper residuals for the full time series applied in the landfill model (i.e., from 1941 to present). As such, these data sources replace the previously extrapolated activity data. Detailed information on the new data sources is provided in Annex 3.6.

7.3.6. Planned Improvements

The model input values used for the solid wood industry component of the industrial wood waste sector are under review.

7.4. Biological Treatment of Solid Waste (CRT Category 5.B)

7.4.1. Category Description

This source category includes emissions from composting and anaerobic digestion at biogas facilities and residential waste composting. Many municipalities in Canada utilize centralized composting facilities and some are establishing centralized anaerobic digestion facilities to reduce the quantity of organics sent to landfill. Additionally, several municipalities across Canada are considering, or have already established, organic waste bans on landfills in their jurisdiction to further divert organic waste to biological treatment. These practices have contributed to a large increase in the quantity of organic waste diverted in Canada since 1990.

GHG emissions from composting are affected by climate, moisture content and composition of the waste and the ability to maintain aerobic decomposition conditions among other factors. Anaerobic digestion of organic waste accelerates the natural decomposition of organic material without oxygen by maintaining optimal conditions for the process. Both biological treatment processes result in the production of CO_2, CH_4 and N_2O emissions. However, CO_2 emissions are not included in the national inventory total as the carbon is considered of biogenic origin and accounted for under the Agriculture, Forestry and Other Land Use (AFOLU) sector (IPCC, 2006).

In 2024, the Biological Treatment of Solid Waste category contributed 610 kt of CO_2 eq or 2.7% of total emissions to the Waste sector and 0.09% to Canada's total. Current year emissions from this category have increased 460 kt (310%) compared to 1990, and 280 kt (86%) compared to 2005.

7.4.2. Methodological Issues

The estimation of CH_4 and N_2O emissions from the biological treatment of waste at Canadian facilities is carried out by using a Tier 3 method. Facility-level data are available for both anaerobic digestion and composting facilities in Canada. These data have been collected with industry associations, online literature searches and annual reports as well as other contracts led by ECCC. Composting emissions are calculated based on the waste type accepted in wet tonnes at the facility-level in Canada. The emission factors by waste type have been developed through a literature review that compiled information from primary literature sources (ECCC, 2020a). In addition to the facility-based estimates, emissions are estimated for at-home composting of residential organic waste based on IPCC Tier 1 methods.

Under the Biological Treatment of Solid Waste category, anaerobic digestion emissions are calculated for industrial and municipal facilities. Emissions are calculated as the percent of CH_4 lost from the total biogas produced at the facility level. This percentage was developed based on primary literature and/or facility-based insight and compiled through a literature review (ECCC, 2020b). Some gaps exist in the activity data for both composting and anaerobic digestion, including a lack of data prior to the year 1992 for composting. To fill data gaps occurring at the beginning of the time series, the earliest available data point was carried back to 1990 for facilities that were known to be operating at that time. For gaps in subsequent parts of the time series, the last available data point was carried forward to the next available data point. For anaerobic digestion, there were no facilities in the industrial and municipal sectors that were in operation in 1990. Therefore, the earliest data point available for the facility was carried back to its opening year and carried forward until the next available data point for the facility. For verification of facility operational periods a review was completed of Statistics Canada's Waste Management Industry Survey: Business and Government Sectors (Statistics Canada, n.d.[a]), which includes waste diverted quantities to both composting and anaerobic digestion facilities. Further work will be conducted for future cycles to verify the operational status of these facilities.

7.4.3. Uncertainty Assessment and Time-Series Consistency

The combined uncertainties for emissions of CH_4 and N_2O from composting and anaerobic digestion were calculated by waste type for composting and by the fugitive loss percentage for CH_4 for anaerobic digestion. Uncertainty ranges from ±176% to ±99% for CH_4 and ±136% to ±65% for N_2O based on waste type for composting and ±79% for CH_4 for anaerobic digestion fugitive loss. This is based on emission factors collected and compiled through a literature review. Activity data uncertainty was not calculated given that it is based on facility data.

7.4.4. QA/QC and Verification

The quality control process for the Biological Treatment of Solid Waste category consisted of visual inspection and comparison of activity data against previous values; following calculations in prescribed steps to ensure that equations, parameters and unit conversions were appropriately used, and that links were accurate; review of emission factors used; and inspection of emission estimate time series. Emissions were plotted to observe trends for any unusual patterns that were inconsistent with changes in activity data over time. When they occur, recalculated estimation values are compared to the previous submission, and a comparison was made of changes from one year to the next along the time series to identify unsupported significant changes that may point to a data processing error.

7.4.5. Recalculations

New for the current inventory edition, greenhouse gas emissions from the residential composting of organic waste are included. These emissions are calculated based on IPCC Tier 1 methods using the quantity of residential waste disposed in outdoor composting bins or piles, combined with CH_4 and N_2O emission factors from literature. Further details on emission estimates calculation are provided in Annex 3.6. For industrial and municipal anaerobic digestion facilities, recalculations occurred at the facility level that impact emissions from 2021 forward.

7.4.6. Planned Improvements

Opportunities for acquiring more refined data on the amounts of waste being composted and/or anaerobically digested in the provinces and territories will continue to be investigated. Increased collaboration with provincial and other regional authorities may result in a more complete data set and higher quality data that could be used to improve or verify the current emission estimates.

7.5. Incineration and Open Burning of Waste (CRT Category 5.C)

7.5.1. Category Description

This category includes emissions from the incineration and open burning of waste. There are 28 incinerators currently in operation in Canada. Incinerators are classified by the source of their primary feed material: MSW, hazardous waste, sewage sludge or clinical waste. Some municipalities in Canada use incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application. Incineration can also be used for energy recovery from waste, and emissions from these facilities are reported in the Energy sector. GHG emissions from open burning of waste in residential settings are included as a part of this category.

Emissions from waste incineration include CO_2, CH_4 and N_2O. In accordance with the 2006 IPCC Guidelines, CO_2 emissions from biomass waste combustion are not included in the inventory totals. The only CO_2 emissions detailed in this section are from fossil fuel-based carbon waste, such as in the form of plastics, rubber, inorganics, and fossil liquids. CH_4 and N_2O emissions are estimated from all incinerated waste.

GHG emissions from incinerators vary with the amount of waste incinerated, the composition of the waste, the carbon content of the non-biomass waste, and the facilities' operating conditions. Emissions are derived from the quantities of waste incinerated that were provided directly by facilities in a series of surveys conducted by ECCC, as well as additional reports which provide quantities of clinical waste incinerated for the early years in the time series (Chandler, 2006; Sawell, 1996; RWDI AIR Inc., 2014).

Incineration of MSW is not a common practice across most of Canada. In the 1990s, approximately 5% of Canada's total MSW is incinerated, mostly in energy-from-waste facilities. Since the 2000s, only about 3-4% of Canada's total MSW has been incinerated. The vast majority of Canada's incinerated MSW is processed in large, highly regulated facilities. However, there are still a small number of remote communities that rely on rudimentary incinerators to dispose of their MSW. There are currently four incinerators in operation in Canada that are classified as hazardous waste incinerators, all located in Ontario and Alberta. Two different types of sewage sludge incinerators exist in Canada: multiple hearth and fluidized bed. In both types of incinerators, the sewage sludge is partially dewatered prior to incineration. The dewatering is typically done using a centrifuge or a filter press. There is currently one major centralized clinical waste incinerator in Canada, the other clinical waste incinerators are small hospital-based incinerators and incinerators operated by the Government of Canada.

The Incineration and Open Burning of Waste category contributed 147 kt CO_2 eq (0.65%) of total emissions to the Waste sector or 0.02% of Canada's total emissions in 2024. Emissions from this category are 49% below the 1990 level of 290 kt CO_2 eq, and 58% below the 2005 level of 349 kt CO_2 eq.

7.5.2. Methodological Issues

The emission estimation methodology depends on type of waste incinerated and gas emitted. A more detailed discussion of the methodologies is presented in Annex 3.6.

Given the relatively small number of incinerators in Canada, emissions from incineration can be estimated at the facility level. Facilities that emit greater than 10 kt CO_2 eq per year are required to report emissions to ECCC on an annual basis through the Greenhouse Gas Reporting Program (GHGRP). These publicly available data represent a significant portion of emissions from this sector.

Estimates for smaller facilities that are not required to report to the GHGRP are generated by ECCC using Tier 3 methodology and activity data from a biennial survey of incinerators across Canada. Estimates are further supported by historical emissions for those facilities operating before the GHGRP was put in place in 2004. This includes currently operating facilities that operated prior to 2004 and those that closed before the program began.

The ECCC emission estimates are developed using the IPCC default values for carbon content of waste and fossil carbon as a percentage of total carbon (IPCC, 2006). N_2O and CH_4 emissions are estimated based on the type of waste being incinerated as well as the facility specific incineration technology. IPCC default factors were used for all waste categories except for hazardous waste, for which emission factors were derived from site-specific data provided by a facility and are considered to be more representative than IPCC default values. As the IPCC 2006 Guidelines do not contain default emission factors for clinical waste incineration, the IPCC 2006 Guidelines default emission factors for MSW incineration were used in accordance with the IPCC 2000 Good Practice Guidance.

Facilities are distinguished as either energy-from-waste (EFW) facilities or non-EFW facilities, depending on whether they produce energy and/or heat from the incineration process. Emissions from EFW facilities are reported under the Energy sector, while emissions from non-EFW facilities are reported under the Waste sector.

Emissions from open burning of waste are estimated based on survey data, population data, and IPCC Tier 1 estimation methods. The survey data used in the calculation represents the best available information, though some sources may require periodic updating to reflect more recent waste incineration practices.

7.5.3. Uncertainty Assessment and Time-Series Consistency

IPCC default values are used to quantify uncertainty for the incineration and open burning sector. The activity data uncertainty is ±5%, while the CO_2, CH_4 and N_2O emission factor uncertainties are ±35%, ±97%, and ±90%, respectively.

7.5.4. QA/QC and Verification

The quality control process consisted of verification in the model that all activity data updates were made, that all links were valid, and that the cells addressed by those links were populated. Recalculated estimation values were compared to the previous submission, and a comparison was made of changes from one year to the next along the time series to identify unsupported significant changes that may point to a data manipulation error. The emissions trend has been reviewed for the entire time series.

7.5.5. Recalculations

GHG emissions reported to the GHGRP were used where available. For facilities not reporting under the GHGRP, data from the ECCC surveys and online reports are used. The latest survey was conducted in 2024, and some new information from online reports was added in 2025, which resulted in revised activity data for several facilities.

New for the current inventory edition, GHG emissions from residential waste burning are included. Further details on emission estimates calculations are provided in Annex 3.6.

7.5.6. Planned Improvements

No improvement are currently planned for this category.

7.6. Wastewater Treatment and Discharge (CRT Category 5.D)

7.6.1. Category Description

The Wastewater Treatment and Discharge category is comprised of Municipal Wastewater Treatment systems and Industrial Wastewater treatment. In Canada, most wastewater from domestic and industrial sources is treated in centralized municipal wastewater treatment plants. Wastewater can also be treated by private, and occasionally communal septic systems, notably in rural areas; these are included in the municipal wastewater category. In some coastal areas, untreated wastewater is discharged directly to the sea, though this practice has been reduced in recent decades following the completion of large wastewater infrastructure projects. Most industrial facilities discharge their wastewater to municipal treatment systems where it is treated in common with domestic wastewater.

The Industrial Wastewater treatment and discharge category captures large industrial facilities that treat or pre-treat their wastewater on-site before discharging it to the environment or to municipal wastewater treatment systems for further treatment.

Wastewater treatment involves the removal of organics, measured as biological oxygen demand, or BOD_5, and nutrients such as nitrogen and phosphorus. The treatment process results in emissions of CO_2, CH_4 and N_2O.

Centralized treatment systems can encompass several technologies, often classified by the method of organic matter and nutrient removal: whether the removal mechanism is settling (primary treatment) or involves microbial activity to further breakdown organics and nutrients in the wastewater (secondary treatment). Tertiary treatment involves additional filtration and disinfection.

The most common types of wastewater treatment in Canada are primary treatment, secondary waste activated sludge, and private septic systems. Other common treatment technology used in Canada include aerobic lagoons, facultative lagoons, wetland treatment systems, sequence batch reactors, rotating biological contactors, trickling filters, and membrane filtration. Many of the largest systems in Canada use secondary waste activated sludge systems with tertiary level treatment.

Wastewater treatment produces varying amounts of CH_4, depending on the organic load (BOD_5)—determined by the population—and the treatment type. CH_4 is produced from certain treatment processes, steps, or areas of the treatment systems that are anaerobic. For example, primary and secondary treatment and aerobic lagoons produce little or no CH_4 emissions, whereas anaerobic steps in sequence batch reactors, anaerobic lagoons and septic systems produce relatively higher amounts of CH_4. Facultative lagoons have both naturally aerated and anaerobic layers and produce CH_4, but less than a fully anaerobic lagoon.

Centralized municipal wastewater treatment plants often have anaerobic sludge digestion, which produces CH_4 in the form of biogas or digester gas. The CH_4 generated in these systems is typically contained and combusted, with a growing portion used for energy (Figure 7–2). Industrial on-site wastewater treatment in Canada uses relatively more anaerobic treatment technology, where methane from the treatment process itself is collected and used as a source of energy (Figure 7–2).

All methane recovery from municipal wastewater treatment came from recovery of biogas generated from anaerobic digestion of sludge; whereas, all methane recovery from industrial wastewater treatment came from the treatment process.

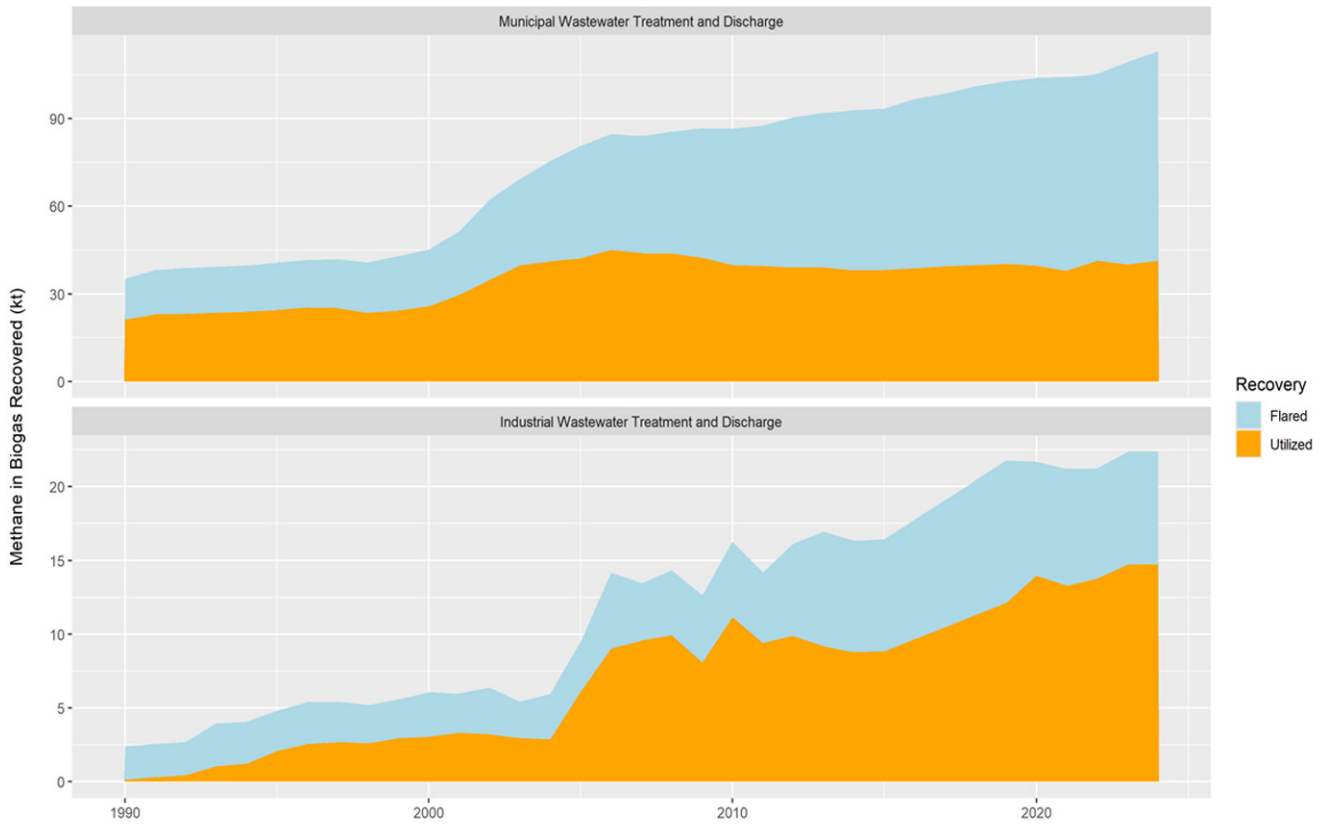
Wastewater treatment generates N_2O through the nitrification and denitrification of sewage nitrogen at treatment facilities. N_2O emissions are also considered to occur from the receiving body of discharged effluent, whether treated or untreated.

CO_2 is also a product of aerobic and anaerobic wastewater treatment. As detailed in section 7.1, CO_2 emissions originating from the decomposition of organic matter of biogenic origin are not included in the Waste sector total emissions. CO_2 emissions from organic matter of fossil origin, such as methanol or organic products of chemical manufacturing or oil refining, for example, are included in Waste sector totals.

The Wastewater Treatment and Discharge category accounted for 2600 kt CO_2 eq, or 12%, of the total emissions of the Waste sector in 2024. Wastewater Treatment and Discharge emissions in 2024 were 790 kt CO_2 eq (43%) above the 1990 level (1800 kt), and 470 kt CO_2 eq above the 2005 level (2200 kt).

Emissions from wastewater treatment show an increasing trend over time that roughly follows the trend in population growth. Changes in treatment technology have impacts on emission trends at the provincial level. For example, the growing percentage of the population using septic systems in several provinces results in increases in total emissions (septic systems have a relatively high emission factor). In contrast, recent upgrades of several major wastewater systems from untreated discharge to sea to primary and secondary treatment decreased total emissions in other provinces (reductions in emission from the receiving water body are greater than the added emissions from the new treatment). Overall, the increasing trend in emissions is consistent, with a slight acceleration in 2010 and 2011, largely due to an increase in the estimated population using septic systems in many provinces around that time. Overall, population growth is the most important factor in the emissions trend for Wastewater Treatment and Discharge. In part, this is because of assumed constant per capita organics loading (BOD_5) and reasonably steady per capita protein consumption rates (increasing from 66.17 g per person per day in 1991 to 69.85 g per person per day in 2009, the earliest and latest data points available) (Statistics Canada, 2009).

Figure 7–2 **Methane Recovered from Wastewater Treatment and Discharge**



7.6.2. Methodological Issues

Wastewater treatment emissions are estimated from three process steps: the treatment, the effluent discharged to receiving water bodies, and, where applicable, from anaerobic digestion of sewage sludges.

Although the emission generating processes are the same for both Municipal and Industrial wastewater treatment, the methods differ based on the type of data available. In both cases, estimates are calculated by facility and aggregated to quantify provincial/territorial totals. The methods follow the 2006 IPCC Guidelines and 2019 Refinement to the IPCC Guidelines, with model parameters based on additional information (AECOM [2011] and Envirosim [2019]). Annex 3.6 provides additional information on the methodologies used for estimating emissions from Municipal Wastewater Treatment, and Industrial Wastewater Treatment.

Municipal Wastewater Treatment

Municipal Wastewater Treatment emission estimates are based on the population served by each treatment technology and the per capita inputs of organic matter (measured as BOD_5) and nitrogen (N). The population served, each year, by each of the more than 3000 wastewater treatment or discharge systems in Canada is estimated based a spatial analysis, which considers regional population and the relative regional volumes of wastewater treated by (or discharged through) each facility or system at the census division and census metropolitan area levels. The population connected to private septic systems are estimated from an analysis of Statistics Canada's Households and the Environment Survey (Statistics Canada, n.d.[b]).

Emissions of CH_4 and N_2O from treatment are based on BOD_5 and N inputs, respectively, and treatment technology-based emission factors. These are obtained from the 2006 IPCC Guidelines (IPCC, 2006) and 2019 Refinement (IPCC, 2019), with a few exceptions for treatment types not detailed in the Guidelines.

Treatment technology-specific parameters of treatment efficiency (removal rates) are used to estimate BOD_5 and N discharged to receiving water bodies with the effluent. Emissions of CH_4 and N_2O from the receiving water body are based on the BOD_5 and N discharged with effluent and emission factors based on the waterbody type and eutrophic state.

Technology specific parameters are used to estimate the quantity of sludge generated and volatile suspended solids of the sludge. If the facility has on-site sludge digestion, emissions are estimated based on quantity and characteristics of the sludge, and fate of biogas (flared, used, vented). Where available, facility reported biogas production and fates are used.

Industrial Wastewater Treatment

Organic (BOD_5) and N inputs to industrial wastewater treatment is highly variable between industry type, and between individual facilities based on production and practices. Emission estimates for industrial wastewater treatment are based on facility reported data. Three sources of data are used: Emissions reported through the GHGRP, quantities of N discharged with effluent reported through the National Pollutant Release Inventory (NPRI) (emission estimates calculated using emission factors), and emissions and methane recovery reported through ECCC voluntary surveys.

Emissions from the receiving water body are based on the BOD_5 and N estimated in effluent and emission factors. The CH_4 emissions are a function of the receiving water body type (e.g., lake, river, ocean).

7.6.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty associated with the Municipal Wastewater Treatment and Discharge category was estimated to be in the range of ±55% for CH_4 and ± 51% for N_2O; and is based on default IPCC 2006 values. Uncertainty for Industrial Wastewater Treatment and Discharge, which is based on facility-reported emissions, is estimated as the standard deviation about the mean at 95% confidence interval. This results in estimated uncertainty of 790% in 2005 and 345% in 2023 for CH_4 emissions, 269% in 2005 and 360% in 2023 for CO_2 emissions, and 265% and 279% for N_2O in 2005 and 2023, respectively.

Time series consistency is ensured through the use of consistent methods and activity data (type and sources) for all inventory years. Where necessary, time-series gaps in activity data are imputed with interpolated or extrapolated values, with consideration taken for details such as start of facility operations, collection system installation dates are considered.

7.6.4. QA/QC and Verification

The quality control process consisted of following calculations step by step to ensure that equations, parameters and unit conversions were appropriately used, and that links were accurate. Emissions were plotted to observe trends for any unusual jumps or patterns that were inconsistent with changes in activity data over time. Recalculated estimation values were compared to the previous submission, and a comparison was made of changes from one year to the next along the time series to identify unsupported significant changes that may point to a data processing error.

7.6.5. Recalculations

An improvement to the Municipal Wastewater Treatment and Discharge sector was the mapping of discharge to receiving waterbody types, allowing for emission factors for discharge to receiving waterbodies specific to each waterbody type to be used. Previously, the IPCC Tier 1, default emission factor was used for all cases. This update generally decreases emissions from the discharge to receiving waterbodies, in particular for regions where most discharge is to rivers and oceans, which have lower emission factors than the default. In some regions, emissions increased, where much of the effluent is discharged to estuaries, lakes or reservoirs which have higher emission factors than the default.

Recalculations in Municipal and Industrial Wastewater Treatment and Discharge are comprised of updated facility-level data and error corrections. Updated data includes volumes treated and treatment technology (Municipal); reported emissions via GHGRP and reported N in effluent via NPRI (Industrial). A thorough review of facility-reported (GHGRP) CO_2 emissions from industrial wastewater was conducted. Several cases were identified to be CO_2 from biogenic sources (which is not reported in the Waste sector of the NIR), resulting in a decrease in CO_2 emission estimates for this sector. The remaining cases were identified to be specifically CO_2 emissions of materials of fossil origin (e.g., glycols, petroleum, chemicals, etc.).

7.6.6. Planned Improvements

Planned improvements for Wastewater Treatment and Discharge include updated mapping of septic system use in Canada and gathering of data to capture the influence of combined sewer overflows on emissions.

CHAPTER 8

RECALCULATIONS AND IMPROVEMENTS

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Canada's greenhouse gas (GHG) inventory undergoes a continuous process of updates, revisions, and improvements to maintain and to enhance its transparency, accuracy, completeness, consistency and comparability. Section 8.1 of this chapter provides an overview of the recalculations performed in this year's GHG inventory, including analyses by sector to facilitate an integrated view of changes in, and impacts on, emission levels and trends. A summary of the inventory improvements implemented this year can be found in section 8.2 and planned improvements for future inventories are described in section 8.3.

Further details on recalculations and improvements can be found in the individual chapters for each sector (Chapter 3 to Chapter 7).

8.1. Impact of Recalculations on Emission Levels and Trends

Continuous improvement is a good inventory preparation practice. Environment and Climate Change Canada (ECCC) consults and works with key federal, provincial and territorial partners, along with industry stakeholders, research centres and consultants, on an ongoing basis to improve the quality of the underlying variables and scientific information used to compile the national inventory. As new information and data become available and more accurate methods are developed, previous estimates are updated to provide a consistent and comparable trend in emissions and removals.

Recalculations occur annually for a number of reasons, including the following:

- correction of errors detected by quality control procedures
- incorporation of updates to activity data, including changes in data sources
- reallocation of activities to different categories (this only affects subtotals)
- refinements of methodologies and emission factors (EF)
- inclusion of categories previously not estimated (which improves inventory completeness)
- recommendations from United Nations Framework Convention on Climate Change (UNFCCC) reviews
- implementation of modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement (MPGs)[1]

8.1.1. Estimated Impacts on Emission Levels and Trends

In this GHG inventory, total emissions were revised slightly upward for most years and, similarly, downward for the four most recent years, as shown in Figure 8–1. Overall, as shown in Table 8–1, recalculations of previously reported 1990–2023 estimates have resulted in a change in emissions between a minimum of +0.1% (+0.7 Mt) in 2019 and a maximum of -1.0% (-7.0 Mt) in 2023. The average recalculation for all years in absolute terms is representing 0.4% (2.7 Mt). The trend between 1990 and 2023 is now reported as a +13.0% increase in total GHG emissions since 1990, compared with a +14.4% increase reported in last year's NIR. The trend between 2023 and the base year (2005) corresponds to a decrease of -10.0% (-76 Mt) in total GHG emissions. There is a net upward recalculation of +0.6% (+4.3 Mt) for the base year.

1 https://unfccc.int/sites/default/files/resource/cp24_auv_transparency.pdf

Figure 8–1 **Comparison of Emission Trends (2025 NIR vs 2026 NIR)**

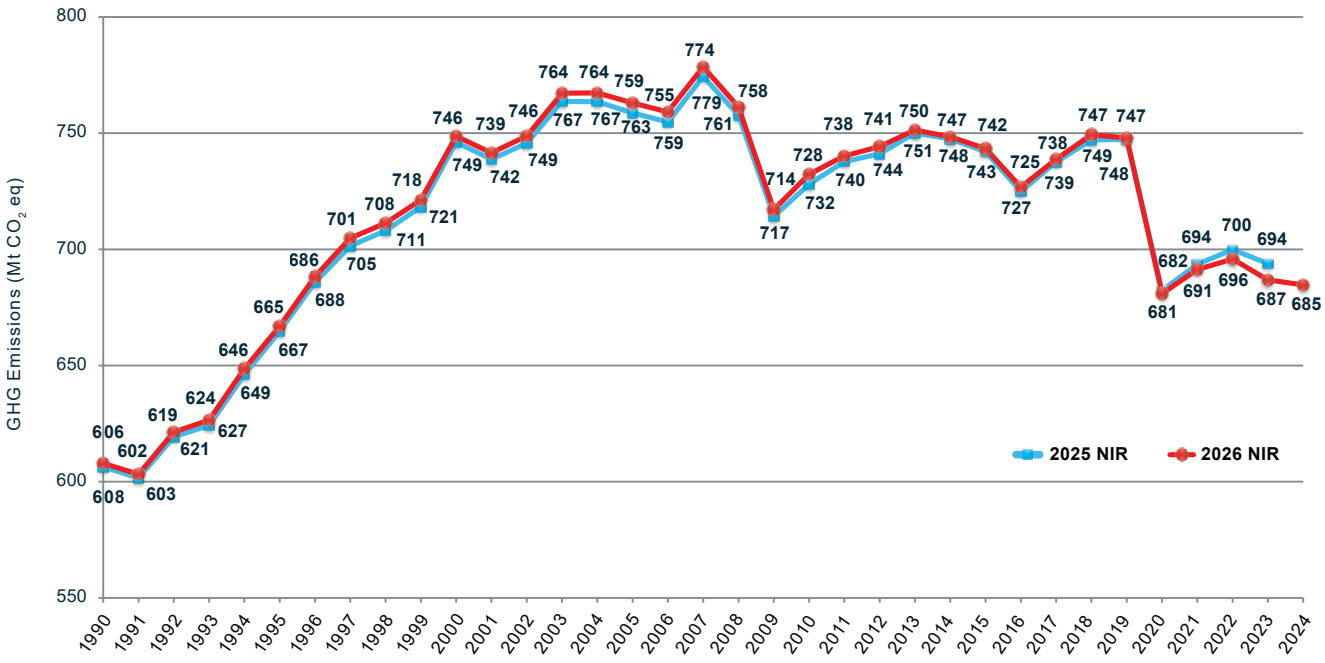


Table 8–1 **Summary of Recalculations in the 2026 National Inventory (without Land Use, Land-Use Change and Forestry)**

National Total	Annual Emissions (kt CO_2 eq)								Trends	
	1990	2005	2018	2019	2020	2021	2022	2023	1990–2023	2005–2023
Previous Submission (2025 NIR)	606 392	758 718	747 051	747 308	682 283	693 574	699 899	693 912	14.4%	-8.5%
Current Submission (2026 NIR)	607 907	763 017	749 308	748 008	680 926	691 322	695 853	686 881	13.0%	-10.0%
Change in Total Emissions	1 515	4 300	2 257	700	-1 357	-2 252	-4 046	-7 031	-	-
	0.2%	0.6%	0.3%	0.1%	-0.2%	-0.3%	-0.6%	-1.0%	-	-

Note:
" - " = Not applicable

8.1.2. Recalculations by Sector

As previously noted, good inventory preparation practice requires that methodological improvements and updates be applied across the time series (i.e., from 1990 to the most recent year reported). Methodological consistency across the time series avoids confounding a methodological change with an actual change in GHG emissions or removals.

Recalculations conducted this year have resulted in changes to previously reported emissions/removals for the majority of the Intergovernmental Panel on Climate Change (IPCC) sectors (Energy; Industrial Processes and Product Use [IPPU]; Agriculture; Land Use, Land-Use Change and Forestry [LULUCF]; and Waste), Energy subsectors (Stationary Combustion, Transport and Fugitive Sources), and for all applicable years in the time series (1990–2023).

Table 8–2 indicates that the largest revisions for 2023 occurred in the Transport (-5.7 Mt) and Fugitive Sources (-2.9 Mt) sectors. These revisions are largely due to improved estimation methodologies and allocation as well as updated energy data. The national total was revised downward from 694 Mt for the year 2023 (as presented in the previous inventory) to 687 Mt for 2023 (as presented in the current inventory) because of the sum of recalculations of -7.0 Mt for all sectors. Between 2023 and 2024, the national total then decreased by -2.2 Mt to reach 685 Mt in 2024. Change and recalculation contribution for each source are presented in Table 8–2. Emission and recalculation values of those sources, for current and previous inventory, are presented in Table 8–3.

Table 8–2 **Change in Canada's GHG Emissions: from 694 Mt (for 2023, Previous Submission) to 685 Mt (for 2024, Current Submission)**

Sector	2023 to 2024 Change (Mt CO_2 eq)	2023 Change Due to Recalculations (Mt CO_2 eq)
Energy (Stationary Combustion)	-0.9	0.1
Energy (Transport)	-0.8	-5.7
Energy (Fugitive Sources)	0.4	-2.9
Industrial Processes and Product Use	-1.5	1.2
Agriculture	1.0	0.3
Waste	-0.4	0.0
Total Change	**-2.2**	**-7.0**

Note: Totals may not add up due to rounding.

Table 8–3 **Summary of Recalculations by Sector**

	Annual Emissions (kt CO_2 eq)								Trends	
	1990	2005	2018	2019	2020	2021	2022	2023	1990–2023	2005–2023
ENERGY (STATIONARY COMBUSTION)										
Previous Submission (2025 NIR)	276 753	334 956	318 694	322 372	299 257	300 632	303 574	298 331	7.8%	-10.9%
Current Submission (2026 NIR)	277 404	335 886	318 859	321 969	299 471	300 382	303 243	298 399	7.6%	-11.2%
Change in Emissions	**651**	**930**	**165**	**-403**	**214**	**-250**	**-330**	**68**	-	-
	0.2%	**0.3%**	**0.1%**	**-0.1%**	**0.1%**	**-0.1%**	**-0.1%**	**0.0%**	-	-
ENERGY (TRANSPORT)										
Previous Submission (2025 NIR)	145 073	190 308	208 613	209 151	177 962	186 792	194 641	195 399	34.7%	2.7%
Current Submission (2026 NIR)	144 943	190 292	207 695	208 211	176 017	184 059	191 809	189 726	30.9%	-0.3%
Change in Emissions	**-131**	**-16**	**-918**	**-940**	**-1 945**	**-2 733**	**-2 832**	**-5 673**	-	-
	-0.1%	**0.0%**	**-0.4%**	**-0.4%**	**-1.1%**	**-1.5%**	**-1.5%**	**-2.9%**	-	-
ENERGY (FUGITIVE SOURCES)										
Previous Submission (2025 NIR)	65 542	97 569	87 560	84 312	74 692	74 918	70 214	68 478	4.5%	-29.8%
Current Submission (2026 NIR)	65 761	99 750	89 079	85 472	73 603	73 996	68 266	65 607	-0.2%	-34.2%
Change in Emissions	**219**	**2 181**	**1 519**	**1 160**	**-1 089**	**-923**	**-1 948**	**-2 871**	-	-
	0.3%	**2.2%**	**1.7%**	**1.4%**	**-1.5%**	**-1.2%**	**-2.8%**	**-4.2%**	-	-
IPPU										
Previous Submission (2025 NIR)	55 096	56 032	54 719	53 737	51 414	53 217	52 522	53 530	-2.8%	-4.5%
Current Submission (2026 NIR)	55 744	56 808	55 856	54 462	52 149	53 886	53 231	54 750	-1.8%	-3.6%
Change in Emissions	**648**	**776**	**1 137**	**725**	**734**	**668**	**710**	**1 220**	-	-
	1.2%	**1.4%**	**2.1%**	**1.3%**	**1.4%**	**1.3%**	**1.4%**	**2.3%**	-	-
AGRICULTURE										
Previous Submission (2025 NIR)	42 541	56 286	54 146	54 287	55 986	55 109	55 912	55 150	29.6%	-2.0%
Current Submission (2026 NIR)	42 767	56 793	54 804	54 911	56 682	55 787	56 183	55 429	29.6%	-2.4%
Change in Emissions	**225**	**508**	**658**	**625**	**697**	**678**	**271**	**280**	-	-
	0.5%	**0.9%**	**1.2%**	**1.2%**	**1.2%**	**1.2%**	**0.5%**	**0.5%**	-	-
WASTE										
Previous Submission (2025 NIR)	21 386	23 567	23 319	23 391	22 863	22 875	23 001	22 987	7.5%	-2.5%
Current Submission (2026 NIR)	21 288	23 488	23 015	22 982	23 003	23 212	23 121	22 970	7.9%	-2.2%
Change in Emissions	**-98**	**-79**	**-304**	**-409**	**140**	**338**	**120**	**-18**	-	-
	-0.5%	**-0.3%**	**-1.3%**	**-1.8%**	**0.6%**	**1.5%**	**0.5%**	**-0.1%**	-	-
LULUCF										
Previous Submission (2025 NIR)	49 847	65 973	24 024	14 629	25 006	14 770	50 797	4 169	-91.6%	-93.7%
Current Submission (2026 NIR)	61 095	81 054	23 915	16 363	25 758	14 321	45 809	-8 696	-114.2%	-110.7%
Change in Emissions	**11 247**	**15 081**	**-109**	**1 734**	**752**	**-449**	**-4 989**	**-12 865**	-	-
	22.6%	**22.86%**	**-0.5%**	**11.9%**	**3.0%**	**-3.0%**	**-9.8%**	**-308.6%**	-	-

Note:
" - " = Not applicable

Energy (Stationary Combustion)

With respect to Stationary Combustion emissions, most of the recalculations for 2023 occurred in Public Electricity and Heat Production (+0.8 Mt [+1.4%]), Petroleum Refining Industries (+0.3 Mt [+2.0%]), Oil and Gas Extraction (-1.2 Mt [-1.1%]), Mining and Quarrying (+0.3 Mt [6.3%]), Manufacturing Industries (-1.0 Mt [-2.6%]), and Commercial (+0.1 Mt [+0.3%]). Recalculations also occurred throughout the time series, with the major sources being updates to still gas volumes, natural gas EFs, fuel consumption data in the Report on Energy Supply and Demand (RESD), and the reallocation of emissions to Coal Production, Biofuel Manufacturing, and Flaring.

Recalculations in the Public Electricity and Heat Production category occurred from 1995 to 2023. These recalculations were a result of revised natural gas EFs with the impact ranging from -0.03 Mt (-0.2%) to +0.01 Mt (-0.01%). Revisions to the RESD, specifically coal, diesel, light fuel oil, heavy fuel oil and natural gas volumes from 2011 to 2023 caused changes in emissions ranging from -0.01 Mt (-2.3%) to +0.6 Mt (+1.7%).

Recalculations to Petroleum Refining Industries occurred for the entire time series. These recalculations were a result of revised still gas volumes with the impact ranging from +0.7 Mt (+8.6%) to +2.1 Mt (+22%). Updates to emissions reallocated to Flaring and Biofuel Manufacturing resulted in revisions from 2004 to 2023 ranging from -0.1 Mt (-1.7%) to -0.9 Mt (-8.3%). Revisions to the RESD, specifically volumes of natural gas, petroleum coke, still gas, propane, and butane from 2019 to 2023 resulted in updates ranging from -0.1 Mt (-1.2%) to -0.4 Mt (-3.9%).

Recalculations to the Oil and Gas Extraction category occurred from 1990 to 2023. Updates to producer-consumed natural gas CO_2 EFs in British Columbia caused revisions ranging from -0.5 Mt (-1.5%) to +0.04 Mt (+0.1%). Revisions to natural gas, heavy fuel oil, propane, and still gas volumes from 1990 to 2023 caused changes in emissions ranging from -0.8 Mt (-9.1%) to +0.1 Mt (+0.8%).

Recalculations for Mining and Quarrying category occurred for the entire time series. These recalculations were a result of revisions to natural gas and propane volumes resulting in changes ranging from -0.1 Mt (-6.4%) to +0.5 Mt (+18%).

Recalculations for Manufacturing Industries occurred for the entire time series. Revisions to the RESD occurred from 2014 to 2023, with impacts ranging from -0.3 Mt (-0.6%) to +0.5 Mt (+1.2%). The reallocation of emissions from Chemical and Other Manufacturing subcategories to Biofuel Manufacturing resulted in downward revisions ranging from -0.1 Mt (-0.1%) to -1.0 Mt (-2.2%) from 1990 to 2023.

Recalculations in the Commercial category occurred between 1990 and 2023. These revisions were due to changes to landfill gas, sludge gas, municipal solid waste, light fuel oil and propane volumes, causing recalculations ranging from -0.03 Mt (-0.1%) in 2017 to +0.1 Mt (+0.3%).

See Chapter 3, section 3.1 for further recalculation details.

Energy (Transport)

Recalculations for Transport were made to all reporting years, ranging from +0.6 Mt (+0.3%) in 2010 to -5.7 Mt (-3.1%) in 2023. Changes at this level were primarily due to updated renewable fuel content of transportation fuels for reporting years 2010 and later and revised RESD fuel volumes for reporting years 2011 and later. The updated renewable fuel content impacted all transport sectors except aviation and pipelines and resulted in increased biomass combustion volumes and decreased fossil fuel combustion volumes for reporting years 2013 and later. Thus, decreasing overall emissions because CO_2 emissions of biogenic origin are reported as memo items within the Energy sector, in accordance with the 2006 IPCC guidelines.

Recalculations for Domestic Aviation and Military Aviation were insignificant and solely a result of revised RESD fuel volumes. These recalculations were only applicable for the 2017 and 2022 reporting years, resulting in combined revisions of +7.0 kt (+0.1%) and +21 kt (+0.2%), respectively.

Recalculations for Road Transportation were made to all reporting years and were primarily due to updated renewable fuel content of transportation fuels and revised RESD fuel volumes. The revised RESD volumes resulted in small increases in gasoline and diesel fuel combusted by Road Transportation for reporting years 2022 and 2023. In addition, revisions to road vehicle registration resulted in minor recalculations for the 2023 reporting year. Cumulatively, these recalculations resulted in Road Transportation revisions ranging from +0.6 Mt (+0.5%) in 2010 to -2.7 Mt (-2.2%) in 2023.

Recalculations for Railways were insignificant, ranging from +47 kt (+0.8%) in 2011 to -131 kt (-2.2%) in 2023. Changes were primarily due to updated renewable fuel content of diesel fuel oil.

Recalculations for Domestic Navigation, Fishing, and Military Water-Borne Navigation were made to all reporting years and were significant for reporting years 2014 and later. Changes were due to updated auxiliary engine information and updated renewable fuel content of marine fuels. Cumulatively, these recalculations resulted in revisions ranging from -0.4 Mt (-11%) in 2023 to +0.5 Mt (+16%) in 2020, for Domestic Navigation, Fishing, and Military Water-Borne Navigation combined.

Recalculations for Other Transportation (Off-Road) were made to all reporting years and were primarily due to updated renewable fuel content of transportation fuels and revised RESD fuel volumes. The revised RESD volumes resulted in decreases in gasoline and diesel fuel combusted by Off-Road for reporting years 2017 to 2023 and 2011 to 2023, respectively. In addition, updates to the NONROAD emissions model resulted in minor recalculations for all reporting years. Cumulatively, these recalculations resulted in Off-Road revisions ranging from +0.1 Mt (+0.2%) in 2010 to -2.5 Mt (-5.4%) in 2023.

Energy (Fugitives)

Recalculations occurred in the Oil and Natural Gas category of the Fugitives subsector for the entire time series. Updates to methodologies and activity data resulted in upward revisions from 1990 to 2019, with overall increases ranging from +0.2 Mt (+0.4%) in 1990 to +2.3 Mt (+2.3%) in 2006. Recalculations led to downward revisions from 2020 to 2023, ranging from -1.1 Mt (-1.5%) in 2020 to a decrease of -2.9 Mt (-4.3%) in 2023. These changes resulted from several recalculations with varying impacts:

1. Atmospheric measurements of CH_4: measurement-based CH_4 emissions were revised following methodological improvements by the Energy and Emissions Research Laboratory (EERL), primarily to incorporate more precise meteorological data and to update facility classifications. As a result, CH_4 emissions for storage tanks, unlit flares, compressor buildings, engine sheds, and wellheads (Saskatchewan only) at Upstream Oil and Gas (UOG) facilities were revised. Alberta, Saskatchewan, and British Columbia estimates were revised for 2023, while updated EERL inventories for 2020/2021 in Saskatchewan and 2021 in British Columbia also resulted in further recalculations from 1990 to 2022.

   Recalculations for measurement-based CH_4 emissions resulted in upward revisions from 1990 to 2021, ranging from +0.2 Mt (+0.6%) in 2021 to +1.4 Mt (+4.2%) in 2005, while emissions were revised downward by -0.2 Mt (-3.2%) in 2022 and by -1.1 Mt (-4.9%) in 2023.

2. British Columbia gas composition: public gas sample analysis data and natural gas production volumes available from the British Columbia Energy Regulator (BCER) were used to update composition data for raw natural gas produced in the province. This update impacted several fugitive emissions sources: flaring, reported venting, pneumatics, equipment leaks, formation CO_2, and surface casing vent flow. Overall, the adoption of province-specific gas composition data for British Columbia resulted in downward revisions in 1996, 1997, and from 2013 to 2023, with the largest revision in 2014 of -0.3 Mt (-6.1%). Upward revisions from 1990 to 1995 and from 1998 to 2012 ranged from +37 kt (+1.0%) in 1998 to +0.1 Mt (+3.0%) in 2006.

3. Fugitive equipment leaks: model parameters were updated to better reflect the impact of provincial leak detection and repair (LDAR) requirements for specific facilities in the Alberta UOG sector from 2020 onwards. Following an internal review of the LDAR modelling parameters for other provinces, similar updates were made for Manitoba, resulting in recalculations for the entire time series. From 2020 to 2023, equipment leak emissions were revised downward by approximately -2.0 Mt (-27%) each year, while the Manitoba changes resulted in upward revisions from 1990 to 2019 with the largest change of +24 kt (+0.2%) in 2005.

4. Petroleum refinery flaring: the methodology for flaring emissions from the petroleum refining sector was updated to incorporate facility reported emissions and product-specific flaring activity data from the GHG Reporting Program. This update led to recalculations with upward revisions from 2004 to 2023, ranging from +0.1 Mt (+58%) in 2004 to +0.9 Mt (+451%) in 2021.

5. Heavy crude oil production fugitives: the methodology for fugitive emissions from thermal heavy oil production in Saskatchewan was updated to use facility-level estimates from 2013 onwards. Emissions are back-casted using facility-level production estimates to 1990, resulting in recalculations for the entire time series in Saskatchewan. Additionally, historical fugitive estimates were updated for cold heavy oil production in Saskatchewan and Alberta, and for thermal in-situ heavy oil production in Alberta to better reflect operational practices. Combined, these updates resulted in downward revisions from 1990 to 2012, ranging from -0.1 Mt (-2.2%) in 2010 to -1.0 Mt (-9.6%) in 2000, and minor upward revisions from 2013 to 2023 with a maximum of +78 kt (+2.3%) in 2019.

6. Abandoned oil and gas wells and surface casing vent flow: methodological changes were made to adopt updated province-specific CH_4 emission factors for plugged and unplugged abandoned wells. The updated EFs incorporated the results of additional measurement studies that improved coverage of regions in Saskatchewan and Alberta where abandoned wells are prevalent. This update resulted in upward revisions from 1990 to 2016 and downward revisions from 2017 to 2023, ranging from -59 kt (-10%) in 2023 to +47 kt (+12%) in 2008.

   Surface casing vent flow emissions in Alberta were also recalculated following a minor update to model assumptions related to vent flow occurrences at inactive wells. This recalculation led to downward revisions from 1990 to 1993 and upward revisions from 1994 to 2023, ranging from -16 kt (-1.2%) in 1993 to +0.2 Mt (+13%) in 2003.

7. Natural gas transmission & storage, distribution: the Canadian Energy Partnership for Environmental Innovation (CEPEI) provided ECCC with updated operator reported emissions data for the year 2023, replacing values that had been extrapolated from 2022 CEPEI data in the previous submission. Recalculations for the natural gas transmission and storage and natural gas distribution sectors resulted in downward revisions of -0.2 Mt (-9.4%) in 2023.

Further recalculations to fugitive Oil and Natural Gas emissions occurred with relatively minor impacts. The most significant changes involved UOG flaring emissions following reconciliation with the updated measurement-based estimates for unlit flares, resulting in upward revisions from 1990 to 2012 and from 2021 to 2023, and downward revisions from 2013 to 2020, ranging from -6.5 kt (-0.2%) in 2014 to +0.3 Mt (+7.9%) in 1998. Other activity data updates resulted in revisions to post-meter fugitives (ranging from -15 kt in 2016 to +10 kt in 2007), petroleum refining equipment leaks and process venting (ranging from +20 kt in 1991 to +75 kt in 2012), and pneumatics Alberta UOG sector (ranging from -0.2 kt in 2010 to +69 kt in 2005).

Note that more detailed recalculation explanations for Fugitive Emissions from Fuels can be found in Chapter 3, section 3.3.

CO_2 Transport and Storage

Recalculations occurred for the CO_2 transport and storage category due to updates to facility reported emissions data, resulting in downward revisions from 2019 to 2023 with a maximum change of -0.1 Mt in 2020. Further details on these recalculations can be found in Chapter 3, section 3.4.

Industrial Processes and Product Use

There were recalculations for the IPPU sector for the whole time series (1990–2023), ranging from +0.14 to +1.2 Mt. Explanations on the category- and subsector-specific recalculations are provided below.

2010 to 2023 hydrofluorocarbon (HFC) emissions from the Product Uses as Substitutes for Ozone-Depleting Substances (ODS) category were recalculated using revised activity data based on corrections made to address time-series consistency issues identified during the UNFCCC simplified review of the 2025 inventory, revised end-use categorizations guided by more in-depth company research, and revisions to proxy variables used for extrapolation for years with no data collection. Recalculations ranged from -0.41 Mt in 2014 to +0.23 Mt in 2018.

1990 to 2023 emissions for the Non-Energy Products from Fuels and Solvent Use subsector have undergone recalculations due to revisions to Statistics Canada's RESD data, updates to the use of lubricating oils and greases for off-road two-stroke engines and updates to the petroleum coke EF. The changes ranged from -0.53 Mt in 2001 to +0.43 Mt in 2023.

For the Iron and Steel Production category, the entire time series (1990-2023) were recalculated due to facility-reported data corrections for the years 2021 to 2023 and a methodological change that added emissions coming from the use of carbonates during iron ore pellet production. The magnitude of recalculations ranged from +0.54 Mt in 2018 to +0.79 Mt in 2005.

Recalculations also occurred for the Cement Production category for 2018 and 2020 due to revisions made by facilities to their Greenhouse Gas Reporting Program (GHGRP) reports. The magnitude of the recalculations ranged from +0.046 to +0.32 Mt.

For the Magnesium Production category, recalculations (for magnesium casting) occurred for the years 2010 to 2023 due to updates in provincial gross output (GO) data (2010–2023) and revised facility data reporting to the GHGRP (2017–2023). The magnitude of the recalculations ranged from a minute negative value to +0.26 Mt.

Agriculture

Recalculations were carried out in the Agriculture sector across the full time series. These reflect the following methodological updates and corrections:

1. An updated method to estimate methane conversion factors (MCF) for dairy and swine liquid manure systems resulted in a net national upward revision in CH_4 emissions, with recalculations ranging from +0.2 Mt in 1990 to +0.4 Mt in 2023.
2. Following the recommendation from the TERT, a 5% impurity was included in the activity data for limestone and dolomite applied to croplands, which proportionately reduced the CO_2 emissions from lime application. Recalculations were -0.02 Mt in 1990, -0.01 Mt in 2005 and -0.01 Mt in 2023.
3. A method correction resulting in refinements to crop yields impacted the amount of crop residue C inputs added to the soil and resulted in recalculations of direct soil N_2O emissions. Recalculations were +0.03 Mt in 1990, +0.12 Mt in 2005 and -0.12 Mt in 2023.

The aggregated impact on these recalculations in the Agriculture sector resulted in upward revisions of emission estimates of +0.23 Mt in 1990, +0.51 Mt in 2005 and +0.28 in 2023.

Land Use, Land-Use Change and Forestry

Recalculations occurred in the estimates of emissions and removals from the LULUCF sector, notably in the Forest Land, Cropland, Harvested Wood Products (HWP), Wetlands and Settlements categories. The most important recalculations were:

1. Refinement to decomposition parameters for soil and dead organic matter (DOM) pools resulted in upward revisions to emissions from 1990 to 2008 and downward revisions from 2009 to 2023, with the largest single-year change occurring in 2005 (+10 Mt).
2. Forest management activity data were updated for clearcutting, commercial thinning, firewood collection and slash burning, including minor revisions for 2020 to 2022 and a major downward correction (-10%) to the 2023 conventional harvest targets, resulting in a -13.4 Mt revision of emission in 2023.
3. The combined impact of the DOM parameter update, the forest management activity data updates, and other minor recalculations, resulted in a net upward revision of +6.2 Mt and +10.2 Mt in 1990 and 2005, respectively, and a net downward revision of -22.3 Mt in 2023 in the Forest Land category.
4. The forest management activity data update, with a minor offset from updates to HWP model parameters for commodity conversion and export proportions, resulted in a net upward revision of +5.8 Mt of emissions in the HWP category for 2023.
5. In the Cropland category, estimates of emission and removals in soil organic carbon pools have been revised for the entire time series (1990 to 2023) due to a correction to a processing error in the procedure that distributes carbon from crop residues to soils. The recalculations resulted in upward revisions in emissions from crop residues of +0.75 Mt in 1990, +1.57 Mt in 2005 and +0.91 Mt in 2023.
6. Flooded Land emissions were recalculated for the full time series (1990 to 2023) using an updated methodology, revised activity data, and the inclusion of CH_4 emissions. While the overall trend remains downward, the updates resulted in upward revisions of +4.5 Mt in 1990, +4.4 Mt in 2005, and +3.1 Mt in 2023 in the Wetlands category.
7. To address UNFCCC review recommendations on reporting completeness, C emissions and removals for the Wetlands converted to Settlements and Wetlands Remaining Wetlands subcategories, associated with resource extraction activities in the Alberta oil sands region have been estimated using an IPCC Tier 2 approach. Overall, these estimates represent upward revisions of +0.5 Mt in 1990, +0.18 Mt in 2005, and +0.32 Mt in 2023.

The combined impact of these and other minor recalculations in the LULUCF sector resulted in upward revisions of emission estimates of +11 Mt in 1990, +15 Mt in 2005, and a downward revision of -13 Mt in 2023.

Refer to Table 8–4 and Chapter 6 for more details on recalculations.

Waste

Recalculations in the Waste sector resulted in changes to emission estimates of -0.10 Mt (+0.46%) in 1990, -0.08 Mt (-0.34%) in 2005 and -0.02 Mt (-0.08%) in 2023 compared to the previous submission. These changes are the result of updated activity data and ongoing refinement of the emissions estimates, detailed as follows:

1. Recalculations for municipal solid waste landfills include new landfill data collected from a voluntary survey of landfill gas operators, conducted by ECCC. The new data includes landfill gas recovery and landfill site-specific waste disposal data, which replaces previously extrapolated values (for 2023), and on occasion includes revisions to previously held landfill gas collection estimates and site-specific disposal data. The updates to methane recovery impact net emissions estimates, which are calculated based on modelled methane production minus the total recovery by province and territory. The latest long-term climate data and site-specific disposal were used to update estimates of proportions of waste landfilled by climate zone (wet, dry) for each province and territory, with changes for Ontario (from 7% dry climate to 3%) and Alberta (from 100% dry climate to 99%). New waste characterization (composition) data and recompilation of recent (2016-present) composition have resulted in some updates to emissions in recent years.
2. Improvements made to Municipal Wastewater Treatment and Discharge include new mapping of the waterbody types receiving wastewater effluents and use of EFs specific to those waterbody types. Additional recalculations in municipal wastewater treatment and discharge include updates and revisions to facility-level data, such as volumes treated, treatment technology and methane recovered. Most of these updates were derived from the latest data reported through the Effluent Reporting Information System, as part of the Wastewater Systems Effluent Regulation (Canada, 2012).
3. Industrial wastewater recalculations include updated data from the latest GHGRP and National Pollutant Release Inventory (NPRI; releases to water) data, which includes new data and revisions throughout the time series.

4. Recalculations for incineration of waste include updates and revisions to facility-level quantities of waste incinerated for the entire time series and updates from the latest GHGRP inventory. The carbon content of materials for textiles, leather and organics has also been corrected.
5. Additional sources of wood waste residual activity data were used to replace extrapolated values in the calculation of emissions estimates from industrial wood waste facilities, resulting in improved accuracy of the estimates. The new data source resulted in changes to the emissions estimates ranging from -0.02 Mt (for the current year) to -0.09 Mt (in 1990).
6. Emissions from residential waste composting were added to the facility-based emission estimates under the biological treatment of waste category. These account for changes ranging from +0.07 Mt (in 1990) to +0.13 Mt (for the current year).
7. Emissions from open burning of residential waste were added to the facility-based emission estimates under the incineration category. These account for changes of approximately +0.003 Mt over the reporting period.

8.2. Inventory Improvements

Inventory improvements aim to improve the accuracy of GHG estimates or enhance components of the inventory preparation process, including the supporting institutional, legal and procedural arrangements. Improvements that involve a methodological change or refinement are documented and reviewed prior to implementation. Where applicable, improvements that lead to recalculations of estimates for multiple years are applied to maintain time series consistency.

Improvements to Canada's inventory result from recommendations from the UNFCCC reviews completed in previous years, continued implementation of the reporting requirements and *2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories* (2006 IPCC Guidelines), and internal continuous improvement activities, for example, with the integration of the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019).

Table 8–4 provides additional information about the improvements implemented this year presented by IPCC sectors and UNFCCC Common Reporting Table (CRT) categories.

8.2.1. UNFCCC Review Recommendations

Up to 2023, Canada's inventory submission was typically reviewed annually by an Expert Review Team (ERT) following agreed-upon UNFCCC review guidelines[2] as adopted in Decision 13/CP.20 in 2014. Starting in 2025, in accordance with Decision 18/CMA.1 (2018) and under Article 13 of the Paris Agreement, information submitted by each Party will undergo a technical expert review (TER) consistent with the MPGs. Every 2 years, these reviews will examine the information presented in the NIR and Biennial Transparency Report (BTR).[3] The BTR summarizes some of the information presented in the NIR, but also include information on progress towards Nationally Determined Contributions (NDCs), policies and measures, climate change impacts and adaptation, levels of financial, technology development and transfer and capacity-building support, and areas of improvement. Parties to the Paris Agreement are required to submit BTRs every two years, with the first submission that was due by the end of the year 2024.

Reviews are coordinated by the UNFCCC Secretariat, and the ERT (or now referred to as technical expert review team [TERT] under the Paris Agreement) is composed of inventory experts from developed and developing countries. The purpose of the review is to provide a thorough and comprehensive technical assessment of the implementation of the Convention and adherence to the reporting requirements. At the end of the review, the TERT provides technical feedback on any methodological and procedural issues encountered. The TERT focuses on instances where the guiding principles of transparency, consistency, comparability, completeness, and accuracy of the inventory could be improved. The outcome of the review is presented in a review report (referred to as technical expert review report [TERR] under the Paris Agreement) that is provided to the country under review and made public by the UNFCCC.

On the years that a BTR isn't due to the UNFCCC, Canada's NIR will undergo a simplified review instead of a TER. A simplified review consists of an initial assessment of completeness and consistency with the MPGs of predetermined aspects, mostly quantitative from the CRTs. This type of review is conducted by the UNFCCC Secretariat and in line with procedures developed by the lead reviewers. The findings of this initial assessment, to be published on the UNFCCC website, will form part of the subsequent TER of the NIR.

2 The *Guidelines for the technical review of information reported under the Convention related to GHG inventories, biennial reports and national communications by Parties included in Annex I to the Convention* can be found here: http://unfccc.int/resource/docs/2014/cop20/eng/10a03.pdf#page=3.

3 Further details about the scope of technical expert reviews, including on exclusions from its scope, are available in the MPGs.

The recommendations from ERTs, from 2023 and prior, were taken into consideration when identifying potential improvements for this year. The latest review report completed by the TERT can be found on the UNFCCC website.[4] A tracker compiling all TERT recommendations and their status can be found on the Government of Canada's Open Data webpage. Methodological changes made this year that addressed the TERT recommendations include:

- the inclusion of emissions from carbonate use for iron ore pellet production
- revised methods in the Agriculture sector for estimating methane conversion factors for dairy and swine liquid manure systems
- the adjustment of emissions from lime application to account for impurities in limestone and dolomite applied to croplands
- the inclusion of emissions and removals in the Wetlands Converted to Settlements and Remaining Wetlands subcategories
- the inclusion of emissions from residential waste burning and residential waste composting

8.2.2. Continuous Improvements

The GHG inventory team also identifies improvements based on evolving science, quality assurance / quality control (QA/QC) and verification activities (in accordance with the QA/QC Plan), and new and innovative modelling approaches or new sources of activity data. Implementation of the improvements is prioritized by taking into consideration the outcomes of the key category and uncertainty analysis, the level of effort and the significance of the improvements. Examples of continuous improvement activities implemented in this year's inventory include:

- updated model parameters for fugitive emissions from equipment leaks in the Alberta upstream oil and gas sector
- updates to renewable fuel content of transportation fuels
- the reallocation of emissions from Chemicals, Other Manufacturing, and Petroleum Refining to Other Energy Industries to transparently report emissions from biofuel manufacturing
- the inclusion of rare earths production in the inventory
- refinements in the LULUCF sector, with updated dead organic matter (DOM) decomposition parameters in managed forests, forest management and wildfire activity data for the Forest Land category, and revised activity data and EFs for Flooded Land in the Wetlands category
- continued refinement of waste models with waste-specific parameters for municipal solid waste (MSW) and industrial wood waste landfills, and for wastewater treatment and discharge

8.3. Planned Inventory Improvements

Canada's official GHG inventory identifies and tracks potential planned improvements to emission estimates (including underlying activity data, EFs and methodologies). The planned improvements are based on recommendations from a variety of sources, including external review processes, collaborative work between inventory sector experts and industry, and other government departments and academia.

In addition, planned improvement activities (Table 8–5) are prioritized by taking into consideration key category analysis, QA/QC activities, uncertainty assessments, the level of effort and the significance of the improvements. Although the quantification of uncertainty for the emission estimates (Annex 2) helps prioritize improvement activities for future inventories, uncertainty itself is not an indicator of potential future changes resulting from continuous improvement activities. Table 8–4 and Table 8–5 are updated annually to track progress in implementing improvements to the inventory.

A detailed interdepartmental improvement plan has been developed specific to estimates related to the Forest Land and Harvested Wood Products categories reported in the LULUCF sector as described in section 8.3.1.

4 See Technical Expert Review Report (TERR) column for Canada at: https://unfccc.int/first-biennial-transparency-reports

8.3.1. Improvement Plan for Forest Land and Harvested Wood Products Greenhouse Gas Estimates

The improvement plan for Forest Land and Harvested Wood Products GHG estimates (NRCan and ECCC, 2024) was developed jointly and is updated annually by the Carbon Accounting Team of the Canadian Forest Service in Natural Resources Canada (NRCan-CFS-CAT) and the Pollutant Inventory and Reporting Division of the Science and Technology Branch in ECCC (S&T-PIRD) and approved by a Director Oversight Committee from both departments. Implementation schedules are re-evaluated annually in light of scientific and technical progress, changing priorities and resource availability.

The improvement plan provides a summary of recent consultation that the federal government has undertaken related to the quantification of carbon from the land sector. The government has engaged with experts and stakeholders through multiple fora to identify knowledge and information gaps and prioritise input to the scientific process that underlies carbon reporting to develop and continually improve the LULUCF inventory. Early in the development of the Forest Land reporting methodology, NRCan-CFS undertook the development of A Blueprint for Forest Carbon Science in Canada. Prior to the implementation of the methodology used to focus reporting on the anthropogenic component of forest management, in 2016, an international review was commissioned and organized by NRCan-CFS and ECCC. Over the past four years, ECCC has led or commissioned consultations such as Climate Science 2050, the 2019 Canadian Carbon Cycle Research Workshop or the recent Canadian Council of Academies report on Nature-Based Climate Solutions. In addition, department officials have also engaged in dialogues with environmental groups who have published reports on the topic of forest carbon reporting and accounting. The most recent consultation focused directly on forest carbon science and including representatives from government, academia, industry and environmental organisations, the *2023 Blueprint for Forest Carbon Science*, was completed in 2023 and published in 2024. The projects developed in the improvement planning process reflect these dialogues as well as recommendations from the ERT of the UNFCCC.

The improvement plan consists of projects that (1) can be operationalized[5] in the inventory within a three-year period (including a "testing phase"); (2) will bring measurable and justifiable improvements in the representation of anthropogenic emissions and removals reported in the GHG inventory for the Forest Land and Harvested Wood Products categories and in categories related to forest conversion – including their accuracy, consistency, transparency and completeness; and (3) may involve, but are not limited to, the development of new or updated activity data, improved algorithms, independent validation or calibration leading to the refinement of parameters.

The improvement plan associated with the 2026 GHG inventory submission represents the seventh edition of the 3-year rolling (2026 to 2028) GHG emissions and removals from forests, land-use change events involving forests, and HWP that are reported in the NIR. The current three-year window includes improvements being implemented in this inventory submission, as noted in Table 8–4.

Several improvements are planned for the Forest Land category in future inventory submission, some details on the most significant changes are provided in section 6.3.1.6. In Table 8–5, a summary of improvement projects is provided, and the complete improvement plan is published annually on the Government of Canada's Open Data webpage.

Table 8–4 **Improvements to Canada's 2026 NIR**

IPCC Sector	CRT Category	Improvement	Description and Basis of Improvement	Section in NIR for more details
Energy (Stationary combustion Emissions)	Other Energy Industries (1.A.1.c.iii)	Reallocate emissions to transparently report biofuel manufacturing emissions.	This update improves the transparency of GHG estimates through reporting emissions from biofuel manufacturing in a separate category instead of distributed across a variety of sectors. Facility-level data collected by Statistics Canada was used to reallocate activity data from the Chemicals, Other Manufacturing, and Petroleum Refining categories into Other Energy Industries.	section 3.2.1.5
Energy (Fugitive Emissions)	Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Updates to model parameters for fugitive equipment leaks.	This update improves equipment leak emissions estimates for Alberta and Manitoba. Model parameters were updated to better reflect the impacts of Leak Detection and Repair (LDAR) programs under the provincial and federal methane regulations that have been in force since 2020.	section 3.3.2.5
	Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Updates to British Columbia natural gas composition data.	This update incorporates public British Columbia Energy Regulator (BC-ER) gas composition data into oil and gas fugitive emission estimates. The updates to raw natural gas compositions impact several sources, including flaring, venting, and other unintentional leaks. Use of the provincial data enables fugitive estimates for British Columbia to better reflect changes in oil and gas production over time.	section 3.3.2.5
	Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Updates to abandoned well EFs.	New methane EFs were adopted for abandoned oil and gas wells. The new EFs incorporate direct measurements conducted in Saskatchewan, which were not included in previous field studies, and additional measurements in Alberta. The expanded sample size makes the new EFs more representative of abandoned wells in Canada, improving the accuracy of emission estimates.	section 3.3.2.5
	Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Updates to fugitive emissions from thermal and cold heavy oil production.	The extrapolation of fugitive emissions from cold and thermal heavy oil production in Saskatchewan were updated to use cold heavy oil production and thermal heavy oil production volumes, respectively, rather than total heavy oil production which was used previously. This approach better reflects changes in these subsectors in the province over time. In addition, historical emission estimates were revised to reflect operational practices in both Alberta and Saskatchewan heavy oil production subsectors.	section 3.3.2.5
	Flaring – oil (1.B.2.c.ii.1)	Updates to petroleum refinery flaring estimates.	This update utilized data collected under expanded GHGRP requirements to improve the accuracy of petroleum refining flaring emissions.	section 3.3.2.5

5 "Operationalized" means being incorporated into the annual inventory production process.

Table 8–4 **Improvements to Canada's 2026 NIR** (cont'd)

IPCC Sector	CRT Category	Improvement	Description and Basis of Improvement	Section in NIR for more details
Energy (Transport Emissions)	Transport (General)	Updates to renewable fuel content of transportation fuels.	This update improves the accuracy of renewable fuel volumes combusted by transportation sources. Renewable fuel content values were updated in multiple transportation emissions methodologies such that the collective total of renewable fuel volumes align with those reported by Navius Research (Navius Research, 2019).	section 3.2.3.5
	Domestic Navigation (1.A.3.d) Fishing (1.A.4.c.iii) Military Water-borne Navigation (1.A.5.b) International navigation (marine bunkers) (1.D.1.b)	Updates to auxiliary engine information and reallocation of at berth emissions for marine vessels.	Improved information on auxiliary engines improves the accuracy of the fuel consumption of marine vessels. At berth emissions occurring at Canadian ports that were previously associated with inbound international voyages were reallocated to the International Navigation category. This allows Canada to fully capture the emissions occurring at Canadian ports.	section 3.2.3.5
	Off-Road Transportation (General)	Updates to NONROAD model.	This update improves the accuracy of the off-road emissions methodology by porting the NONROAD model from an MS-DOS environment to an SQL environment. The previous version of NONROAD did not wholly respect engine age distributions specified by the user, resulting in less accurate fuel consumption rates.	section 3.2.3.5
IPPU	Cement Production (2.A.1)	Correction to 2018 activity data.	Following a TERT recommendation, an activity data outlier was reviewed and corrected for the 2018 data year.	section 4.2.1.5
	Iron and Steel Production (2.C.1)	Inclusion of emissions from the use of carbonates for iron ore pellet production (2.C.1.e).	Based on TERT recommendations, a Tier 1 emission estimate of CO_2 resulting from the use of carbonates in iron ore pellet production was added to the inventory. Iron ore pellet activity data was collected from various sources, including Statistic Canada, NRCan, company annual reports and GHGRP to complete the time series.	section 4.4
	Rare Earths Production (2.C.7.a)	Inclusion as a category in the inventory.	This category was introduced into the inventory using Tier 1 activity data collected from online sources alongside default EFs from the IPCC, 2019.	section 4.4
	Product Uses as Substitutes for ODS (HFCs, 2.F)	Corrections to 2010, 2013 and 2014 activity data.	Based on some time-series consistency outliers identified during the UNFCCC Simplified Review of the 2025 NIR, revisions were made to correct errors in activity data.	section 4.7
Agriculture	Manure Management (3.B)	Refinement of MCFs.	Based on a TERT recommendation, a time series of MCFs based on regional annual average temperature for swine and dairy animal sectors has been implemented.	sections 5.3.1.2 and A3.4.3.4
	Agricultural Soils (3.G-J)	Inclusion of impurities in lime application.	Based on a TERT recommendation, activity data have been updated to account for the impurities in the limestone and dolomite applied to croplands.	sections 5.6.6 and A3.4.8.1
LULUCF	Forest Land (4.A)	Refinements to decay rates and other DOM-related parameters.	Decomposition parameters for DOM pools have been refined based on a Bayesian calibration of CBM-CFS3 model parameters using National Forest Inventory (NFI) ground-plot data.	sections 6.3.1.5 and A3.5.2.1
	Harvested Wood Products (4.G)	Updates to residential bioenergy appliance types and EFs.	Residential bioenergy appliance classification and EFs have been updated based on an empirical study of representative Canadian appliances in a controlled environment, improving the representation of emissions from residential wood combustion in NFCMARS-HWP, the carbon dynamics model for HWP.	sections 6.4.5 and A3.5.3
	Harvested Wood Products (4.G)	Improvements to carbon allocation model.	Carbon allocation in the HWP model, already implemented using ANSE software, has been enhanced by a new feature that replaces proportion-based allocations with target-based allocations where activity data are available.	sections 6.4.5 and A3.5.3
	Cropland Remaining Cropland (4.B)	Corrections to crop residue C added to soil.	Carbon estimates for crop residues were corrected by revising a procedure that excluded high and low C input outliers in calculating carbon input to soils resulting in a small net loss or over estimate of crop residue carbon returned annually to soils.	sections 6.5 and A3.5.4
	Wetland Remaining Wetland (4.D.1) Land Converted to Wetlands (Flooded Land) (4.D.2.b)	Updates to activity data and EFs for CH_4 and CO_2.	Methodological update replaces EFs based on a limited data set from a single region in Canada with regionally specific, modelled EFs that account for regional variations in parameters that impact annual emissions such as temperature and the characteristics of the watershed. The new approach now includes CH_4 emissions alongside CO_2, providing a more complete representation of flooded land emissions Activity data updates include a more complete dataset of reservoirs across Canada, including historically flooded reservoirs that continue to emit methane.	sections 6.7 and A3.5.6.2
	Wetlands Remaining Wetlands (4.D.1) Wetlands Converted to Settlements (4.E.2.d)	Land-use change improvements.	To address completeness for LULUCF subcategories reported as not estimated (NE), as indicated by a TERT recommendation, a new methodology has been implemented to estimate C emissions and removals for wetland conversion and management activities associated with resource extraction activities in Alberta's oil sands region.	sections 6.7 and A3.5.6.3
	Land Representation (4.1)	Land-use change improvements.	Based on a TERT recommendation, unmanaged land areas have been added to the CRT 4.1 Land Representation. This change does not impact emission estimates.	sections 6.2 and A3.5.1
Waste	Municipal Wastewater Treatment and Discharge (5.D.1)	Implementation of Tier 2 activity data for CH_4 emissions from discharge to receiving waterbody.	Discharges of wastewater treatment effluents have been mapped to waterbody classification (lake, reservoir, river, estuary, etc.). CH_4 emissions from this source are now calculated using IPCC 2019 EFs specific to the waterbody type. Formerly all discharged CH_4 emissions were calculated using the IPCC 2019 Tier 1 default EF of Unspecified Aquatic Environment.	sections 7.6 and A3.6.4
	Industrial Wood Waste Landfills (5.A.1)	Replacement of extrapolated activity data with historical estimates of wood waste residuals quantities.	Emissions from industrial wood waste facilities were previously based on extrapolated quantities of wood waste residuals, which were specified as a constant value from 1940 to 1981. These extrapolated values were replaced with historical data that showed smaller quantities of wood waste landfill residuals as compared to the extrapolated values.	sections 7.3 and A3.6.1
	Residential Waste Composting (5.B)	Inclusion of new subcategory.	Based on a TERT recommendation, emissions from the composting of residential waste in settings is now included in the NIR under the biological treatment of waste category.	sections 7.4 and A3.6.2
	Residential Waste Burning (5.C)	Inclusion of new subcategory.	Based on a TERT recommendation, emissions from the combustion of waste in outdoor residential settings is now included in the NIR under the incineration category.	sections 7.5 and A3.6.3

Table 8–5 **Summary of Canada's Inventory Improvement Plan**

IPCC Sector	CRT Category	Improvement	Description
Energy	Fuel Combustion (1.A)	Improved tracking of low-carbon fuels.	Work is underway to improve tracking and allocation of emissions associated with low-carbon fuel (e.g., bio-ethanol, biodiesel, renewable natural gas, etc.) combustion.
	Fuel Combustion (1.A)	Update EFs for fuels with variable carbon content.	Work is underway to analyze data reported to ECCC's GHGRP to improve EFs for fuels with carbon contents that vary such as still gas, natural gas and petroleum coke.
	Fuel Combustion – Other Sectors (1.A.4)	Analyze and incorporate digester gas into emission estimates.	Work is underway to incorporate emissions from on-farm digester gas used for energy purposes into the stationary combustion model.
	Fugitive Emissions from Fuels – Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Incorporate fugitive emissions from Liquified Natural Gas (LNG) production and export.	Emissions from LNG export facilities are currently included in emission estimates. Work is underway to disaggregate and transparently report emissions as a distinct oil and gas subsector in the economic sector estimates. Additionally, emissions reported to the GHGRP and volumetric data reported to provincial regulators will be evaluated to ensure completeness in emission estimates.
	Fugitive Emissions from Fuels – Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Continuous improvement of natural gas composition data and uncertainty estimates for the upstream oil and gas sector.	In collaboration with the Clean Air and Emissions Research (CAER) group at NRCan, work is underway to improve key model parameters for the Upstream Oil and Gas sector. CAER is developing a machine learning approach to produce location-specific natural gas compositions using a consistent method for all western provinces that can be used in emission calculations. This work may also enable future improvements to uncertainty estimates.
	Fugitive Emissions from Fuels – Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Analyze reported data to improve fugitive emission estimates from equipment leaks.	Work is underway to review and analyze data reported to British Columbia's industrial GHG reporting program and Alberta's OneStop reporting system in order to ensure emission estimates for equipment leaks accurately track the impact of Leak Detection and Repair (LDAR) programs on Upstream Oil and Gas emissions.
	Fugitive Emissions from Fuels – Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Petroleum refining fugitive emissions.	Work is underway to evaluate data collected under ECCC's expanded GHGRP for the purpose of improving the quality of petroleum refining venting and unintentional leak emissions.
	Transport (General)	Evaluate and update renewable fuel content for transportation fuels.	Work is underway to evaluate and update average renewable fuel content values used as input in several transportation emissions methodologies, for the entire time series.
	Road Transportation (1.A.3.b)	Adoption of MOVES5.	Work is underway to adopt the latest version of the United States Environmental Protection Agency's Motor Vehicle Emissions Simulator (MOVES5). Notable changes compared to MOVES3 include updates to energy consumption rates and N_2O emission rates associated with heavy-duty vehicles. In addition, MOVES5 will be executed to better respect Canadian road vehicle population input for all reporting years.
	Road Transportation (1.A.3.b)	Updates to road vehicle populations.	Work is underway to update the road vehicle fleet data used to allocate Statistics Canada's vehicle registration data amongst the appropriate IPCC categories. It is possible that the road vehicle fleet data will serve as direct input to MOVES, pending a thorough review of those data.
	Off-Road Transportation (General)	Updates to CH_4 and N_2O EFs.	Work is underway to update CH_4 and N_2O EFs, using the latest engine emissions certification data available.
	Off-Road Transportation (General)	Updates to geographical distributions of off-road engine populations.	Work is underway to update the geographical distributions used to quantify modelled off-road engine populations by province/territory, using the latest geospatial data available.
	Domestic Navigation (1.A.3.d) Fishing (1.A.4.c.iii) Military Water-borne Navigation (1.A.5.b) International navigation (marine bunkers) (1.D.1.b)	Updates to marine activity data.	Work is underway to recompile the vessel movement data from the Marine Emission Inventory Tool to improve the allocation of emissions (nationally and provincially). Part of the work to recompile the dataset will involve redefining georeferenced objects, developing new spatial tools, and implementing additional QC measures.
IPPU	Titanium Dioxide Production (2.B.6)	Collect activity data and report as a category in the inventory.	Process emissions are currently included elsewhere in CRT categories 1.A.2.b, 1.A.2.c and 2.C.3. Efforts are being made to collect activity data that would allow for reallocation of emissions from other categories to this category.
	Ethylene Oxide Production (2.B.8.d)	Collect activity data to apply a Tier 2 method and account for permanent carbon capture and storage.	Currently, Tier 1 emission estimates are developed using production data, and a mix of IPCC default EFs and consultant-informed EFs from 2010. Work is underway to obtain activity data, including carbon capture and storage information, from facilities to increase the emission estimate accuracy.
	Iron and Steel Production (2.C.1.e)	Improve EFs for the production of iron ore pellets.	Currently, a Tier 1 emission estimate using the 2006 IPCC Guidelines default factor is used for this category and a future improvement includes determining a suitable Tier 2 country-specific EF for carbonate use only. In addition, efforts will be made to disaggregate the combustion emissions associated with iron ore pellet production from category 1.A.2.a to 2.C.1.e.
	Non-Energy Products from Fuels and Solvent Use (2.D)	Update EFs for various non-energy petroleum products and natural gas.	EFs for various non-energy petroleum products and natural gas were developed based on studies conducted in 1992 and 2005, respectively. There is a plan to evaluate whether these emissions factors are still valid and to update if necessary.
	Product Uses as Substitutes for ODS (HFCs, 2.F)	Update imports and exports of manufactured items containing HFCs.	To update data on imports and exports of HFC-containing items and explore alternative data sources.
	Product Uses as Substitutes for ODS (HFCs, 2.F.1 & 2.F.2)	Update end-of-life EFs for HFCs in refrigeration, air-conditioning and foam blowing applications.	To examine the possibility of EF updates, sources of quantitative information on recent end-of-life practices are being explored.
	Electrical Equipment (2.G.1)	Reporting of CF_4 emissions.	Currently, only SF_6 is reported for this source category. It is planned to report CF_4 emissions as well, as it can be used with SF_6 in certain electrical equipment.
	Hydrogen Production (2.B.10.a)	Include CO_2 emissions resulting from stand-alone hydrogen production facilities in Canada.	Work is underway to estimate CO_2 emissions from hydrogen production using methods presented in the 2019 Refinement to the 2006 IPCC Guidelines.
	SF_6 and PFCs from other product use (2.G.2)	Data collection and significance assessment.	This category is currently reported as "not estimated". An evaluation of the significance of emissions from this category will be conducted. An activity data collection is planned and analysis of existing historical data is underway.
	PFC Emissions from Other Contained Product Uses (2.G.4)	Reallocation of all activity data to other CRT categories, such as applications in CRT 2.E.1, 2.F, or 2.G.2.	Following a TERT recommendation, activity data contributing to CRT 2.G.4 are under review and historical data sources are being looked at to reallocate activity data to the appropriate categories.

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

IPCC Sector	CRT Category	Improvement	Description
Agriculture	Enteric Fermentation / Manure Management (3.A/3.B) Agricultural Soils (3.D)	Integrate new information on animal nutrition.	Based on a TERT recommendation noting that production data have not been reviewed recently, continued improvements to the animal nutrition time series are being considered through the review and compilation of multiple data sources. Although priority is given to the beef sector, minor refinements to the dairy and swine sectors will be carried out as required. Data have been collected and analyzed, but new machine learning techniques are being evaluated and model development is not complete. Approval and alignment with Agriculture and Agri-Food Canada (AAFC) methodologies, specifically those used for estimating ammonia volatilization are required before database implementation.
	Enteric Fermentation / Manure Management (3.A/3.B) Agricultural Soils (3.D)	Update dairy nutrition parameters.	Based on a TERT recommendation noting that production data have not been reviewed recently, the dairy nutrition time series currently used to track changes in animal feed and characteristics for dairy cattle are being extended. Updates to the nutrition data for dairy cattle are being derived for years after 2010. Data have been acquired and are undergoing analysis. Approval and alignment with AAFC methodologies will be followed by a database implementation.
	Manure Management (3.B)	Integrate new information on manure management systems.	Based on the need to integrate new data into models, efforts are ongoing to integrate information from multiple surveys to develop a consistent representation of the changes in manure storage systems for beef over the reporting period, better capture changes in farm practices, and improve the accuracy of emission estimates. Data have been collected and analyzed, but machine learning techniques are being considered and require approval and alignment with AAFC methodologies, specifically those used for estimating ammonia volatilization before database implementation.
	Agricultural Soils (3.D)	Integrate estimates of N_2O emissions from land application of compost.	The availability of new data may allow the reporting of N_2O emissions from the application of compost to agricultural soils. A contract was carried out to collect information on land application of compost in Canada, and the resulting data is under analysis for future alignment and integration with the existing organic nitrogen fertilizer methodology.
	Field Burning of Agricultural Residues (3.F)	Improve estimates of crop residue burning.	More recent data on crop residue burning are available from the latest versions of the Farm Environmental Management Survey and Farm Management Survey, but these data have not yet been used for estimating GHG emissions. Survey data on field burning of agricultural residues will be extracted and incorporated into the database.
LULUCF	Cross-cutting	Address completeness of LULUCF subcategories with estimates reported as not estimated (NE).	A TERT recommendation notes that Canada needs to improve the completeness of reporting for carbon pools in mandatory categories currently reported as NE. Continual progress is expected in each subsequent version of the NIR.
	Cross-cutting	Development of a plan and time frame for estimating and reporting uncertainties for all LULUCF subcategories.	The TERT has noted that Canada provides detailed uncertainty analysis for most LULUCF subcategories. However, uncertainty analysis for all subcategories has not yet been prioritized. Uncertainty estimates for new and updated categories have been included in recent submissions. Canada aims to develop a plan for estimating, updating and reporting uncertainties for all LULUCF subcategories.
	Forest Conversion and other land-use change categories (it may impact Cropland, Wetlands, Settlements land categories and Harvested Wood Products, i.e., 4.B.2, 4.D.2, 4.E.2 and 4.G respectively)	Land-use change improvements.	As a part of efforts to address the completeness of LULUCF subcategories with estimates reported as not estimated (NE), as indicated by the TERT, improvements include: i) accounting for C loss resulting from agricultural drainage of inland mineral wetlands in the Prairie Potholes Region; ii) refining estimates of northern land-use change to account for wetland disturbances; iii) capturing the impacts of expanding cities on land C stocks and fluxes; iii) updating older time periods of deforestation activity data used by CBM-CFS3, and iv) updating deforestation impact assumptions.
	Forest Land (4.A) Harvested Wood Products (4.G)	Baseline data/processes/parameters improvements.	Improvements include: i) improved spatial distribution of harvest and volume-to-C allocation; ii) updating climate normal data; iii) continued integration of activity data associated with recent afforestation; and iv) provincial inventory updates.
	Forest Land (4.A) Biomass burning (4(V))	Science improvements.	Improvements include: i) refinements to wildfire emissions estimates through variable burn intensity; ii) refinements to British Columbia slash-burning activity; and iii) integrating nationwide estimates of controlled biomass burning in the NIR, Air Pollutant and Black Carbon Emissions Inventories.
	Forest Land (4.A)	Methodological Validation.	Canada will undertake analyses to validate aspects of its Forest Land methodology, specifically: i) revisiting Canada's natural/anthropogenic partitioning methodology in relation with human impacts on wildfire activity in managed forests through a Delphi consultation engaging a broad group of Canadian wildfire experts; ii) exploring long-term historic fluctuations in carbon emissions from fire activity and their interaction with Canada's natural/anthropogenic partitioning methodology using multi-century dendroecological fire history reconstructions; and iii) validating CBM estimates using a provincial network of permanent sampling plots.
	Harvested Wood Products (4.G)	Harvested Wood Products improvements.	Improvements include: i) adding regional detail to HWP production and trade parameters used in the HWP model; ii) enhancing the uncertainty analysis of HWP estimates by considering the uncertainty inherent to the C inputs; iii) developing country-specific half-lives for a significant portion of Canada's HWP production; and iv) improving knowledge and characterization of industrial fuelwood.
	Cropland (4.B.1)	An integrated modeling of soil carbon storage through Bayesian methods.	Datasets from Canadian literature on soil C storage impacted by tillage practices, intensification of cropping systems, perennial/annual crop conversion as well as soil C data from long-term crop rotation studies across Canada are being used to improve model performances through Bayesian optimization (RothC), IPCC Tier 2 Steady State, DeNitrification DeComposition (DNDC) and Introductory Carbon Budget Model (ICBM). As the first step in integration, efforts are underway to include tillage and crop productivity impacts using the IPCC Tier 2 model.

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

IPCC Sector	CRT Category	Improvement	Description
LULUCF (cont'd)	Cropland (4.B.1)	Soil C storage from biosolid application.	Soil N_2O emissions from biosolid applications are accounted for in agricultural soils, but their impact on soil C storage is not yet included, Efforts are underway to develop a method for estimating soil C storage from biosolid application on croplands.
	Cropland (4.B.1)	Woody Biomass improvements.	To better capture changes in woody biomass on croplands resulting from agricultural intensification and concurrent tree-planting efforts, work is underway to improve estimation of woody biomass changes in croplands C stocks using empirical data, earth observation data and deep learning methods. An age and vegetation category distributed model is underway as a first step of integration.
	Wetland Remaining Wetland (4.D.1) Land Converted to Wetland (Flooded Land) (4.D.2.b)	Emission factor improvements.	Improve knowledge and validate CH_4 and CO_2 emissions from flooded lands with new field measurements.
	Wetland Remaining Wetland (4.D.1) Wetland Converted to Settlement (4.E.2.d)	Land-use change improvements.	Improvements in estimates of emissions from wetland soils due to resource extraction activities in Alberta's oil sands region include: i) accounting for CH_4 emissions from saturated wetland soils, and ii) integrating forested wetlands by refining deforestation estimates, which currently classify forested wetlands as upland. Alignment with NRCan methodologies is required.
	Grassland Converted to Settlements (4.E.2.c) Settlements Remaining Settlements (4.E.1)	Land-use change improvements.	Improvements in estimates of carbon loss from northern land-use change include accounting for emissions from (i) non-permafrost soils, using existing spatial products and disturbance maps; and (ii) eventually permafrost soils, using similar data sources and methods (new science required).
	Settlements Remaining Settlements (4.E.1)	Land-use change improvements.	Improvements include: i) Updating 2005, 2015 and 2020 activity data by sampling digital air photos and high-resolution satellite imagery to estimate the proportion of urban tree canopy (UTC) cover in Canada's major urban areas; ii) updating urban area boundaries that better represent settlements, and iii) refine models to improve estimates of net fluxes from urban trees.
Waste	Municipal Landfills (5.A.1)	Inclusion of Tier 3, facility-reported emissions.	Work is underway to incorporate facility-level emissions modelling, and facility reported emissions.
	Wood Waste Landfills (5.A.2)	Improved wood waste emissions modelling.	Improvements underway include updates to the landfill first-order-decay modelling parameters for industrial solid wood waste landfills. Efforts also include improving the characterization of harvested wood products in the waste stream.
	Municipal Wastewater Treatment and Discharge (5.D.1)	Update to population associated with septic system treatment technology.	The improvement include further disaggregating the spatial distribution of septic-use rates to include small and medium sized cities. Current methods assess septic use to the level of larger cities (census metropolitan areas) and with the remainder of the provinces or territories assessed as one region. Updates to regional septic use will also influence estimates of population using centralized treatment systems.
	Municipal Wastewater Treatment and Discharge (5.D.1)	Inclusion of combined sewer overflow.	Efforts are underway to compile and model occurrences of combined sewer overflow, to account for this contribution to untreated discharge to receiving waterbodies.
	Municipal Wastewater Treatment and Discharge (5.D.1)	Development of country-specific parameters.	Work is underway to update and develop country-specific parameters for the removal of biological oxygen demand (BOD_5) and nitrogen removal from wastewater via treatment. These parameters influence the estimated amounts remaining in effluent discharged to the environment and the resulting emissions.

KEY CATEGORIES

A1.1. Key Categories – Methodology

This annex presents the use of an Intergovernmental Panel on Climate Change (IPCC) Approach 1 key category analysis and results for Canada's inventory submission. The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) recommend as good practice the identification of key categories of emissions and removals. The intent is to help inventory agencies prioritize their efforts to improve overall estimates. A key category is defined as "one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level of emissions and removals, the trend in emissions and removals, or uncertainty in emissions and removals" (IPCC, 2006); this term is used in reference to both source and sink categories. As such, higher tiered methodologies (Tier 2 or Tier 3) are encouraged for key categories.

Good practice first requires that inventories be disaggregated into categories from which key sources and sinks may be identified. Source and sink categories are defined according to the following guidelines:

- IPCC categories should be used with emissions expressed in carbon dioxide (CO_2) equivalent units according to standard global warming potentials (GWPs).
- A category should be identified for each gas emitted or removed, since the methods, emission factors, and related uncertainties differ for each gas.

The IPCC Approach 1 is used to identify key categories from two perspectives: their contribution to the overall emissions and their contribution to the emission trend. The level assessment analyzes the emission contribution that each category makes to the national total (with and without Land Use, Land-Use Change and Forestry [LULUCF]). The trend assessment uses each category's relative contribution to the overall emissions while assigning greater weight to the categories whose relative trend departs from the overall trend (with and without LULUCF). A cumulative contribution threshold of 95% for both level and trend assessments is a reasonable approximation of 90% uncertainty for the Approach 1 method of determining key categories (IPCC, 2006). This threshold has therefore been used in this analysis to define an upper boundary for key category identification. Hence, when source and sink contributions are sorted in decreasing order of importance, those largest ones that together contribute to 95% of the cumulative total are considered quantitatively to be key categories.

Key categories were assessed for the 2024 inventory year using level and trend criteria and for the base year using the level criterion only. The IPCC Approach 1 key categories tool provided within the Enhanced Transparency Framework (ETF) GHG Inventory Reporting Tool was used for this inventory.[1] It was found that when excluding LULUCF, there were 29 level key categories in 1990, while in 2024 there were 35 with all combined criteria. Combined assessment results are presented in Table A1–1. The top five categories that have the strongest influence on the national trend (excluding LULUCF) are:

1. 1.A.1 – Fuel Combustion – Energy Industries – Gaseous Fuel, CO_2
2. 1.A.1 – Fuel Combustion – Energy Industries – Solid Fuel, CO_2
3. 1.A.3.b – Transport – Road Transportation, CO_2
4. 1.A.4 – Other Sectors – Liquid Fuels, CO_2
5. 1.A.2 – Fuel Combustion – Manufacturing Industries and Construction – Liquid Fuels, CO_2

The integration of the LULUCF sector introduces additional key categories and alters the categories' relative contributions and overall trends, which causes a rearrangement in the ranking of key categories. For example, the LULUCF category, Forest Land Remaining Forest Land (CO_2) is ranked as the second-highest contributor in the trend assessments. When including LULUCF, there were 37 level key categories in 1990, while in 2024, there are 43 with all combined criteria. The trend assessment for 2024 without LULUCF identifies 29 key categories, while the same analysis with LULUCF results in 35 key categories, including eight categories from the LULUCF sector. The top five categories that have the strongest influence on the national trend (including LULUCF) are:

1. 1.A.1 – Fuel combustion – Energy Industries – Gaseous Fuels, CO_2
2. 4.A.1 – LULUCF – Forest Land – Forest Land Remaining Forest Land, CO_2
3. 1.A.1 – Fuel combustion – Energy Industries – Solid Fuels, CO_2
4. 4.G – LULUCF – Harvested Wood Products, CO_2
5. 1.A.3.b – Transport – Road Transportation, CO_2

1 https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review/transparency-data-and-tools/etf-reporting-tools

Table A1–1 represents the analysis of key categories for the latest inventory year and the base year. This table is adapted from the common reporting tables (CRT) Table 7. The disaggregation by gas and by fuel type (when appropriate) follows the suggested aggregation level of analysis for Approach 1 as indicated in the 2006 IPCC Guidelines.

The complete key category assessment along with the percent contributions to both levels and trends in emissions for both the base year and the latest year is available on the Government of Canada's Open Data website.[2]

Table A1–1 1990 Key Categories by Level Assessment With and Without LULUCF

Key Categories of Emissions and Removals	Gas	Criteria used for key source identification		Key category excluding LULUCF	Key category including LULUCF
		L	T		
1.A.1 Fuel combustion – Energy Industries – Liquid Fuels	CO_2	X	X	X	X
1.A.1 Fuel combustion – Energy Industries – Liquid Fuels	CH_4				
1.A.1 Fuel combustion – Energy Industries – Liquid Fuels	N_2O				
1.A.1 Fuel combustion – Energy Industries – Solid Fuels	CO_2	X	X	X	X
1.A.1 Fuel combustion – Energy Industries – Solid Fuels	CH_4				
1.A.1 Fuel combustion – Energy Industries – Solid Fuels	N_2O				
1.A.1 Fuel combustion – Energy Industries – Gaseous Fuels	CO_2	X	X	X	X
1.A.1 Fuel combustion – Energy Industries – Gaseous Fuels	CH_4	X	X	X	X
1.A.1 Fuel combustion – Energy Industries – Gaseous Fuels	N_2O				
1.A.1 Fuel combustion – Energy Industries – Other Fossil Fuels	CO_2				
1.A.1 Fuel combustion – Energy Industries – Other Fossil Fuels	CH_4				
1.A.1 Fuel combustion – Energy Industries – Other Fossil Fuels	N_2O				
1.A.1 Fuel combustion – Energy Industries – Peat	CO_2				
1.A.1 Fuel combustion – Energy Industries – Peat	CH_4				
1.A.1 Fuel combustion – Energy Industries – Peat	N_2O				
1.A.1 Fuel combustion – Energy Industries – Biomass	CH_4				
1.A.1 Fuel combustion – Energy Industries – Biomass	N_2O				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Liquid Fuels	CO_2	X	X	X	X
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Liquid Fuels	CH_4				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Liquid Fuels	N_2O				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Solid Fuels	CO_2	X	X	X	X
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Solid Fuels	CH_4				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Solid Fuels	N_2O				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Gaseous Fuels	CO_2	X	X	X	X
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Gaseous Fuels	CH_4				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Gaseous Fuels	N_2O				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Other Fossil Fuels	CO_2				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Other Fossil Fuels	CH_4				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Other Fossil Fuels	N_2O				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Peat	CO_2				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Peat	CH_4				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Peat	N_2O				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Biomass	CH_4				
1.A.2 Fuel combustion – Manufacturing Industries and Construction – Biomass	N_2O				
1.A.3.a Domestic Aviation	CO_2	X		X	X
1.A.3.a Domestic Aviation	CH_4				
1.A.3.a Domestic Aviation	N_2O				
1.A.3.b Road Transportation	CO_2	X	X	X	X
1.A.3.b Road Transportation	CH_4				
1.A.3.b Road Transportation	N_2O		X	X	X
1.A.3.c Railways	CO_2	X		X	X
1.A.3.c Railways	CH_4				
1.A.3.c Railways	N_2O				
1.A.3.d Domestic Navigation – Liquid Fuels	CO_2	X		X	X

2 https://data-donnees.az.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/

Table A1–1 **1990 Key Categories by Level Assessment With and Without LULUCF** (cont'd)

Key Categories of Emissions and Removals	Gas	Criteria used for key source identification		Key category excluding LULUCF	Key category including LULUCF
		L	T		
1.A.3.d Domestic Navigation – Liquid Fuels	CH_4				
1.A.3.d Domestic Navigation – Liquid Fuels	N_2O				
1.A.3.d Domestic Navigation – Gaseous Fuels	CO_2				
1.A.3.d Domestic Navigation – Gaseous Fuels	CH_4				
1.A.3.d Domestic Navigation – Gaseous Fuels	N_2O				
1.A.3.d Domestic Navigation – Other Fossil Fuels	CO_2				
1.A.3.d Domestic Navigation – Other Fossil Fuels	CH_4				
1.A.3.d Domestic Navigation – Other Fossil Fuels	N_2O				
1.A.3.d Domestic Navigation – Biomass Fuels	CH_4				
1.A.3.d Domestic Navigation – Biomass Fuels	N_2O				
1.A.3.e Other Transportation	CO_2	X	X	X	X
1.A.3.e Other Transportation	CH_4				
1.A.3.e Other Transportation	N_2O				
1.A.4 Other Sectors – Liquid Fuels	CO_2	X	X	X	X
1.A.4 Other Sectors – Liquid Fuels	CH_4				
1.A.4 Other Sectors – Liquid Fuels	N_2O				
1.A.4 Other Sectors – Solid Fuels	CO_2				
1.A.4 Other Sectors – Solid Fuels	CH_4				
1.A.4 Other Sectors – Solid Fuels	N_2O				
1.A.4 Other Sectors – Gaseous Fuels	CO_2	X	X	X	X
1.A.4 Other Sectors – Gaseous Fuels	CH_4				
1.A.4 Other Sectors – Gaseous Fuels	N_2O				
1.A.4 Other Sectors – Other Fossil Fuels	CO_2				
1.A.4 Other Sectors – Other Fossil Fuels	CH_4				
1.A.4 Other Sectors – Other Fossil Fuels	N_2O				
1.A.4 Other Sectors – Peat	CO_2				
1.A.4 Other Sectors – Peat	CH_4				
1.A.4 Other Sectors – Peat	N_2O				
1.A.4 Other Sectors – Biomass	CH_4				
1.A.4 Other Sectors – Biomass	N_2O				
1.A.5 Other (Not specified elsewhere) – Liquid Fuels	CO_2				
1.A.5 Other (Not specified elsewhere) – Liquid Fuels	CH_4				
1.A.5 Other (Not specified elsewhere) – Liquid Fuels	N_2O				
1.A.5 Other (Not specified elsewhere) – Solid Fuels	CO_2				
1.A.5 Other (Not specified elsewhere) – Solid Fuels	CH_4				
1.A.5 Other (Not specified elsewhere) – Solid Fuels	N_2O				
1.A.5 Other (Not specified elsewhere) – Gaseous Fuels	CO_2				
1.A.5 Other (Not specified elsewhere) – Gaseous Fuels	CH_4				
1.A.5 Other (Not specified elsewhere) – Gaseous Fuels	N_2O				
1.A.5 Other (Not specified elsewhere) – Other Fossil Fuels	CO_2				
1.A.5 Other (Not specified elsewhere) – Other Fossil Fuels	CH_4				
1.A.5 Other (Not specified elsewhere) – Other Fossil Fuels	N_2O				
1.A.5 Other (Not specified elsewhere) – Peat	CO_2				
1.A.5 Other (Not specified elsewhere) – Peat	CH_4				
1.A.5 Other (Not specified elsewhere) – Peat	N_2O				
1.A.5 Other (Not specified elsewhere) – Biomass	CH_4				
1.A.5 Other (Not specified elsewhere) – Biomass	N_2O				
1.B.1 Fugitive emissions from Solid Fuels	CO_2				
1.B.1 Fugitive emissions from Solid Fuels	CH_4		X	X	X
1.B.2.a Fugitive Emissions from Fuels – Oil and Natural Gas – Oil	CO_2				
1.B.2.a Fugitive Emissions from Fuels – Oil and Natural Gas – Oil	CH_4	X		X	X
1.B.2.b Fugitive Emissions from Fuels – Oil and Natural Gas – Natural Gas	CO_2				
1.B.2.b Fugitive Emissions from Fuels – Oil and Natural Gas – Natural Gas	CH_4	X	X	X	X

Table A1–1 **1990 Key Categories by Level Assessment With and Without LULUCF** (cont'd)

Key Categories of Emissions and Removals	Gas	Criteria used for key source identification		Key category excluding LULUCF	Key category including LULUCF
		L	T		
1.B.2.c Fugitive Emissions from Fuels – Venting and flaring	CO_2	X	X	X	X
1.B.2.c Fugitive Emissions from Fuels – Venting and flaring	CH_4	X	X	X	X
1.B.2.c Fugitive Emissions from Fuels – Venting and flaring	N_2O				
1.B.2.d Fugitive Emissions from Fuels – Other	CO_2				
1.B.2.d Fugitive Emissions from Fuels – Other	CH_4				
1.B.2.d Fugitive Emissions from Fuels – Other	N_2O				
1.C CO_2 Transport and Storage	CO_2				
1. Energy (indirect CO_2 emissions)	CO_2				
2.A.1 Cement Production	CO_2	X		X	X
2.A.2 Lime Production	CO_2				
2.A.3 Glass Production	CO_2				
2.A.4 Other Process Uses of Carbonates	CO_2				
2.B.1 Ammonia Production	CO_2				
2.B.1 Ammonia Production	CH_4				
2.B.1 Ammonia Production	N_2O				
2.B.2 Nitric Acid Production	N_2O				
2.B.3 Adipic Acid Production	CO_2				
2.B.3 Adipic Acid Production	N_2O				
2.B.4 Caprolactam, Glyoxal and Glyoxylic Acid Production	CO_2				
2.B.4 Caprolactam, Glyoxal and Glyoxylic Acid Production	N_2O				
2.B.5 Carbide Production	CO_2				
2.B.5 Carbide Production	CH_4				
2.B.6 Titanium Dioxide Production	CO_2				
2.B.7 Soda Ash Production	CO_2				
2.B.8 Petrochemical and Carbon Black Production	CO_2				
2.B.8 Petrochemical and Carbon Black Production	CH_4				
2.B.9 Fluorochemical Production	Aggregate F-gases				
2.B.10 Other	CO_2				
2.B.10 Other	CH_4				
2.B.10 Other	N_2O				
2.B.10 Other	Aggregate F-gases				
2.C.1 Iron and Steel Production	CO_2	X	X	X	X
2.C.1 Iron and Steel Production	CH_4				
2.C.2 Ferroalloys Production	CO_2				
2.C.2 Ferroalloys Production	CH_4				
2.C.3 Aluminium Production	CO_2	X	X	X	X
2.C.3 Aluminium Production	PFCs		X	X	X
2.C.3 Aluminium Production	SF_6				
2.C.4 Magnesium Production	CO_2				
2.C.4 Magnesium Production	HFCs				
2.C.4 Magnesium Production	PFCs				
2.C.4 Magnesium Production	SF_6		X	X	X
2.C.4 Magnesium Production	Unspecified mix of HFCs and PFCs				
2.C.5 Lead Production	CO_2				
2.C.6 Zinc Production	CO_2				
2.C.7 Other	CO_2				
2.C.7 Other	CH_4				
2.C.7 Other	N_2O				
2.C.7 Other	Aggregate F-gases				
2.D Non-energy Products from Fuels and Solvent Use	CO_2	X	X	X	X
2.D Non-energy Products from Fuels and Solvent Use	CH_4				
2.D Non-energy Products from Fuels and Solvent Use	N_2O				

Table A1–1 **1990 Key Categories by Level Assessment With and Without LULUCF** (cont'd)

Key Categories of Emissions and Removals	Gas	Criteria used for key source identification		Key category excluding LULUCF	Key category including LULUCF
		L	T		
2.E Electronics Industry	N_2O				
2.E Electronics Industry	Aggregate F-gases				
2.F.1 Refrigeration and Air conditioning	Aggregate F-gases	X	X	X	X
2.F.2 Foam Blowing Agents	Aggregate F-gases		X	X	X
2.F.3 Fire Protection	Aggregate F-gases				
2.F.4 Aerosols	Aggregate F-gases				
2.F.5 Solvents	Aggregate F-gases				
2.F.6 Other Applications	Aggregate F-gases				
2.G Other Product Manufacture and Use	CO_2				
2.G Other Product Manufacture and Use	CH_4				
2.G Other Product Manufacture and Use	N_2O				
2.G Other Product Manufacture and Use	Aggregate F-gases				
2.H Other	CO_2				
2.H Other	CH_4				
2.H Other	N_2O				
2.H Other	Aggregate F-gases				
2. Industrial Proccesses and Produc Use (indirect CO_2 emissions)	CO_2				
3.A Enteric Fermentation	CH_4	X	X	X	X
3.B Manure Management	CH_4	X	X	X	X
3.B Manure Management	N_2O	X		X	X
3.C Rice Cultivation	CH_4				
3.D Agricultural Soils	CH_4				
3.D.1 Direct N_2O Emissions From Managed Soils	N_2O	X	X	X	X
3.D.2 Indirect N_2O Emissions From Managed Soils	N_2O	X	X	X	X
3.E Prescribed burning of savannas	CH_4				
3.E Prescribed burning of savannas	N_2O				
3.F Field burning of agricultural residues	CH_4				
3.F Field burning of agricultural residues	N_2O				
3.G Liming	CO_2				
3.H Urea Application	CO_2		X	X	X
3.I. Other carbon-containing fertlizers	CO_2				
3.J. Other	CO_2				
3.J. Other	CH_4				
3.J. Other	N_2O				
3. Agriculture (indirect CO_2 emissions)	CO_2				
4.A.1 Forest Land Remaining Forest Land	CO_2	X	X		X
4.A.2 Land Converted to Forest Land	CO_2				
4.B.1 Cropland Remaining Cropland	CO_2	X	X		X
4.B.2 Land Converted to Cropland	CO_2	X	X		X
4.C.1 Grassland Remaining Grassland	CO_2				
4.C.2 Land Converted to Grassland	CO_2				
4.D.1.1 Peat Extraction Remaining Peat Extraction	CO_2				
4.D.1.2 Flooded Land Remaining Flooded Land	CO_2				
4.D.1.3 Other Wetlands Remaining Other Wetlands	CO_2				
4.D.2 Land Converted to Wetlands	CO_2		X		X
4.E.1 Settlements Remaining Settlements	CO_2	X			X
4.E.2 Land Converted to Settlements	CO_2	X			X
4.F.1 Other Land Remaining Other Land	CO_2				
4.F.2 Land Converted to Other Land	CO_2				
4.G Harvested Wood Products	CO_2		X		X
4(I). Direct and indirect N_2O emissions from N inputs to managed soils	N_2O				
4(II). Emissions and removals from drainage and rewetting and other management of organic and mineral soils	CO_2				

Table A1–1 **1990 Key Categories by Level Assessment With and Without LULUCF** (cont'd)

Key Categories of Emissions and Removals	Gas	Criteria used for key source identification		Key category excluding LULUCF	Key category including LULUCF
		L	T		
4(II). Emissions and removals from drainage and rewetting and other management of organic and mineral soils	CH_4				
4(II). Emissions and removals from drainage and rewetting and other management of organic and mineral soils	N_2O				
4(III). Direct and indirect N_2O emissions from N mineralization/immobilization	N_2O				
4(IV) Biomass Burning	CO_2	X	X		X
4(IV) Biomass Burning	CH_4				
4(IV) Biomass Burning	N_2O				
4.H Other	CO_2				
4.H Other	CH_4				
4.H Other	N_2O				
4. LULUCF (indirect CO_2 emissions)	CO_2				
5.A Solid Waste Disposal	CH_4	X	X	X	X
5.B Biological Treatment of Solid Waste	CH_4				
5.B Biological Treatment of Solid Waste	N_2O				
5.C Incineration and Open Burning of Waste	CO_2				
5.C Incineration and Open Burning of Waste	CH_4				
5.C Incineration and Open Burning of Waste	N_2O				
5.D Wastewater Treatment and Discharge	CH_4				
5.D Wastewater Treatment and Discharge	N_2O				
5.E Other	CO_2				
5.E Other	CH_4				
5.E Other	N_2O				
5. Waste (indirect CO_2 emissions)	CO_2				
6. Other	CO_2				
6. Other	CH_4				
6. Other	N_2O				
6. Other	Aggregate F-gases				
6. Other (indirect CO_2 emissions)	CO_2				

Note:
L = level assessment
T = trend assessment

ANNEX 2

UNCERTAINTY

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A2.1. Introduction

Each Party to the Paris Agreement shall report the results of the uncertainty analysis as well as methods used, underlying assumptions, as applicable, and trends, at least for the starting year and the latest reporting year of the time series in their respective national inventory reports. Uncertainty analysis helps to prioritize improvements of future inventories and to guide decisions on methodological choice (IPCC, 2006).

In this submission, Canada used the error propagation method (Approach 1) for combining uncertainties, as outlined in Volume 1 (Chapter 3) of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). This method is used to assess the uncertainty in emission estimates for the base year, the latest year and the trend. Uncertainty estimates were combined by completing Table 3.3 (of the 2006 IPCC Guidelines) at the source category level. Uncertainty estimates for each source/sink category were either retained from previous studies (e.g., a comprehensive Monte Carlo analysis (Approach 2) conducted in 2003/2004), improved upon on the basis of these studies, or derived independently as in the Agriculture (methane [CH_4] and nitrous oxide [N_2O]), Energy (some fuel combustion categories and fugitive emissions), Industrial Processes and Product Use (IPPU) and Land Use, Land-Use Change and Forestry (LULUCF) sectors. For details on uncertainty related to specific sectors, refer to the uncertainty sections throughout chapters 3 to 7.

The complete uncertainty assessment tables are available on the Government of Canada's Open Data website.[1] The current annex refers to tables on that website.

A2.2. Interpretation of Uncertainty about Inventory Estimates

Often, uncertainty about GHG estimates is incorrectly interpreted as a measure of accuracy or reliability. In fact, accuracy (or its inverse, bias) can only be quantified by measuring departure from the true value. Uncertainty estimation for inventories is not designed as a measure of accuracy, rather in the context of national inventories, the process of uncertainty estimation mostly aims to quantify precision. High uncertainty about a category estimate suggests it would be difficult to obtain agreement among repeated measurements. This can arise from many factors, including true heterogeneity over time and space: variability is an inherent property of many systems, including nature.

In IPCC good practice guidance, uncertainty information is primarily a "means to help prioritise efforts to improve the accuracy of inventories in the future and guide decisions on methodological choice…" (IPCC, 2006, vol 1, Chapter 3). Minimizing bias and obtaining reliable estimates are better achieved by implementing good practice in estimate development.

1 https://data-donnees.az.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/

A2.3. Uncertainty Assessment on 2024 Greenhouse Gas Emissions and Removals

Separate analyses were conducted for the inventory as a whole with and without LULUCF. The 2024 national emission estimate (not including the LULUCF sector) of 685 Mt CO_2 eq lies within an uncertainty range of 666 Mt CO_2 eq to 703 Mt CO_2 eq (±2.7%) (refer to Table A2–1 on the Government of Canada's Open Data website). The five emission source categories that made the largest contributions to uncertainty at the national level, for 2024, when LULUCF is not included were:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
2. Agriculture – Enteric Fermentation, CH_4
3. Agriculture – Direct Agriculture Soils, N_2O
4. Agriculture – Indirect Agriculture Soils, N_2O
5. Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries, CH_4

The 2024 national emission estimate, including LULUCF emissions and removals, of 689 Mt CO_2 eq, lies within an uncertainty range of 639 Mt CO_2 eq to 739 Mt CO_2 eq (±7.2%) (refer to Table A2–2 on the Government of Canada's Open Data website). The top five contributors influencing the national uncertainty when LULUCF is included were:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
2. Agriculture – Enteric Fermentation, CH_4
3. Agriculture – Direct Agriculture Soils, N_2O
4. Agriculture – Indirect Agriculture Soils, N_2O
5. Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries, CH_4

A2.4. Uncertainty Assessment on Base Year Greenhouse Gas Emissions and Removals

The uncertainty for the base year of the national emission estimate (not including the LULUCF sector) is similar to the 2024 uncertainty (±2.9% and ±2.7%, respectively) (refer to Table A2–1 on the Government of Canada's Open Data website). The five emission source categories that made the largest contributions to uncertainty at the national level, for 1990, when LULUCF is not included are:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
2. Agriculture – Enteric Fermentation, CH_4
3. Fuel Combustion – Public Electricity and Heat Production, CO_2
4. Wastewater Treatment and Discharge, CH_4
5. Agriculture – Direct Agriculture Soils, N_2O

When LULUCF emissions and removals are included, the uncertainty for the base year is different from 2024 uncertainty (±11.0% and ±7.2%, respectively) (refer to Table A2–2 on the Government of Canada's Open Data website). The top five influencers to the national uncertainty for 1990 when LULUCF is included are:

1. LULUCF – Forest Land Remaining Forest Land, CO_2
2. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
3. LULUCF – Conversion of Forest Land, CO_2
4. Agriculture – Enteric Fermentation, CH_4
5. Energy – Fuel Combustion – Public Electricity and Heat Production, CO_2

A2.5. Uncertainty Assessment by Trend

The calculation of trend uncertainty was performed without and with the LULUCF sector (refer to Table A2–3 and A2–4 on the Government of Canada's Open Data website). The trend uncertainty, excluding LULUCF, was found to be 0.77%. Therefore, the total increase in emissions since 1990 of 77 Mt CO_2 eq (+12.6%) falls within an uncertainty range of a minimum of +76 Mt CO_2 eq to a maximum of +77 Mt CO_2 eq. When including LULUCF, the trend uncertainty was found to be 9.71%. Therefore, when including LULUCF, the total increase in emissions since 1990 of 20 Mt CO_2 eq (+3.0%) falls within an uncertainty range of a minimum of +18 Mt CO_2 eq to a maximum of +22 Mt CO_2 eq.

A2.6. Planned Improvements

Continuous improvement is one of the principles upon which Canada develops its annual GHG inventory. Planned improvements associated with uncertainty assessment will likely build on previous methods and databases, including making use of the Monte Carlo simulation data and methods performed in 2003–2004. New methodological changes and refinements consider the impact on uncertainty prior to implementation and therefore provide a basis for regular incremental improvement to the uncertainty analysis.

Uncertainty estimation of national emissions is the topic of a working paper released in 2020 (Laferrière et al., 2020). This study compares actual Tier 1 uncertainty estimates with a more general approach, namely Monte Carlo simulations. The comparison highlights:

- the impact on emissions uncertainty related with asymmetrical probability distribution function (PDF) and PDF other than normal;
- the effect of incorporating emission correlation across IPCC source category—often, it is difficult to justify the Tier 1 assumption that emission factors are uncorrelated across categories—the paper shows the importance of its recognition and compares trend uncertainty and category contribution to uncertainty; and
- the possibility to factor in dual uncertainty levels for the activity variables (for example, categories comprised of multiple activity datasets may individually have high uncertainty values but when aggregated the final result may have a lower uncertainty value).

For the current version of the inventory, uncertainty estimates in the Waste sector were updated to accommodate the inclusion of emissions from residential waste composting and residential waste burning. Improvements with respect to uncertainty estimates will continue for other categories in future inventories. Chapter 8 provides a summary of planned improvements.

ANNEX 3

METHODOLOGIES

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A3.1. Methodology and Data for Estimating Emissions from Fossil Fuel Combustion

The following presents an overview of the methodology, activity data and emission factors used to estimate carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions from fuel combustion sources for the Energy sector.

A3.1.1. Methodology

In general, estimating greenhouse gas (GHG) emissions from fuel combustion activities uses a top-down method, following the Tier 3 and Tier 2 sectoral approach from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). As illustrated by Equation A3.1–1, to calculate the emission for each source category, the quantity of fuel at the national, provincial and territorial level is multiplied by the corresponding fuel-specific emission factor. Sections A3.1.4.1 and A3.1.4.2 discuss refinements and deviations from the general approach to estimating combustion emissions from stationary and transport sources, respectively. The purpose of these refinements is to continuously improve the accuracy and allocation of the emissions when additional details or parameters are available. The Energy chapter (Chapter 3) of this report discusses specific methodological issues.

Equation A3.1–1 **for general fuel combustion**

$$E_{Category,G} = FC_{F,R} * EF_{G,F,R,T}$$

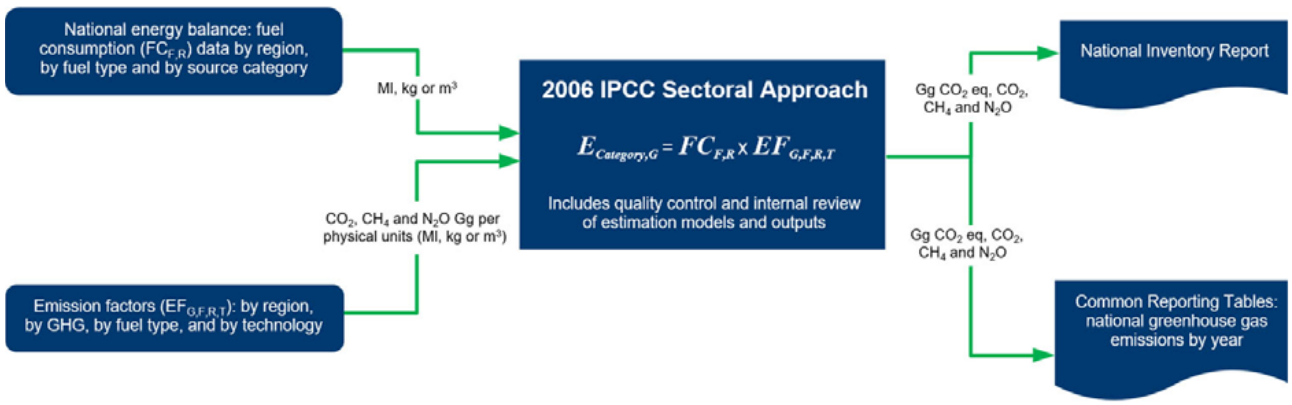
$E_{Category,G}$ = GHG emissions by source category and by GHG (CO_2, CH_4 or N_2O)

$FC_{F,R}$ = quantity of fuel consumed (in physical units, such as kg, L, or m^3) by fuel type (i.e. natural gas, sub-bituminous coal, kerosene, etc.) and by region

$EF_{G,F,R,T}$ = country-specific emission factor (in physical units) by GHG, by fuel type, by region (where available) and by technology (for non-CO_2 factors)

The stationary combustion and transport models primarily use relational databases to process the national-, provincial- and territorial-activity data and emission factors used to estimate GHG emissions (Figure A3.1–1). Statistics Canada presents the national energy balance in physical units using data reported by the producing and consuming sectors. For this reason, the physical units were judged the most accurate for generating emission estimates. Country-specific emission factors, as applied, are in physical units to minimize the number of additional conversion factors and thus limit the uncertainty associated with estimates. The uncertainty of estimates is further reduced by applying available higher-resolution emission factors at the provincial and territorial level rather than the national level (e.g., regional coal and natural gas emission factors are used to account for the variation in carbon content). Non-CO_2 emission factors address any existing combustion technology differences.

Figure A3.1–1 **GHG Estimation Process Flow**



A3.1.2. Activity Data from Statistics Canada

The principal source of fuel and energy data used to estimate combustion emissions is the annual *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada, n.d.[d]), also referred to as the national energy balance. The RESD uses both top-down and bottom-up approaches to compile the supply of, and demand for, energy in Canada. The production of fuels in Canada is balanced with the use of fuels in broad categories such as import/export, producer consumption, residential, and industry. Industrial energy-use data is allocated using the North American Industry Classification System (NAICS). Currently, the RESD reports energy used to generate electricity or steam by industry (auto producers) in two separate lines (one for electricity and one for steam), without any further disaggregation by industrial subcategories. Prior to 1998, the Industrial Consumption of Energy Survey (ICE) (Statistics Canada, n.d.[a]) provided these summary line quantities. From 1998 on, the electricity line (from auto producers) is based on the quantities reported in the Annual Survey of Electric Power Thermal Generating Station Fuel Consumption (EPTG) (Statistics Canada, n.d.[b]). Statistics Canada implemented this improvement to increase the transparency and accuracy of subsector information, since the fuel used to generate electricity is more complete and of higher quality. The steam line continues to be populated using the ICE data.

While the RESD provides fuel use data at a provincial and territorial level, the accuracy of these data is generally not as high as that of the national data. Statistics Canada typically allocates final fuel demand by subcategories for the RESD through several surveys directed at producers and suppliers of energy, provincial and territorial energy ministries and some end-users of energy. The accuracy following these allocations is less than that of the total available energy supply at the national level. As a result, the total emission estimates for Canada are more certain than the emissions from specific subcategories. Since 1995, Statistics Canada has been collecting energy statistics directly from end users through the annual ICE survey. Estimating fuel use by industry using a bottom-up approach provides more accurate subcategory information. Refer to Annex 4, National Energy Balance, for additional discussion on the development of the RESD and the ICE data set, including a discussion of Statistics Canada's quality assurance / quality control activities. Sector-specific surveys provide verification of sector trends and emissions allocation.

In general, combustion models apply the quantity of fossil fuel consumed in physical units rather than in energy units, as up-to-date energy content values are not always available to some suppliers and end-users when completing their respective Statistics Canada surveys. As a result, it is assumed that information in gross calorific units is less accurate. When converting to energy values, except for natural gas, Statistics Canada applies constant energy conversion factors (a factor for 1990 to 1997 and another factor for 1998 onward) to each fuel type without considering year-to-year variability in fuels such as coal, petroleum coke and refinery fuel gas (still gas). These energy conversion factors are applied for the reporting of fuel quantities in the Common Reporting Tables (CRT), and nationally weighted values are determined for reference approach calculations (refer to Table A4–2 for details). One exception involves waste fuels, for which the data from 1990 to 2016 are only available in energy units from the Cement Association of Canada. From 2017 on, waste fuel data comes from the Greenhouse Gas Reporting Program (GHGRP), which is aggregated in energy units to account for the variation in waste fuels. Statistics Canada and Environment and Climate Change Canada (ECCC) have initiated a multi-year work program to better track and update energy conversion factors. Refer to the Planned Improvement section of Chapter 3 for further details.

Additional non-Statistics Canada data sources used by the combustion and transport models, such as landfill gas quantities, waste fuel consumption and vehicle fleet information, are included in the specific methodological discussions (sections A3.1.4.1 and A3.1.4.2).

A3.1.3. Fuel Combustion Emission and Oxidation Factors

The following is a summary of the emission factors for fuels that are the largest contributors to Canadian GHG emissions. A detailed description of emission factors used in the current fossil fuel combustion models can be found in Annex 6.

Natural Gas: CO_2 emission factors vary depending on the source of natural gas and whether the product is marketable or non-marketable (raw natural gas for on-site consumption by natural gas producers). It also accounts for the change in hydrocarbon composition of marketable natural gas over time, as presented in Table A6.1–1. Therefore, provinces and territories have varying emission factors based on yearly domestic and foreign natural gas supplied and its hydrocarbon composition. The emission factors for CH_4 and N_2O vary with the combustion technology.

Refined Petroleum Products (RPP): Refined petroleum products include, but are not limited to, fuels such as diesel, gasoline, light fuel oil and heavy fuel oil. The emission factors vary with fuel type and/or combustion technology (for CH_4 and N_2O).

Coal: CO_2 emission factors vary by the coal properties, province of use and coal origin, whether domestic or foreign. The emission factors for CH_4 and N_2O vary by the combustion technology.

The Intergovernmental Panel on Climate Change (IPCC) default oxidation value applies to all fuels except coal, where country-specific oxidation factors applied at the provincial and territorial level reflect regional variations in combustion efficiencies. Refer to Annex 6 for more detail on coal oxidation factors.

A3.1.3.1. CO_2 Emission Factors

CO_2 emissions from fuel combustion activities depend on the amount of fuel consumed, the carbon content of the fuel and the applied oxidation factor. The applied emission factors vary by fuel type and by region, where applicable. There is discussion of CO_2 emission factor derivation in Annex 6. Fuel properties, such as carbon content, density and heating value, were determined using accepted industrial testing standards from the American Society for Testing and Materials (ASTM) and the Canadian General Standards Board (CGSB).

The waste fuel emission factor is based on energy content since activity data reported by the Cement Association of Canada and the GHGRP are in energy units.

A3.1.3.2. Non-CO_2 Emission Factors

Emission factors for all non-CO_2 GHGs from combustion activities vary to a greater or lesser degree with:

- fuel type
- technology
- operating conditions
- maintenance and vintage of technology

During the combustion of carbon-based fuels, a small portion of the fuel remains unoxidized as CH_4. Additional research is needed to better establish CH_4 emission factors for many combustion processes. Overall factors were developed for sectors based on typical technologies and available emission factors.

During combustion, some of the nitrogen in the fuel and air is converted to N_2O. The production of N_2O is dependent on the combustion temperature and the emission control technology employed. Additional research is needed to better establish N_2O emission factors for many combustion processes. Overall factors were developed for sectors based on typical technologies and available emission factors. Annex 6 lists non-CO_2 emission factors used in this inventory.

A3.1.4. Methodology for Stationary Combustion and Transport

This section discusses methods used to calculate and report emissions associated with the Energy sector, and specifically stationary combustion and transport.

For reporting under the Enhanced Transparency Framework of the Paris Agreement, CO_2 emissions from biomass fuels (including landfill gas) are not to be included in the Energy sector total. The Land Use, Land-Use Change and Forestry (LULUCF) sector accounts for CO_2 emissions from biomass fuel combustion as a loss of biomass (forest) stocks. CO_2 emissions from biomass combustion for energy use is a memo item in the data reporting tables and is provided for information purposes. The Energy sector reports CH_4 and N_2O emissions from biomass fuel combustion in the appropriate subcategories and includes them in the inventory totals.

A3.1.4.1. Stationary Combustion

The methodology used to estimate GHG emissions from stationary fuel combustion is consistent with the IPCC Tier 2 sectoral approach, along with country-specific emission factors as outlined in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). The Industrial Processes and Product Use sector (Annex 3.3) presents the methodology for calculating SF_6 emissions from electrical transmission systems.

Emission calculations use provincial and territorial reported activity data and national emission factors, except when emission factors are available at the provincial and territorial level. The national total is the aggregated sum of the provincial and territorial emissions.

Emission estimates are calculated using Equation A3.1–1 exclusively.

Table A3.1–1 presents activity data sources used in the stationary combustion model methodology. The data provided to ECCC is in electronic format and may differ slightly when compared with Statistics Canada's published values, which are rounded.

Table A3.1–1 **Activity Data Model References**

Statistics Canada. No date [d]. *Report on energy supply and demand in Canada*. Annual report. Catalogue no. 57-003-X. Available online at: https://www150.statcan.gc.ca/n1/pub/57-003-x/57-003-x2023002-eng.htm.
[CEEDC] Canadian Energy and Emissions Data Centre. *CEEDC Database on Energy, Emissions and Production for Canadian industry*. NAICS 32731 Cement Manufacturing. https://cieedacdb.rem.sfu.ca/naics-database/#.
Environment and Climate Change Canada. 2024. *Residential Fuelwood Consumption in Canada.* Unpublished report. Prepared by Kay J., Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.
Environment and Climate Change Canada. 2025. Greenhouse Gas Reporting Program. Available online at: https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/facility-reporting/data.html.
Environment and Climate Change Canada. 2026. Landfill Gas, Sludge Gas from Wastewater Treatment and Anaerobic Digester Gas Utilization, and Waste Incineration, National Inventory Report, Annex 3.6: Methodology for Waste Sector.

Much of the stationary combustion model's complexity lies in the reallocation of data presented in the RESD to comply with the requirements of IPCC categories and the CRT. In addition, in keeping with the 2006 IPCC Guidelines, the allocation of all fuel types uses the CRT fuel grouping (solid, liquid, gaseous, biomass and other) (see Table A4–2 in Annex 4).

Combined Heat and Power Allocation

Activity data, in the form of fuel used by utilities, are currently aggregated to two summary lines in the RESD (Transformed to Electricity by Utilities and Transformed to Steam Generation), representing electricity generation, and combined heat and power facilities. In addition, solid wood waste and spent pulping liquor used by utilities are allocated to Table 25-10-0031-01 – Consumption of Solid Wood Waste and Spent Pulping Liquor for Energy Production.

The Transformed to Electricity by Utilities line is populated with EPTG survey data, from facilities falling under North American Industry Classification System (NAICS) 2211: Electric power generation, transmission and distribution. ECCC has compiled a list of facilities within NAICS 2211 that are combined heat and power plants (CHP). For each fuel and each province and territory, the fuel use data reported in the EPTG, along with the CHP list, are used to develop the CHP fraction of the total fuel use. The fractions are then used with the Transformed to Electricity by Utilities line to determine what portion of that line should be reallocated to combined heat and power. The remainder is allocated to electricity generation.

A portion of solid wood waste is reallocated to electricity generation or combined heat and power. A portion of the fuels in the Transformed to Steam Generation line are reallocated to combined heat and power. The solid wood waste and spent pulping liquor allocation and the Transformed to Steam Generation allocation are discussed below.

Electricity by Industry and Steam Generation Allocation

Activity data, in the form of fuel used by industry (including Petroleum Refining) to generate electricity or steam, are currently aggregated to two summary lines in the RESD (Transformed to Electricity by Industry and Transformed to Steam Generation). In addition, solid wood waste and spent pulping liquor used by industry are allocated to Table 25-10-0031-01 – Consumption of Solid Wood Waste and Spent Pulping Liquor for Energy Production.

The Transformed to Electricity by Industry line is populated with EPTG survey data. The reallocation of values from 1998 to present was completed using fractions developed based on the fuel quantities reported in the EPTG survey, as follows:

- For each fuel and each province and territory, the fuel use data reported by industry in the EPTG for electricity generation are used to develop each industry's fraction of the total fuel use.
- The fractions are then used with the Transformed to Electricity by Industry line to determine what portion of that line should be reallocated to a particular industry.
- This portion is added to the activity data already reported for that industry.

The reallocation of the Transformed to Electricity by Industry values between 1990 and 1997 was completed using fractions developed from the quantities reported in the ICE survey, since EPTG data are not available prior to 1998.

- For each fuel and each province and territory, the fuel use data reported by industry in the ICE survey for electricity generation are used to develop each industry's fraction of the total fuel use.
- The fractions are then used with the Transformed to Electricity by Industry line to determine what portion of that line should be reallocated to a particular industry.
- This portion is added to the activity data already reported for that industry.
- Since ICE data did not exist prior to 1995, for years between 1990 and 1995, the 1995 fractions were used.

Since the Transformed to Steam Generation line is populated with ICE data, the procedure used to reallocate the Transformed to Electricity by Industry values between 1990 and 1997 is also applied to the Transformed to Steam Generation values (for all years) using corresponding ICE data representing steam generation.

The solid wood waste and spent pulping liquor allocation is discussed below.

Solid Wood Waste and Spent Pulping Liquor Allocation

Activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 25-10-0031-01 – Consumption of Solid Wood Waste and Spent Pulping Liquor for Energy Production).

Table 25-10-0031-01 is populated with ICE data. The procedure used to reallocate the Transformed to Electricity by Industry values between 1990 and 1997 is also applied to the RESD Table 25-10-0031-01 values (for all years) using corresponding ICE data representing solid wood waste and spent pulping liquor consumption.

A3.1.4.1.1. Public Electricity and Heat Production (CRT Category 1.A.1.a)

The Public Electricity and Heat Production subcategory includes 1.A.1.a.i – Electricity Generation, 1.A.1.a.ii – Combined Heat and Power Generation, and 1.A.1.a.iii – Heat Plants. This subcategory should include all emissions from main activity producers (previously known as public utilities) of electricity generation, combined heat and power generation, and heat plants. Emissions from auto producers are allocated to their respective industrial subcategories.

Two lines in the RESD (one for electricity and one for steam) report activity data from this subcategory; however, they are summary lines and are not divided into electricity generation, combined heat and power, and heat plants. In addition, activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 25-10-0031-01 – Consumption of Solid Wood Waste and Spent Pulping Liquor for Energy Production). The aggregated data need to be reallocated to the appropriate subcategory where the fuel is used. Section A3.1.4.1 provides a detailed discussion of the method used.

CO_2, CH_4 and N_2O emissions are estimated by applying Equation A3.1–1 to activity data and emission factors for each specific fuel. As previously discussed, to obtain higher accuracy in GHG emissions, regional emission factors are applied to provincial and territorial data where available. For this sector, there are regional emission factors for coal, natural gas and petroleum coke. For the remaining fuels, the emission factors are applied to the nationally reported data.

Table A3.1–2 provides a summary of the methodology for the Public Electricity and Heat Production category.

Table A3.1–2 **Emission Estimation Methodology for Public Electricity and Heat Production**

CRT Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Supply and Demand Characteristics
1.A.1.a.i Electricity Generation	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by utilities[e] Transformed to steam generation[e]
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Biomass	RESD	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor	
1.A.1.a.ii Combined Heat and Power Generation	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by utilities[e] Transformed to steam generation[e]
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Biomass	RESD	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor	
1.A.1.a.iii Heat Plants	Emissions from this subcategory are reported under 1.A.4.a.i Commercial/Institutional			

Notes:
a. The CRT categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC (2006) (Volume 2, Table 1.1).
c. Publication references are provided in Table A3.1–1.
d. ECCC uses coal data by rank; however, this data is considered confidential. The publicly available data has a rolled-up coal total.
e. A portion of this data source is allocated to this CRT source category prior to calculating emissions.

A3.1.4.1.2. Petroleum Refining (CRT Category 1.A.1.b) and Manufacture of Solid Fuels and Other Energy Industries (CRT Category 1.A.1.c)

To meet the modalities, procedures, and guidelines (MPGs) for the Enhanced Transparency Framework of the Paris Agreement reporting requirements, activity data from the Manufacture of Solid Fuels and Other Energy Industries category were reallocated to three separate IPCC subcategories, all of which comprise the emissions associated with the combustion of fuels produced at the facilities (e.g., combustion of coal at a coal mine or natural gas at an oil and gas facility) as well as the combustion of purchased fuels. Combustion emissions that support coal production are allocated to 1.A.1.c.i – Manufacture of Solid Fuels, combustion emissions that support crude oil and natural gas production and crude bitumen and heavy oil upgrading are allocated to 1.A.1.c.ii – Oil and Gas Extraction, and combustion emissions that support biofuel manufacturing are allocated to 1.A.1.c.iii – Other Energy Industries.

The methodology for estimating emissions from these subcategories involves applying Equation A3.1–1 on a national basis and subtracting volumes of flared and vented fuel for Petroleum Refining and Oil and Gas Extraction. The fuel use data reported in the RESD include volumes of flared and vented fuels; however, flaring and venting emissions are calculated and reported separately in the Fugitive category. To avoid double counting, the model subtracts fuel use, energy content and emission data associated with flaring and venting. See section A3.2.2.8 for more details.

Determining the activity data associated with the Petroleum Refining subcategory requires the reallocation of some of the data reported as Producer Consumption in the RESD. The Petroleum Refining subcategory includes all refined petroleum products reported as Producer Consumption, except in provinces where no refinery exists; these producer-consumed RPPs are assigned to Oil and Gas Extraction. Physical quantities of liquefied petroleum gases (LPGs) reported in the RESD as producer consumption are divided between propane and butane using energy data reported in the RESD.

Calculating the emissions associated with the fuels listed below involves summing the activity data reported under the RESD's Refined Petroleum Products Manufacturing and Producer Consumption lines and applying Equation A3.1–1 to:

- petroleum coke
- still gas
- kerosene
- light fuel oil
- heavy fuel oil
- butane
- propane

In addition, activity data in the form of fuel used by industry to generate electricity or steam are currently aggregated to two summary lines in the RESD (Transformed to Electricity by Industry and Transformed to Steam Generation). The aggregated data need to be reallocated to the appropriate industry where the fuel is used. Reallocation involves one of the two methods discussed in detail in section A3.1.4.1. Because of a lack of resolution in the RESD Producer Consumption line by specific industry, the Manufacture of Solid Fuels and Other Energy Industries subcategory does not include emissions associated with the transportation fuels listed below; these emissions are reported in the Petroleum Refining subcategory. In general, the combustion emissions calculations from the following transportation fuels, for the Petroleum Refining subcategory, use activity data reported in the RESD under Producer Consumption, together with Equation A3.1–1:

- aviation gasoline
- aviation turbo fuel
- diesel
- motor gasoline

The estimated N_2O emissions for petroleum coke and motor gasoline use IPCC default emission factors, which are based on the calorific value of the fuel. The RESD reports the gross calorific value for petroleum coke, which is adjusted to account for the annual variation in petroleum coke density based on weighted fuel use reported by upgraders and refineries. As a result, the petroleum coke emission factors for both crude bitumen upgrading and crude oil refining change on an annual basis. The conversion between the gross calorific value and the net calorific value, a necessary step in generating annual emission factors, uses data reported to, and published by, the Canadian Energy and Emissions Data Centre (CEEDC) (CEEDC, 2023).

To calculate GHG emissions from the Manufacture of Solid Fuels and Oil and Gas Extraction subcategories, activity data associated with the fuels listed below and reported under the Producer Consumption line and applicable portion of the Total Mining and Oil and Gas Extraction line of the RESD are used in Equation A3.1–1:

- natural gas
- coal
- diesel
- propane
- butane
- petroleum coke
- still gas
- heavy fuel oil

The Producer Consumption line of the RESD includes petroleum coke, still gas and diesel used by refineries and by the crude bitumen upgrading industry. Information on the proportion of fuel consumed by the crude bitumen upgrading industry is provided in Table 25-10-0085-01, Estimated Additions to Still Gas, Diesel, and Petroleum Coke, of the RESD. This information is used to reallocate the relevant quantities of petroleum coke and still gas to the Oil and Gas Extraction subcategory (CRT category 1.A.1.c.ii). Diesel reported as producer consumption is used in oil sands mining trucks and is reallocated to Other Transportation (Off-Road) (see section A3.1.4.2.1).

The Total Mining and Oil and Gas Extraction line of the RESD includes fuel consumption that occurs at coal mines, non-energy mines (including metal mining, sand, gravel and other aggregate mining, potash mining, diamond mining, etc.) and at facilities involved in the production of crude oil and natural gas. The RESD does not contain a sufficient level of detail to separate the fuel consumed at coal mines, non-energy mines and oil and gas extraction operations to allocate into the following CRT categories; Manufacture of Solid Fuels (1.A.1.c.i), Mining (1.A.2.g.iii), and Oil and Gas Extraction (1.A.1.c.ii). Other data sources therefore are used to allocate the fuel consumption to the proper categories. Fuel consumption at coal mining operations is estimated based on data from the study of the Canadian coal mining industry (Cheminfo and Clearstone, 2014), while fuel consumption for the non-energy mining industry is based on data from CEEDC (CEEDC, n.d.[a]; NAICS 2122 and 2123). As the oil and gas industry in Canada is the largest of these three industries, the remainder of fuel consumed in the Total Mining and Oil and Gas Extraction line after subtracting coal mining and non-energy mining fuel consumption is allocated to Oil and Gas Extraction. For a more detailed explanation of the allocation procedure, please see the Relationship between GHG emissions by Canada's Economic Sectors and IPCC Sectors table in the Economic Sector folder on the Government of Canada's Open Data website.

As previously mentioned in section A3.1.4.1.1, national level coal emissions from combusted coal use aggregated provincial and territorial level estimates.

The Other Energy Industries subcategory encompasses data related to biofuel manufacturing. In the RESD there is no single line reporting biofuel manufacturing. Depending on the type of biofuel and other primary activities at the facility, activity data can be reported under the Chemicals and Fertilizer Manufacturing, Other Manufacturing, and Refined Petroleum Products Manufacturing lines of the RESD. To calculate GHG emissions from the Other Energy Industries subcategory, reallocating some of the activity data associated with the fuels listed below and reported under the Chemicals and Fertilizer Manufacturing, Other Manufacturing, and Refined Petroleum Products Manufacturing lines of the RESD is required. These fuels are used in Equation A3.1–1:

- natural gas
- diesel
- light fuel oil
- kerosene & stove oil
- heavy fuel oil
- butane
- propane

The reallocation of these fuels was completed using fractions developed from the fuel quantities reported in the ICE survey, as follows:

- Biofuel manufacturing facilities reporting to ICE were identified based on their reporting to the Monthly Renewable Fuels and Hydrogen Survey.
- For each fuel, RESD line, and province and territory, the fuel use data reported by biofuel manufacturers in the ICE survey are used to develop a fraction of the total fuel use.
- The fractions are then used with the Chemicals and Fertilizer Manufacturing, Other Manufacturing, and Refined Petroleum Products Manufacturing lines to determine what portion of that line should be reallocated to Other Energy Industries.
- This portion is subtracted from the activity data reported under that line and added to the Other Energy Industries subcategory.
- In cases where ICE data do not exist for every year the facility has been in production, the earliest fraction available is used.

In addition, activity data in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 25-10-0031-01 – Consumption of Solid Wood Waste and Spent Pulping Liquor for Energy Production). A portion of solid wood waste is reallocated to the Other Energy Industries subcategory using the method discussed in detail in section A3.1.4.1.

Table A3.1–3 provides a summary of the methodology for this CRT category.

A3.1.4.1.3. Manufacturing Industries and Construction (CRT Category 1.A.2)

The Manufacturing Industries and Construction category includes several industrial categories. Activity data in the RESD are reported for the main economic and fuel-consuming industrial categories; however, this does not include fuel used to generate electricity or steam by industry. This energy is captured in the RESD in two separate summary lines (Transformed to Electricity by Industry and Transformed to Steam Generation), which are not broken down by industrial categories. In addition, activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 25-10-0031-01 – Consumption of Solid Wood Waste and Spent Pulping Liquor for Energy Production). The aggregated data need to be reallocated to the appropriate industry where the fuel is used. Section A3.1.4.1 describes this reallocation method in detail.

Emissions are calculated for the following categories:

- Mining
- Iron and Steel
- Non-ferrous Metals
- Chemicals
- Pulp, Paper and Print
- Non-metallic Minerals
- Construction
- Other Manufacturing (includes Food Processing, Beverages and Tobacco)

GHG emissions associated with the Manufacturing Industries and Construction category are calculated by applying Equation A3.1–1 to activity data reported in the RESD and corresponding emission factors for each fuel type (as presented in A6.1). Section A3.1.4.1.1 describes the handling of coal and natural gas emissions. The Industrial Processes and Product Use sector reports emissions from fuels used as feedstocks, while the Transport category reports emissions generated from the use of transportation fuels (e.g., diesel and gasoline).

Table A3.1–3 **Estimation Methodology for Petroleum Refining, Manufacture of Solid Fuels and Oil and Gas Extraction**

CRT Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Supply and Demand Characteristics
1.A.1.b Petroleum Refining	Solid Fuels[d]	NO		
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy Table 25-10-0026-01 Supply and demand of natural gas liquids	Transformed to Electricity by Industry[e] Transformed to Steam Generation[e] Producer Consumption[h] Refined Petroleum Products Manufacturing
			Table 25-10-0085-01 Estimated additions to still gas, diesel and petroleum coke	NA
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to Electricity by Industry[e] Transformed to Steam Generation[e] Refined Petroleum Products Manufacturing
	Biomass	NO		
1.A.1.c.i Manufacture of Solid Fuels	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Producer Consumption[f] Total Mining and Oil and Gas Extraction[g]
	Liquid Fuels	RESD	Table 25-10-0026-01 Supply and demand of natural gas liquids	Total Mining and Oil and Gas Extraction[g]
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Total Mining and Oil and Gas Extraction[g]
	Biomass	NO		
1.A.1.c.ii Oil and Gas Extraction	Solid Fuels[d]	NO		
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy Table 25-10-0026-01 Supply and demand of natural gas liquids	Transformed to Electricity by Industry[e] Producer Consumption[h] Total Mining and Oil and Gas Extraction[i]
			Table 25-10-0085-01 Estimated additions to still gas, diesel and petroleum coke	NA
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to Electricity by Industry[e] Producer Consumption[h] Total Mining and Oil and Gas Extraction[i]
	Biomass	NO		
1.A.1.c.iii Other Energy Industries	Solid Fuels[d]	NO		
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy Table 25-10-0026-01 Supply and demand of natural gas liquids	Transformed to Electricity by Industry[e] Transformed to Steam Generation[e] Chemicals and Fertilizer Manufacturing[e] Other Manufacturing[e]
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to Electricity by Industry[e] Transformed to Steam Generation[e] Refined Petroleum Products Manufacturing[e] Chemicals and Fertilizer Manufacturing[e] Other Manufacturing[e]
	Biomass	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor		

Notes:
NO = Not occuring
NA = Not applicable
a. The CRT categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC (2006) (Volume 2, Table 1.1).
c. Publication references are provided in Table A3.1–1.
d. ECCC uses coal data by rank; however, this data is considered confidential. The publicly available data has a rolled-up coal total.
e. A portion of this data source is allocated to this CRT source category prior to calculating emissions.
f. Producer consumption of solid fuels is allocated to this CRT category and fuel type.
g. The portion of fuel consumed at coal mining operations is allocated to this CRT category.
h. Producer consumption of liquid and gaseous fuels are allocated to this CRT category.
i. The portion of fuel consumed at oil and gas extraction facilities is allocated to this CRT category.

The Industrial Processes and Product Use sector reports all emissions associated with the manufacture and use of metallurgical coke in the iron and steel industry for the reduction of iron ore in blast furnaces.

Industrial consumption of biomass and spent pulping liquor is reported in the RESD; however, some of the data are limited. The RESD data for Newfoundland and Nova Scotia are combined. Facility-level data are used to reallocate this consumption to Nova Scotia.

As previously described in section A3.1.4.1.2 the Total Mining and Oil and Gas Extraction line in the RESD includes fuel consumption that occurs at coal mines, non-energy mines (including metal mining, sand, gravel and other aggregate mining, potash mining, diamond mining, etc.) and at facilities involved in the production of crude oil and natural gas. The RESD does not contain a sufficient level of detail to separate the fuel consumed at coal mines, non-energy mines and oil and gas extraction operations for allocation to the Manufacture of Solid Fuels (1.A.1.c.i), Mining (1.A.2.g.iii), and Oil and Gas Extraction (1.A.1.c.ii) categories, respectively. Other data sources are therefore used to allocate the fuel consumption to the proper categories. Fuel consumption for the non-energy mining industry is based on data from CEEDC (n.d.[a]; NAICS 2122 and 2123). For a more detailed explanation of the allocation procedure, please see the Relationship between GHG emissions by Canada's Economic Sectors and IPCC Sectors table in the Economic Sector folder on the Government of Canada's Open Data website.

The Other Manufacturing category also includes GHG emissions associated with the combustion of waste for energy purposes, which is composed of municipal solid waste, including some medical waste. A portion of the waste is considered biogenic, so CO_2 emissions associated with combustion of this portion are reported but not included in the national total. The CH_4 and N_2O emissions associated with the biogenic portion are reported under biomass, while the CO_2, CH_4 and N_2O emissions associated with the combustion of the non-biogenic portion are reported under other fossil fuels.

Mixed waste fuel in the cement industry is composed of waste oil, tires, shingles, plastics, solvents, and other fossil-based wastes, along with dried sewage sludge, paper, animal meal, animal fat and other biomass wastes. CO_2, CH_4 and N_2O emissions from the combustion of mixed waste fuel are calculated using data provided by the Cement Association of Canada and reported by CEEDC (n.d. [b]) on an energy basis from 1990 to 2016. From 2017 onward, emissions from the combustion of mixed waste fuel are sourced from facility reported data provided through the GHGRP (ECCC, 2025). The CH_4 and N_2O emissions associated with the biogenic portion are reported under biomass, while the CO_2, CH_4 and N_2O emissions associated with the combustion of the non-biogenic portion are reported under other fossil fuels. Table A3.1–4 provides a summary of the methodology for the Non-Metallic Minerals category.

The Chemicals, Other Manufacturing, and Pulp, Paper and Print categories include GHG emissions associated with the combustion of sludge gas from wastewater treatment. As sludge gas is considered a biofuel, CO_2 emissions associated with combustion are reported but not included in the national total. CH_4 and N_2O emissions are, however, included.

A3.1.4.1.4. Other Sectors (CRT Category 1.A.4)

The Other Sectors category consists of three subcategories: Commercial/Institutional, Residential, and Agriculture/Forestry/Fishing. GHG emissions associated with the Other Sectors category (with the exception of emissions from the combustion of residential firewood) are calculated by applying Equation A3.1–1 to activity data reported in the RESD and corresponding emission factors for specific fuels (refer to section A6.1).

The activity data used in the calculation of GHG emissions from the combustion of residential firewood are based on estimated fuel use, as determined from the *Residential Fuelwood Consumption in Canada* study (ECCC, 2024). Firewood consumption data for the provinces were collected through the Survey on Household Energy Use for the years 1997 and 2003 (Statistics Canada, n.d.[e]), and through the Households and Environment Survey (HES) for the years 2007, 2015, 2017, 2019, and 2021 (Statistics Canada, n.d.[c]). Pellet and manufactured log consumption data were collected for the years 1996, 2006, and 2012 through the Residential Fuelwood Combustion in Canada survey (Canadian Facts, 1997; TNS, 2006; TNS, 2012), and for the years 2017, 2019, and 2021 through the HES (Statistics Canada, n.d.[c]). These data were collected by province and grouped into eight major appliance-type categories:

- Fireplaces
- Fireplace Inserts
- Wood Stoves
- Wood Furnaces
- Pellet Stoves
- Hydronic Heater
- Water Heater
- Other Equipment

Table A3.1–4 Estimation Methodology for Manufacturing Industries and Construction

CRT Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Supply and Demand Characteristics
1.A.2.a. Iron and Steel	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by industry[e] Transformed to steam generation[e] Iron and Steel Manufacturing
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Biomass	RESD	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor	
1.A.2.b. Non-Ferrous Metals	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by industry[e] Transformed to steam generation[e] Aluminium and Non-ferrous Metal Manufacturing
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Biomass	RESD	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor	
1.A.2.c. Chemicals	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by industry[e] Transformed to steam generation[e] Chemicals and Fertilizer Manufacturing
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Biomass	RESD	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor	
		NIR	Figure 7–2 Methane recovered from wastewater treatment	
1.A.2.d. Pulp, Paper and Print	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by industry[e] Transformed to steam generation[e] Pulp and Paper Manufacturing
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Biomass	RESD	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor	
		NIR	Figure 7–2 Methane recovered from wastewater treatment	
1.A.2.e. Food Processing, Beverages and Tobacco	Emissions for this subcategory are included in 1.A.2.g.viii.1 Other Manufacturing.			
1.A.2.f. Non-Metallic Minerals	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by industry[e] Transformed to steam generation[e] Cement Manufacturing
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Other Fossil Fuels[f]	CEEDC	CEEDC Database on Energy, Emissions and Production for Canadian Industry	
		GHGRP	Greenhouse Gas Reporting Program (GHGRP) – Facility Greenhouse Gas (GHG) Data – Open Government Portal (canada.ca)[g]	
	Biomass	RESD	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor	
		GHGRP	Greenhouse Gas Reporting Program (GHGRP) – Facility Greenhouse Gas (GHG) Data – Open Government Portal (canada.ca)[g]	
1.A.2.g.iii Mining (excluding fuels) and quarrying	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by industry[e] Transformed to steam generation[e] Total Mining and Oil and Gas Extraction[h]
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Biomass	RESD	NO	
1.A.2.g.v Construction	Solid Fuels[d]	RESD	NO	Transformed to electricity by industry[e] Construction
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Biomass	RESD	NO	
1.A.2.g.viii.1 Other Manufacturing	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by industry[e] Transformed to steam generation[e] Other Manufacturing
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Other Fossil Fuels	NIR	Table A3.6–10 Estimated tonnes of Waste Incinerated[i]	
	Biomass	RESD	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor	
		NIR	Table A3.6–10 Estimated tonnes of Waste Incinerated[i]	
			Figure 7–2 Methane recovered from wastewater treatment	

Notes:
NO = Not occuring
a. The CRT categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC (2006) (Volume 2, Table 1.1).
c. Publication references are provided in Table A3.1–1.
d. ECCC uses coal data by rank; however, this data is considered confidential. The publicly available data has a rolled-up coal total.
e. A portion of this data source is allocated to this CRT source category prior to calculating emissions.
f. The other fossil fuels reported under this CRT category is mixed waste fuel used in Cement kilns.
g. The non-biogenic portion of mixed waste fuel incineration is included under Other Fossil Fuels, the biogenic portion is under biomass.
h. The portion of fuel consumed at non-energy mining operations is allocated to this CRT category.
i. The non-biogenic portion of MSW incineration is included under Other Fossil Fuels, the biogenic portion is under biomass.

Some of these appliance types were further broken down into either advanced technology (catalytic or non-catalytic) or conventional technology.

The 2017, 2019, and 2021 surveys also collected data on the type of wood used, by reconciliation unit, and the moisture content of the wood. Section A3.5.1 describes the boundaries of reconciliation units in detail. Since the firewood consumption data were collected on a volume basis, an average density value was determined by reconciliation unit, based on the proportion of the different types of wood used, the corresponding wood densities and the moisture content of the wood. The wood densities were taken from various Canadian wood density studies (Alemdag, 1984; Gonzalez, 1990; Jessome, 2000). The ratio of wood used, by reconciliation unit, and the moisture content of the wood compared to the total firewood consumption in the province was applied to all surveys. The pellet and manufactured log consumption data were collected on a mass basis. The mass of biomass consumed for the other years was interpolated and extrapolated using the number of heating degree days in each province in relation to the survey years.

Firewood consumption data for the territories is acquired from the National Forestry Database (CCFM:NFD, n.d.). Since no data is available on the type of appliances used in the territories, it is assumed that all appliances are conventional.

GHG emissions were calculated by multiplying the amount of biomass burned in each appliance by the emission factors. CO_2 emissions associated with biomass combustion in the Residential category are reported but not included in the national total. CH_4 and N_2O emissions are, however, included.

The Commercial/Institutional category includes GHG emissions associated with the combustion of landfill gas, sludge gas from wastewater treatment, and digester gas used for energy purposes. As landfill gas, sludge gas, and digester gas are considered biofuels, CO_2 emissions associated with combustion are reported but not included in the national total. CH_4 and N_2O emissions are, however, included.

The Commercial/Institutional category also includes GHG emissions associated with the combustion of waste for energy purposes, in the form of municipal solid waste, which includes some medical waste. A portion of the waste is biogenic, and CO_2 emissions associated with combustion of this portion are reported but not included in the national total. The CH_4 and N_2O emissions associated with the biogenic portion are reported under biomass, while the CO_2, CH_4 and N_2O emissions associated with the combustion of the non-biogenic portion are reported under other fossil fuels.

In addition, activity data in the form of fuel used by industry (including the Commercial/Institutional category) to generate electricity are currently aggregated to a summary line in the RESD (Transformed to Electricity by Industry). Activity data in the form of solid wood waste and spent pulping liquor are currently aggregated to a summary table in the RESD (Table 25-10-0031-01 – Consumption of Solid Wood Waste and Spent Pulping Liquor for Energy Production). The aggregated fuel use data need to be reallocated to the appropriate subcategory. Section A3.1.4.1 discusses the disaggregation method used.

The Agriculture/Forestry/Fishing category (CRT category 1.A.4.c) includes emissions from stationary fuel combustion only from the agricultural and forestry industries. Emissions are from on-site machinery operation and space heating and are estimated using fuel use data for agriculture and forestry as reported in the RESD. Fishery emissions are reported under either the Transport or Other Manufacturing (i.e. food processing) category. Mobile emissions associated with this category are not disaggregated and are all included as off-road or marine emissions reported under the Transport category.

Table A3.1–5 provides a summary of the methodology for this CRT category.

Table A3.1–5 **Estimation Methodology for the Other Sectors Category**

CRT Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Supply and Demand Characteristics
1.A.4.a.i Commercial/Institutional – Stationary Combustion	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by industry[e] Commercial and Other Institutional Public Administration
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Other Fossil Fuels	NIR	Table A3.6–10 Estimated tonnes of Waste Incinerated[f]	
	Biomass	RESD	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor	
		NIR	Table A3.6–6 CH_4 Generated, recovered and emitted from MSW Landfills in Canada	
			Table A3.6–10 Estimated tonnes of Waste Incinerated[f]	
			A3.6.2.2.2 Anaerobic Digestion at Biogas Facilities (5.B.2) Data Sources	
			Figure 7–2 Methane recovered from wastewater treatment	
1.A.4.b.i Residential – Stationary Combustion	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Residential
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Biomass	Estimated using ECCC residential fuelwood consumption model.		
1.A.4.c.i Agriculture/Forestry/Fishing – Stationary Combustion	Solid Fuels[d]	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	Transformed to electricity by industry[e] Transformed to steam generation[e] Forestry and Logging and Support Activities for Forestry Agriculture
	Liquid Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
			Table 25-10-0026-01 Supply and demand of natural gas liquids	
	Gaseous Fuels	RESD	Table 25-10-0030-01 Supply and demand of primary and secondary energy	
	Biomass	RESD	Table 25-10-0031-01 Consumption of solid wood waste and spent pulping liquor	

Notes:
a. The CRT categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC (2006) (Volume 2, Table 1.1).
c. Publication references are provided in Table A3.1–1.
d. ECCC uses coal data by rank; however, this data is considered confidential. The publicly available data has a rolled-up coal total.
e. A portion of this data source is allocated to this CRT source category prior to calculating emissions.
f. The non-biogenic portion of MSW incineration is included under Other Fossil Fuels and the biogenic portion under Biomass.

A3.1.4.2. **Transport (CRT Category 1.A.3)**

GHG emissions from the Transport category are divided into six subcategories:

- Domestic Aviation
- Road Transportation
- Railways
- Domestic Navigation
- Other Transportation (Pipeline Transport)
- Other Transportation (Off-Road)

Emission estimates are developed at the provincial and territorial level and aggregated to the national level. Fuel combustion emissions associated with the Transport category are calculated using various adaptations of Equation A3.1–1.

CO_2 emissions are predominantly dependent on the type and characteristics of the fuel being combusted, whereas N_2O and CH_4 emissions are dependent on both the fuel combusted and emission control technologies present. Annex 6 provides a complete listing of transportation-related emission factors and their specific references.

For the Road Transportation and Other Transportation (Off-Road) categories, Canada uses the MOtor Vehicle Emissions Simulator (MOVES) model, MOVES3 version, developed by the United States Environmental Protection Agency (U.S. EPA), and a modified version of the U.S. EPA's NONROAD model. The primary reasons for these updates are to remain current with regulatory changes in the Canadian vehicle fleet, which are harmonized with those of the United States, to align GHG estimates with those published in *Canada's Air Pollutant Emissions Inventory Report 1990–2024* and *Canada's Black Carbon Inventory Report 2013–2024* and to create a bottom-up inventory for off-road emissions by making use of equipment and operational data. Use of the NONROAD model also has the benefit of allocation to additional economic subsectors on an equipment basis. Therefore, under the CRT classification system, some off-road emissions are reported in the 1.A.2 and 1.A.4 categories. The Aviation Greenhouse Gas Emission Model (AGEM) is used to calculate aviation emissions. The Marine Emissions Inventory Tool (MEIT) is used to calculate navigation emissions. Railway emissions are derived from fuel reported in the Railway Association of Canada's Locomotive Emission Monitoring Report. Combustion emissions associated with pipeline transport are estimated separately.

A3.1.4.2.1. Road Transportation (CRT Category 1.A.3.b.i-v) and Other Transportation (Off-Road) (CRT Categories 1.A.2.g.vii, 1.A.3.e.ii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii)

The methodology used to estimate Road Transportation and Other Transportation (Off-Road) GHG emissions follows a detailed IPCC Tier 3 approach. Since these two categories are collectively normalized to fuel available as reported in the RESD, a combined methodology for the two categories is outlined below.

Step 1: On-Road Activity Data – Vehicle Populations, Technology Penetration, Kilometre Accumulation Rates and Fuel Consumption Rates

Vehicle Populations

Vehicles are separated into different classes depending on their fuel type, body configuration (car versus truck) and gross vehicle weight rating (GVWR). GVWR is the maximum allowable weight of a fully loaded road vehicle, including the weight of the vehicle, fuel, passengers, cargo and other miscellaneous items, including optional accessories. Light-duty vehicles (cars) and light-duty trucks (pickups, minivans, SUVs, etc.) are those with a GVWR of less than or equal to 3856 kg, whereas heavy-duty classes have a GVWR above 3856 kg.

Six distinct data sources are used to develop a complete vehicle population profile. Vehicle population totals for 1990–2024 are based on road motor vehicle annual registration datasets from Statistics Canada (Statistics Canada, 2015; Statistics Canada, 2020; Statistics Canada, 2025). For years 1990–2023, the distribution of those vehicle populations by vehicle class and technology type was done using light-duty vehicle population data obtained from DesRosiers Automotive Consultants Inc and heavy-duty vehicle population data obtained from R.L. Polk & Company (2013). For 2024, vehicle population data from S&P Global was used to project distributions established from 2023 data sources.

Technology Penetration

To account for the effects of emission control technologies on emission rates of CH_4 and N_2O, estimates of the number of vehicles on the road equipped with catalytic converters and other control technologies were developed. Most on-road vehicles in use in 2024 are subject to Tier 2 and Tier 3 regulatory standards, approximately representing model years 2004 and onwards. However, because the National Inventory estimates a time series starting at 1990 and considers a small number of pre-1996 model year vehicles still in active fleets, additional technology-specific emission factors for CH_4 and N_2O are also used. These include emission controls ranging from completely uncontrolled vehicles to those using Tier 1 regulatory standards. Similarly, heavy-duty gasoline vehicles, heavy-duty diesel vehicles and motorcycles have advanced emission controls starting with the 1996 model year. Emission factors for vehicles without emission controls and/or moderate controls are used for 1995 and older model years. CH_4 and N_2O emission factors for the full range of emission controls are listed in Annex 6.

Kilometre Accumulation Rates

Kilometre accumulation rates (KARs) are a measure of the average annual kilometres travelled by a single vehicle of a given age in a specific vehicle class. Light-duty car and truck KARs are estimated from the results reported in a study that examined observed differences in a vehicle odometer reading recorded between successive inspection and maintenance tests from Ontario and British Columbia (550572 BC Ltd, 2022). Given the absence of inspection and maintenance programs in other jurisdictions, the Ontario KAR estimates are adopted in all other provinces and territories excluding British Columbia, where the B.C. KAR estimates are directly applied.

Fuel Consumption Rates

In MOVES3, fuel consumption rates are embedded within the model in the form of energy rates in kilojoules per second (kJ/s). The rates vary, considering a range of default parameters or user inputs, such as vehicle type, model year, speed, road type and operating mode. As the Canadian and U.S. vehicle markets are made virtually identical through regulation, it is believed that the MOVES energy rates are representative of fuel consumption for Canadian vehicles. MOVES also factors in more current fuel efficiency regulations, such as the *On-Road Vehicle and Engine Emission Regulations* for light-duty vehicles and the *Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations* for heavy-duty vehicles.

For this submission, Canada only uses MOVES' energy allocation capability. MOVES output is on an energy basis and Canada's current emission factors are developed on a fuel-volume basis. The energy output from MOVES is therefore converted to fuel volumes using energy conversion factors, as reported in *Updated CO_2 Emission Factors for Gasoline and Diesel Fuel* (ECCC 2017), taking into consideration the use of biofuels (see below). MOVES reports energy output on a lower heating value basis. Canada plans to review the GHG emission factors within MOVES for their potential use in a future submission.

Step 2: Off-Road Activity Data – Engine Populations, Technology Penetration, Annual Usage Rates, Engine Load Factors and Fuel Consumption Rates

Engine Populations

Off-Road engines are primarily separated into IPCC categories depending on the vehicle or equipment type defined in off-road engine population data. The main data source for the off-road engine population is obtained from Power Systems Research PartsLink dataset. PartsLink is a comprehensive resource providing in-service population data for engine-powered vehicles and equipment. Supplemental data sources are used to further allocate these populations into the required sectors for modelling. For example, using the open-pit mining database prepared by The Parker Bay Company, the construction equipment used in the oil sands mining operations are removed from the construction equipment in the PartsLink dataset and reallocated to the oil sands mining sector. Note that engine population data sources were limited to years 1990–2023, requiring engine populations for 2024 to be estimated via linear regression.

Technology Penetration

To account for the effects of emission control technologies on emission rates of CH_4 and N_2O, off-road gasoline engines are defined by engine cycle whereas off-road diesel engines are defined by engine power range and exhaust regulatory tier, where applicable.

For off-road gasoline engines, the distinction between two-stroke and four-stroke engine cycles is defined in the vehicle and engine population data sourced from Power Systems Research. For the entire time series, these data indicate that most gasoline engines are four-stroke, which are generally more powerful and used more frequently than their two-stroke counterparts.

For off-road diesel engines, the distinction between engine power above or below 19 kW was determined from the vehicle and engine population data sourced from Power Systems Research. Those engines above 19 kW that are subject to Tier 4 regulatory exhaust standards were determined from engine technology distributions embedded within the NONROAD model. Most off-road diesel engines have a power rating above 19 kW, with those engines subject to Tier 4 regulatory exhaust series being first introduced to the off-road fleet in 2008.

Annual Usage Rates and Engine Load Factors

Annual usage rates (AARs) are a measure of the average annual use of a single off-road engine for a specific off-road engine application. For gasoline-powered off-road motorcycles and all-terrain vehicles, these AARs are defined based on distance travelled whereas all other engine applications are defined based on hours operated. Engine load factors (ELFs) refer to the proportion of the rated engine power typically used during operation. Like AARs, ELFs are defined on a per off-road engine application basis but are not used for cases where the annual usage rate is based on distance travelled because those rates are based on typical operation.

AARs and ELFs are mostly sourced from a significant off-road equipment study conducted by PSR in 2011. However, some AARs are based on Canada-specific information. For example, activity data from nearly 2000 used snowmobile advertisements were used to derive annual hours of use data, by engine cycle (ECCC, 2018).

Fuel Consumption Rates

In the NONROAD model, fuel consumption rates are embedded in the form of brake-specific fuel consumption (BSFC), or in the form of fuel consumed per unit distance travelled; the latter is only applicable to gasoline-powered off-road motorcycles and all-terrain vehicles. BSFC is a measure of fuel efficiency and can be estimated by dividing the fuel consumption rate (g/s) by the power produced (kW). In the NONROAD model, BSFC rates vary by engine application, engine fuel type and engine power rating range.

Step 3: Fuel Calculation – MOVES, NONROAD and Biofuels

MOVES

MOVES is a sophisticated emissions modeling system that can estimate energy use and emissions from a variety of processes and pollutants, for most road vehicle configurations, on an hourly basis. The model utilizes several model inputs, many of which can be user-defined. Key model inputs that Canada feeds into MOVES are kilometer accumulation rates (KARs), vehicle populations and fuel properties. Other key inputs that are used by MOVES but are not provided by Canada include driving cycles, road load coefficients and vehicle masses, which inform the vehicle operating mode distributions conducted by MOVES. A variety of technical reports that describe the default inputs and algorithms used in MOVES are available at: https://www.epa.gov/moves/moves-onroad-technical-reports.

NONROAD

Compared to MOVES, NONROAD is a relatively simple emissions model, but it is still capable of estimating fuel consumption and emissions from several processes and pollutants, for most off-road engine applications. Like MOVES, NONROAD utilizes several model inputs which can be user-defined. Key model inputs that Canada feeds into NONROAD are annual usage rates, engine populations and fuel properties. Other key inputs that are used by NONROAD but are not provided by Canada are fuel consumption rates, engine deterioration rates and engine technology distributions. A variety of technical reports that describe the default inputs and algorithms used in NONROAD are available at: https://www.epa.gov/moves/nonroad-technical-reports.

Since 2008, Canada has occasionally made updates to the NONROAD source code independent of the USEPA. Most of these updates were done to better reflect Canadian conditions. Notable updates to the NONROAD source code include:

- Allowing NONROAD to model emissions from heavy earth-moving equipment operating at oil sands mining (OSM) operations. Includes OSM-specific annual use rates and engine load factors.
- Expanding NONROAD's ability to model higher ethanol blends. The USEPA's version of NONROAD has an upper bound of 10% ethanol blend in gasoline.
- Enabling NONROAD to accept user-defined age distributions, articulated by current engine population data. The USEPA's version of NONROAD uses static age distribution profiles.

As an extension to the NONROAD model, outputs relating to lubricating oils combusted in two-stroke engines were determined using model year-specific lubricating oil to gasoline mixing ratios (Oak Leaf Environmental Inc, 2019).

Biofuels

Both MOVES and NONROAD require biofuel content on a relative content basis (i.e., percent) as an input, which are primarily derived from biofuel quantities reported by Navius Research (Navius Research, 2025) and their respective fuels reported in the RESD. However, volumes of biofuels are recalculated as outputs such that emissions can be estimated by selecting appropriate emission factors in Annex 6 and applying Equation A3.1–1.

Step 4: Normalization

To mitigate some of the uncertainties associated with separate bottom-up calculations for on- and off-road estimates, the fuel consumption estimates from these two subsectors are combined and balanced against top-down fuel availability information. The source of top-down fuel availability data to be considered against the bottom-up fuel consumption estimate is the RESD (Statistics Canada, n.d.[d]).

Statistics Canada has stated that the volumes of gasoline and diesel fuel reported in the RESD include ethanol and biodiesel, respectively. Therefore, the estimated volumes of ethanol and biodiesel are removed from the volumes of gasoline and diesel fuel reported. As a result, when comparing total volumes of gasoline and diesel fuel in the RESD with that of the CRT, note that the CRT gasoline and diesel fuel volume must be added to the CRT ethanol and biodiesel volumes to equate to the RESD gasoline and diesel fuel volumes.

In Step 4, bottom-up estimates of fuel consumption from on- and off-road sources are scaled to match fuel available as reported in the RESD on a per fuel basis at the provincial and territorial level. However, the scaling approach varies by fuel type.

For gasoline and diesel fuel, bottom-up estimates of fuel consumption are pooled according to whether the fuel is assumed to be sourced from retail pumps, whereas fuel reported in the RESD is pooled according to whether the reported category is assumed to exclude off-site transportation use. The bottom-up fuel consumption pool assumed to predominantly source fuel from retail pumps is scaled to match the RESD pool assumed to include off-site transportation use. The bottom-up fuel consumption pool assumed to predominantly source fuel not from retail pumps is scaled to match the RESD pool

assumed to exclude off-site transportation use. The process for defining the bottom-up fuel pools was based on modelled engine application whereas the process for defining the RESD fuel pools was based on reporting guidance from Statistics Canada's Annual Survey on End-Use of Refined Petroleum Products, a key survey that feeds into the RESD.

For propane and natural gas, bottom-up estimates of fuel consumption are pooled on a fuel-type basis at the provincial and territorial level, and the total volume of fuel is scaled to match the fuel available as reported in the RESD.

At a provincial level, top-down and bottom-up consumption estimates differ; however, at a national level, the degree of alignment between the two estimates is higher. For on-road, the degree of alignment is strong for most of the time series whereas for off-road, the degree of alignment is weak for most of the time series. These differences in alignment are due to differences in the quality of model input data used to produce bottom-up estimates, which are relatively low for off-road when compared to on-road. Please refer to Table A3.1–6 and Table A3.1–7 for the normalization factors calculated for on-road and off-road on a national basis for gasoline and diesel fuel, respectively.

Table A3.1–6 **Gasoline Normalization Values, Selected Years**

Category	Statistic	1990	2005	2019	2020	2021	2022	2023	2024
Raw	Bottom-Up On-Road Fuel Consumption Estimate (ML)	37 585	36 280	42 180	35 477	37 343	40 698	40 663	42 339
	Bottom-Up Off-Road Fuel Consumption Estimate (ML)	820	3 344	3 264	3 205	3 131	3 122	3 050	3 011
	Total Bottom-Up Fuel Consumption Estimate (ML)	38 405	39 624	45 444	38 682	40 474	43 820	43 713	45 350
Target	Total Top-Down Fuel Available (ML)	33 943	40 868	47 220	39 703	41 101	42 491	43 501	43 640
	On-Road National Scaling Factor (%)	81	99	100	99	97	93	95	92
	Off-Road National Scaling Factor (%)	442	151	150	140	150	149	154	155
Scaled	Normalized On-Road Fuel Estimate (ML)	30 318	35 814	42 314	35 207	36 401	37 833	38 790	38 976
	Normalized Off-Road Fuel Estimate (ML)	3 625	5 054	4 906	4 496	4 700	4 657	4 711	4 663
	Sum of Normalized On- and Off-Road Fuel (ML)	33 943	40 868	47 220	39 703	41 101	42 491	43 501	43 640

Table A3.1–7 **Diesel Fuel Normalization Values, Selected Years**

Category	Statistic	1990	2005	2019	2020	2021	2022	2023	2024
Raw	Bottom-Up On-Road Fuel Consumption Estimate (ML)	9 508	11 683	16 039	15 152	15 353	15 524	15 579	15 888
	Bottom-Up Off-Road Fuel Consumption Estimate (ML)	1 581	5 918	8 846	8 757	8 707	8 698	8 703	8 676
	Total Bottom-Up Fuel Consumption Estimate (ML)	11 089	17 600	24 885	23 909	24 060	24 221	24 282	24 564
Target	Total Top-Down Fuel Available (ML)	13 188	22 785	28 175	24 622	26 301	27 076	26 500	26 333
	On-Road National Scaling Factor (%)	66	112	92	84	90	94	91	88
	Off-Road National Scaling Factor (%)	438	163	152	135	143	143	142	142
Scaled	Normalized On-Road Fuel Estimate (ML)	6 262	13 135	14 752	12 769	13 864	14 624	14 151	14 049
	Normalized Off-Road Fuel Estimate (ML)	6 926	9 649	13 423	11 853	12 437	12 453	12 349	12 284
	Sum of Normalized On- and Off-Road Fuel (ML)	13 188	22 785	28 175	24 622	26 301	27 076	26 500	26 333

Step 5: Railway Fuel Allocation

Amounts of diesel fuel associated with railways, but not used in locomotives, are allocated to select vehicle and equipment types associated with on-road and off-road. For on-road the allocation is limited to light-duty trucks and heavy-duty single-unit trucks whereas the allocation for off-road is limited to light commercial equipment (e.g., generators, compressors, and pumps) and railway maintenance equipment. The allocation is based on the scaled volumetric proportions of diesel fuel consumed for each of the selected vehicle and equipment types.

Information on how the amounts of diesel fuel are allocated is documented in A3.1.4.2.4.

Step 6: Emission Calculation

Once a final allocation of fuel is complete for all vehicle and equipment types, emissions are calculated using Equation A3.1–1 with the emission factors in Annex 6.

A3.1.4.2.2. Domestic Aviation (CRT Category 1.A.3.a)

The methodology used to estimate GHG emissions from the Domestic Aviation category employs a modified IPCC Tier 3 approach. The Aviation model has been named AGEM as an acronym for Aviation Greenhouse Gas Emission Model.

This category includes all emissions from domestic air transport (commercial, private, agricultural, etc.). In accordance with the 2006 IPCC Guidelines, and because of the Tier 3 approach, military air transportation emissions are reported in the Other – Mobile category (CRT category 1.A.5.b). Excluded are emissions from fuel used at airports for ground transport, which are reported under Other Transportation (Off-Road), and emissions from fuel used in stationary combustion applications at airports. Emissions from international flights are designated as "bunker" emissions and are not included in national totals, but are estimated and reported separately under International Bunkers.

Step 1: Activity Data: Aircraft Movements, Flight Path Length, Airport Coordinates, Aircraft Fuel Use Characteristics, Representative Aircraft Mapping, Aircraft Emission Performance

Aircraft Movements

The aircraft movement data (AMS, 2024) used in AGEM are flight-by-flight tower data collected by NAV Canada (Canada's civil air navigation services provider) starting in November 1996 and by Transport Canada before November 1996. Both data streams are processed by Statistics Canada and redistributed to NAV Canada and Transport Canada. ECCC receives the information directly from Statistics Canada, including aircraft movements from small airports that Statistics Canada collects directly and appends to the tower data from NAV Canada.

The data identify, among other things, the origin, destination and aircraft type for any given movement occurring in Canada. Statistics Canada's processing of the data includes adding information based on other raw data fields provided to it as well as validation of airports, aircraft types and various data fields that are not crucial to modelling fuel use.

Military emissions are estimated on the basis of movement data, as they are labelled as military by Statistics Canada.

Flight Path Length

The flight path length is the true distance travelled between two airports. The movement data used for modelling are not radar data and thus do not track the exact path travelled by each individual movement. AGEM estimates the flight path length based on additional information obtained from the Federal Aviation Administration (FAA). The FAA operates an aviation model called the Aviation Environmental Design Tool (AEDT) (formerly System for Assessing Aviation's Global Emissions [SAGE]) that is based on true radar data. The FAA provided Environment Canada with an extract from its model for calendar year 2005 involving Canadian airports and included the statistical measures (maximum, minimum, average, standard deviation) for the radar distance travelled between any Canadian origin and final destination for a given aircraft type (Fleming, 2008a). The average distance from these combinations was then used as the distance flown when the same combination appeared in AGEM's movement data (regardless of the calendar year of the movement). There are cases, however, when a combination in AGEM exists without a corresponding average distance. In these cases, another method needed to be developed.

An adjusted great circle distance (GCD[1]) is used when the average radar distance is unknown. A factor applied to the GCD was developed by comparing GCD to radar distance for a given origin/destination/aircraft type. Graphing the known radar lengths against their corresponding GCDs leads to an equation that can be used for adjusting all raw GCD distances. Therefore, all GCDs are adjusted by a factor to approximate the flight path length, with the factors decreasing in magnitude as the GCD increases.

Airport Coordinates

All possible airport entries within the AGEM movement data were extracted and defined. Information on the airports, such as latitude, longitude, name, and elevation, were compiled from various sources, including the Canada Flight Supplement publications (NAV Canada, 2009, 2019a, 2020a, 2024a), and the Canada Water Aerodrome Supplement publications (NAV Canada, 2018a, 2019b, 2020b, 2024b), International Air Transport Association (IATA) and International Civil Aviation Organization (ICAO) Airport codes (NAV Canada, 2018b), the FAA (FAA, 2020), Airline and Location Code Search database (IATA, 2020), SAGE (Fleming, 2008b), the Modeling and Database Task Force (MODTF) (Fleming, 2008c) and World Airport Codes (2024). The main data required to calculate a GCD for use in determining the flight path length are the geographical coordinates.

1 Great circle distance is the shortest distance between two points on a sphere; with respect to aviation, it is the shortest possible flight path length between the origin and destination of a flight movement.

Aircraft Fuel Use Characteristics

Once the flight path length is determined, the fuel consumed by the aircraft for that movement can be calculated using the fuel use characteristics of that aircraft. The fuel use characteristics of various representative aircraft are drawn from the Base of Aircraft Data (BADA) (BADA, 2019), the ICAO via their engine emissions databank (ICAO, 2019), the Swedish Defence Research Agency (FOI) via their turbo prop engine emissions databank (Hagstrom, 2010), and the Federal Office of Civil Aviation (FOCA) in Switzerland (FOCA, 2007).

Information from ICAO, FOI and FOCA is used to estimate fuel use for the taxi-out, taxi-in and takeoff phases of each flight. Information from BADA is used to estimate fuel use for the climb-out, climb, cruise, descent and landing phases of each flight.

Representative Aircraft Mapping

All possible aircraft type entries within the AGEM movement data were extracted and defined. Once defined, each aircraft was mapped to a representative aircraft with known fuel use characteristics so that fuel consumption could be calculated for all aircraft in AGEM. The mapping was done using published mapping guides whenever possible (BADA, 2019; FAA, 2018; IPCC, 2006; ICAO, 2016, 2024) and by matching aircraft characteristics (MTOW,[2] number of engines, engine type, etc.) when there was no published mapping for a given aircraft.

Aircraft Emission Performance

To better estimate CH_4 emissions from aviation turbo fuel, aircraft-specific emission factors are used within AGEM, when applicable, for the LTO cycle. When there is no aircraft-specific CH_4 emission factor, the 2006 IPCC default factor is used. The factors are taken from Table 3.6.9 in the 2006 IPCC Guidelines and converted into grams per litre of fuel consumed. For the cruise portion, CH_4 emissions are assumed to be zero (Wiesen et al., 1994). For ease of use by the general public, the published CH_4 emission factor will be a fleet average across the entire time series and will be based on total fuel consumed (LTO and cruise).

Table 3.6.9 in the 2006 IPCC Guidelines also has aircraft-specific aviation turbo fuel N_2O emission factors on a total LTO cycle basis; however, they are calculated using a Tier 1 fuel-based emission factor. Therefore, the Tier 1 factor is used directly since the amount of fuel consumed during the LTO cycle is calculated by AGEM.

Country-specific emission factors on a g/L basis are used for CO_2 emissions from aviation turbo fuel aircraft and for CO_2, CH_4 and N_2O emissions from aviation gasoline aircraft.

Step 2: Aircraft Fuel Calculation

Fuel consumed by each individual movement is estimated using the following equation.

Equation A3.1–2

$$FC_{FlightTotal} = FC_{Taxi\text{–}out} + FC_{Takeoff} + FC_{Climb\text{–}out} + FC_{Climb} + FC_{Cruise} + FC_{Descent} + FC_{Landing} + FC_{Taxi\text{–}in}$$

$FC_{FlightTotal}$	=	total fuel consumed on a per-flight basis
$FC_{Taxi\text{–}out}$	=	fuel consumption during the taxi-out phase
$FC_{Takeoff}$	=	fuel consumption during the takeoff phase
$FC_{Climb\ out}$	=	fuel consumption during the climb-out phase
FC_{Climb}	=	fuel consumption during the climb phase
FC_{Cruise}	=	fuel consumption during the cruise phase
$FC_{Descent}$	=	fuel consumption during the descent phase
$FC_{Landing}$	=	fuel consumption during the landing phase
$FC_{Taxi\text{–}in}$	=	fuel consumption during the taxi-in phase

The landing and takeoff (LTO) phase of flight (3000 ft and below) consists of takeoff (accelerating down the runway until liftoff), climb out (from liftoff to 3000 ft), landing (3000 ft to touchdown) and taxi in/out (manoeuvring from the airport runway to/from the gate). The various LTO phases of flight are quantified by using either standard time-in-modes for that phase multiplied by the fuel consumption rate for that phase (drawn from ICAO, FOI or FOCA) or BADA fuel use characteristics for the aircraft as applicable (only available for the climb-out and approach phases).

The cruise phase of flight (above 3000 ft) is calculated using the BADA fuel use characteristics of the aircraft and the flight path length of the movement. The cruise phase is broken up into three parts, consisting of climb (3000 ft to cruise altitude), steady-state cruise (constant cruise altitude reached after completion of climb) and descent (from cruise altitude to 3000 ft). The distance taken to reach and descend from the steady-state cruise altitude (including the LTO portions of climb out and approach) is subtracted from the flight path length when determining the distance travelled at the steady-state cruise altitude.

2 Maximum takeoff weight.

The LTO and cruise phases of flight for any given movement are estimated by first using the representative aircraft mapping information, which relates the aircraft identified in the movement data to a representative aircraft with known performance characteristics. For the fuel rates of the representative aircraft that are distance-based, the flight path length for the movement is drawn from either the list of radar movement data provided by the FAA or calculated by quantifying the GCD and multiplying by an adjustment factor, as explained above. The fuel rates that are time-based in the LTO cycle already have the time-in-mode defined. With the known fuel use characteristics of the aircraft, the time-in-mode and flight path length, the LTO and cruise fuel estimates can be computed.

Step 3: Normalization

All aviation turbo fuel and aviation gasoline consumed in Canada are reported in the RESD (Statistics Canada, n.d.[d]). The fuel consumed, as estimated by the bottom-up approach of AGEM, is adjusted to match that of the RESD at a national level. The adjustment to LTO and cruise fuel estimates takes place at the individual movement level, across all movements.

Step 4: Emission Calculation

Emission estimates are generated at the individual movement level based on the normalized total fuel consumed and the appropriate emission factor, as outlined in Equation A3.1–1. The individual emission estimates are then summed to generate the national emission estimate.

A3.1.4.2.3. Domestic Navigation (CRT Category 1.A.3.d)

The methodology used to estimate GHG emissions from the Domestic Navigation category is considered an IPCC Tier 2 method for CO_2 emissions and an IPCC Tier 1 method for CH_4 and N_2O emissions.

This category includes emissions from vessels navigating between Canadian ports. In accordance with the 2006 IPCC Guidelines, military marine transportation emissions are reported in the Other Mobile category (CRT category 1.A.5.b). Likewise, emissions from fishing vessels are reported in the Fishing category (CRT category 1.A.4.c.iii). Excluded are emissions from smaller recreational vessels (reported under Other Transportation (Off-Road)). Emissions from outbound international voyages are designated as “bunker” emissions and are not included in national totals but are estimated and reported separately under International Bunkers as a Memo Item. Inbound international voyages and innocent passage through Canadian waters are not reported.

Marine emissions are developed using the MEIT, a model developed using vessel tracking information. Unlike the RESD, where fuel values are based on fuel sales data and organized by flag of vessel, MEIT is based on vessel movements and domestic or international emissions are assigned according to port origin destination information. It is important to give careful consideration when comparing fuel consumption (in terms of energy) in this subcategory against the national energy balance reported in the RESD and IEA data. Due to the design and operating procedures of marine vessels, it is not uncommon for vessels to store significant amounts of fuel onboard. This means that it is possible for vessels to navigate in Canadian waters without purchasing fuel from a Canadian supplier. Since the RESD is based on fuel transactions in Canada, it is possible to have more fuel consumed in the marine sector than what is reported in the national energy balance. When using the reference approach, excess fuel is accounted for as a “temporary import.”

Step 1: Activity Data – Marine Emission Inventory Tool

The Marine Emission Inventory Tool uses vessel traffic data and vessel characteristics to estimate the quantity of fuel required for each vessel manoeuvre within Canadian waters. Vessel traffic data are used for the 2010 and 2015 to 2024 calendar years. However, MEIT developed backcasts from 1990 to 2015 in 5-year increments. Fuel quantities between those years were linearly interpolated. Since the 2015 to 2024 calendar years are the only years for which estimates are available at a detailed level, the proportions of fuel use for those years are applied to the other calendar years to further break down the fuel quantity.

For the 2010 and 2015 to 2024 calendar years, the MEIT data are based on vessel traffic data from the Canadian Coast Guard Information System on Marine Navigation (INNAV) and Automatic Identification System (AIS) and the Department of Fisheries and Oceans’ fishing license data. The vessel movements are grouped into 1-km segments, which provide the distance and time between each point. To estimate the fuel use, the vessel characteristics/classifications are taken into consideration. Three sources of fuel consumption are considered: main engines, auxiliary engines and boilers. MEIT uses general assumptions for the auxiliary engines and boilers, however, more parameters are used to determine the fuel consumed by the main engine. The load factor has a significant influence on the fuel estimate from the main engine and is therefore calculated for each data point based on the propeller law.

From 1990 to 2010, the data were backcasted using multiple factors including Transport Canada commodity data for 1990 to 2005, port dry bulk and containerized (TEU) data, Northwest and Canada Cruise Association (NWCCA) passenger data, and Statistics Canada population data.

Step 2: Fuel Allocation and Time Series Consistency

The amount of fuel from the RESD is compared against the values estimated by the MEIT to determine how much of the fuel burned is likely to have been obtained from Canadian fuel suppliers. The comparison is performed systematically at a regional and category level.

If the RESD values are greater than the fuel consumption values estimated by MEIT (Scenario 1), it is assumed that fuel values from MEIT for military, fishing, domestic and international navigation are all purchased from Canadian suppliers. Any fuel difference between the RESD and MEIT is attributed to the International Navigation (Bunkers) category. It is assumed in this scenario that the MEIT model underestimated the amount of fuel used for international navigation, which is likely due to the MEIT only covering movement within Canadian waters.

If the RESD values are less than the fuel consumption values estimated by MEIT (Scenario 2), the following procedure is followed:

Case 1 – Military. If the amount of fuel available in the RESD is greater than the amount of fuel estimated by MEIT to be used by military vessels, then it is assumed that all fuel used for military operations was obtained from Canadian suppliers. If the amount of fuel available in the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers, while the remainder of the fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 2 – Fishing. If the amount of fuel available in the RESD (minus that used for military operations) is greater than the amount of fuel estimated by MEIT to be used by fishing vessels, then it is assumed that all fuel used for commercial fishing was obtained from Canadian suppliers. If the amount of fuel available in the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers, while the rest of the fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 3 – Domestic Navigation. If the amount of fuel available in the RESD (minus that used for military and fishing operations) is greater than the amount of fuel estimated by MEIT used by vessels involved in domestic voyages, then it is assumed that all fuel used for domestic navigation was obtained from Canadian suppliers. If the amount of fuel available in the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers, while the rest of the fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 4 – International Navigation (Bunkers). The portion of fuel equal to the amount of fuel available in the RESD (minus that used for military, fishing and domestic navigation) is assumed to be purchased from a Canadian supplier to be used for international navigation (bunkers). Then the difference between the MEIT fuel and the RESD fuel is assumed to be purchased from foreign fuel suppliers.

Step 3: Emission Calculation

Emissions are calculated by multiplying the fuel quantity by the fuel-specific emission factors (see Annex 6).

A3.1.4.2.4. Railways (CRT Category 1.A.3.c)

The methodology is an IPCC Tier 2 method for CO_2 emissions and an IPCC Tier 1 method for CH_4 and N_2O emissions. The locomotive fuel consumption is multiplied by fuel-specific emission factors (see Annex 6). The main data source for locomotive fuel consumption is obtained from the Railway Association of Canada (Thibault, 2025). That dataset is compared to the railway fuel volume reported in the RESD (Statistics Canada, n.d.[d]) and adjusted to ensure that the inventory is not accounting for more fuel than what is available in the national energy balance. However, if the total annual rail fuel volume in the RESD is greater than the volume of fuel from the Railway Association of Canada, than the fuel difference is reallocated to the on/off-road sectors. This is because the RESD uses sales data from refineries (NAICS 324) and distributors (NAICS 412). Sales are made to establishments operating in railways (not only to rolling stock). Sales also include all sales to establishments engaged in support services (NAICS 482 and 4882), therefore, sales used for equipment to repair, maintenance, cleaning of rail cars and railroads, loading/unloading equipment, trucks, generators, etc. are included in the RESD fuel volumes.

In Canada, locomotives are powered primarily by diesel fuel. A review of emissions attributable to steam train operations in Canada has determined that emissions associated with steam trains are insignificant. Electrically driven locomotives are accounted for under electricity production.

A3.1.4.2.5. Biomass (CRT Category 1.D.3)

The methodology used to estimate emissions from the consumption of biogenic transport fuels (e.g., ethanol and biodiesel) follows a modified IPCC Tier 1 method for gasoline and diesel fuel for on-road transportation and an IPCC Tier 1 method for off-road transportation, railways and domestic marine. The volume of biofuels consumed for transportation is proportionally reallocated back into the respective diesel fuel and gasoline emission technology classes based on those classes' initial consumption volumes.

The volumes of biofuels used for transport are primarily sourced from Navius Research (Navius Research, 2025), which includes biofuels associated with the road transportation, off-road transportation, rail, and marine categories. Currently, no domestic suppliers have reported biofuels for use in the aviation sector.

In lieu of specific CH_4 and N_2O emission factors for biofuels, the gasoline and diesel fuel emission factors from the equivalent emission technology classes are applied. CO_2 emission factors are developed according to the chemical properties of the fuel.

A3.1.4.2.6. Pipeline Transport (CRT Category 1.A.3.e.i)

Pipelines represent fossil fuel combustion engines used to power motive compressors to transport crude oil and related products, refined petroleum products, natural gas, and carbon dioxide. The fuel used for gaseous pipelines is primarily natural gas, but some refined petroleum, such as diesel fuel or gasoline, is also used. Liquid pipelines tend to use electric motors to operate pumping equipment.

Combustion-related GHG emissions associated with this equipment are calculated by applying Equation A3.1–1 to activity data and emission factors, at the provincial level for natural gas, and at the national level for other fuels.

A3.2. Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution

Detailed methodologies for estimating fugitive emissions from solid fuel production and the oil and gas industry are covered in this annex.

As the primary source of fugitive emissions, Canada's large oil and gas industry consists of a mix of production types, including natural gas production and processing; light, medium and heavy crude oil production; oil sands mining and extraction; and synthetic crude oil production. For a description of all sources of fugitive emissions, refer to Chapter 3.

All greenhouse gas (GHG) emissions from fuel combustion activities associated with fossil fuel exploration, production, processing, transmission, and distribution are reported under the Energy Industries (3.2.4) and Transport (3.2.6) sections of Chapter 3, and their respective methodologies can be found in sections A3.1.4.1 and A3.1.4.2.

A3.2.1. Solid Fuels

A3.2.1.1. Coal Mining

Canada Specific Coal Mining Studies

Canada's fugitive emission estimates are largely based on three studies: *Methane Emissions from Canadian Coal Operations: A Quantitative Estimate*, prepared by B. Hollingshead (1990) for the Transalta Utilities Corp.; *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options*, prepared by B. King (1994) for Neill and Gunter Ltd; and *Compilation of a National Inventory of Greenhouse Gas and Fugitive VOC Emissions by the Canadian Coal Mining Industry*, prepared by Cheminfo Services Inc. and Clearstone Engineering Ltd (Cheminfo and Clearstone, 2014) for Environment and Climate Change Canada (ECCC). These three studies contain mine-specific information upon which Canada has based its country-specific data, parameters and information regarding surface and underground mines, and they are confidential.

The Hollingshead study was commissioned by Transalta Utilities Corp., with the goal of estimating methane (CH_4) emissions from coal mines and coal combustion in Canada. The study developed, for the year 1989, estimates of fugitive emissions from underground and surface mines and combustion emissions from all coal use in Canada. As such, the emphasis of this study was not on developing emission factors (EFs) that would be usable on a yearly basis, but rather on providing a snapshot of all emissions from coal for a particular year. However, in the process of estimating these total emissions, a large amount of useful data was collected pertaining to the CH_4 composition of coal mined in Canada.

Canada has had, in most years, both underground and surface coal mines, and the method developed by King (1994) produced CH_4 EFs for all coal types and all individual coal mines. Where possible, King employed the Canada-specific data included in the Hollingshead study, while clearly identifying and explaining this data source. King's method for surface and underground mines is a modified version of a process developed for the International Energy Agency by the Coal Industry Advisory Board (CIAB). Further discussion of some of these modifications can be found in the section below on surface mines. Prior to the 2016 submission, the CH_4 EFs determined in the King (1994) study were used to estimate the CH_4 fugitive emissions from all 23 operational mines and from all mines abandoned after 1990 in Canada.

In 2014, ECCC awarded a contract to Cheminfo Canada and Clearstone Engineering to update the EFs for coal mines in Western Canada. The study produced new EFs for seven of the then 21 active surface mines using field tests from two sub-bituminous coal mines in central Alberta, one bituminous coal mine in northeast British Columbia and one bituminous coal mine in northwest Alberta. Results from the four tested mines were applied to three nearby mines that exploited the same coal seams and had similar geography. The mobile plume transect system (MPTS) that was employed develops a two-dimensional y-z plot of the pollutant concentration and wind profile downwind of the target source(s). The measurement system comprised: (1) a cavity ring-down spectrometer; (2) an 8-channel multiplexer sampling system; (3) an ultrasonic 3-D wind anemometer; (4) a GPS and inertial system; (5) a vehicle equipped with a vertical sampling mast; and (6) a computer and software.

The emissions model is a hybrid of Intergovernmental Panel on Climate Change (IPCC) Tier 2 and Tier 3 methodologies that depends on the availability of mine-specific data. Gross production values provided by Statistics Canada (StatCan), before any cleaning and prework, are used to calculate fugitive emissions for all mine types. The associated post-mining activity emissions are accounted for in the underground and surface mining EFs. Additional details of the methodologies used to estimate the emissions from underground and surface mines are provided in their respective sections.

Underground Mines

King (1994) estimated emissions for underground mines on a mine-specific basis by summing emissions from the ventilation system, degasification systems and post-mining activities. In the absence of measured data, emissions from the mine shaft ventilation system were estimated using Equation A3.2–1.

Equation A3.2–1

$$Y = 4.1 + (0.023 \times X)$$

Y = emissions of CH_4 per gross tonne of coal mined, m^3 CH_4/t coal
X = depth of mine, m

Emissions from post-mining activities were estimated by assuming that 60% of the remaining coal CH_4 (after removal from the mine) is emitted to the atmosphere before combustion. If the CH_4 content of the mined coal was unknown, then 1.5 m^3/t, the global average for coals (King, 1994) was assumed. All underground mines in Canada are drift mines and have an effective depth of zero metres. Emissions from post-mining activities are integrated into the overall coal production EFs for each mine, after all quantities are converted to mass units, using a standard conversion of 0.67 kg/m^3 CH_4.

Between 1992 and 1999, all underground mining ceased in eastern Canada. The remaining underground mines were in Alberta and British Columbia and were less gassy than mines in eastern Canada. Between 2015 and 2017, there were no active underground coal mines in Canada, however, the Donkin mine in Nova Scotia resumed operation in 2018 and operated for a two-year period.

Surface Mines

The CIAB methodology was modified to incorporate confidential Canadian and U.S. site-specific data (from King, Hollingshead and Cheminfo and Clearstone) for the three coal types mined in Canada, rather than using a generalized international data set to represent country-specific circumstances. King developed EFs by region, by mine and by coal types; the average CH_4 content of bituminous or sub-bituminous coal was 0.4 m^3/t (based on tests at 50 mines in the United States, obtained by King) and the Canada-specific CH_4 content for lignite was 0.05 m^3/t (Hollingshead, 1990), with the assumption that 60% of the gas is released before combustion. A field-testing campaign to measure fugitive emissions of CH_4, carbon dioxide (CO_2) and volatile organic compounds (VOCs) was performed on four coal mines in late February 2014:

- **Sites 1 and 2**: two sub-bituminous coal mines in central Alberta
- **Site 3**: one bituminous coal mine in northeast British Columbia
- **Site 4**: one bituminous coal mine in northwest Alberta

CH_4 emissions were measured remotely using a ground-based mobile plume transect system (MPTS) for area sources and tracer tests for volume and point sources (Cheminfo and Clearstone, 2014). Data from this field-testing was used to modify the CH_4 EFs of 7 of the 23 producing mines in Canada. The EFs in Table A3.2–1 incorporate these data and assumptions. In addition, the overall CH_4 EF uncertainty is reported in Table A2–1 category 1.B.1.a Fugitive Sources – Coal mining and Handling on the Government of Canada's Open Data website.

Surrounding unmined strata are a significant source of emissions from surface mines. Using Canadian mine-specific data from the Hollingshead study, King applied a high-wall adjustment to the surrounding unmined strata, to a depth of 50 m below the mining surface. Base EFs for surface mining were increased by 50% (King 1994) to account for this out-gassing adjustment and are reflected in the EFs in Table A3.2–1.

To obtain the emissions from coal mining, Equation A3.2–2 is used.

Equation A3.2–2

$$\textit{Provincial Emissions} = \sum(EF_{i,j,k,l} \times Coal_{i,j,k,l})$$

$EF_{i,j,k,l}$ = the emission factor from the King (1994) or Cheminfo and Clearstone (2014) studies for province i, coal type j, mine k and coal field l
$Coal_{i,j,k,l}$ = the gross production of coal for province i, coal type j, mine k and coal field l

Emissions are calculated for each province and then summed to determine the emission estimate for Canada.

Despite the closing of east coast underground mines, production increases at less gassy surface mines in Alberta and British Columbia have sustained Canada's total annual coal production. The net effect is that, while production has stayed steady, total fugitive emissions associated with coal mining have declined significantly since 1990.

Table A3.2–1 **Fugitive Emission Factors for Coal Mining, 2024**

Province	Surface Coal Mines	Emission Factor	Units
SK	Lignite	0.07	t CH_4 / kt coal mined
AB	Bituminous	0.31	
AB	Sub-bituminous	0.43[a]	
BC	Bituminous	0.91	

Notes:
Adapted from King (1994) and Cheminfo et al. (2014).
a. Alberta's 2024 weighted sub-bituminous EF reflects a larger contribution from more GHG intensive mines than previous years due to the closure of a less GHG intensive operation.

Activity Data

The model requires the gross mine output data for each type of coal mined in each province. Until 2002, the data was obtained from StatCan's *Coal and Coke Statistics* publication (StatCan, n.d. [a]). In 2002, the publication was discontinued, and StatCan now provides this data directly to ECCC via a memorandum of understanding. In addition, quality control activities of StatCan data rely on comparison with provincial coal statistics as operators report to both federal and provincial departments, for example Alberta Energy Regulator's ST26 – monthly coal statistics (AER, n.d. [a]).

Emission Factors

EFs were developed by coal type, coal mine type and coal field. Because of confidentiality requirements, factors can only be reported at the provincial level. These 2023 EFs were weighted for currently producing mines and coal types using data in the King (1994), and Cheminfo and Clearstone (2014) studies and reported gross production for each mine. Respecting confidentiality, mine specific EFs used in estimating fugitive emissions are not presented. Instead, weighted EFs by region, coal, and mine type (i.e., underground or surface) are presented for information only in Table A3.2–1 and Table A6.1–13. These weighted EFs vary from year-to-year as they are dependent on which mines are in service in the given year and their respective production volumes. These weighted EFs should not be used in estimating mine-specific emissions.

A3.2.1.2. Abandoned Underground Coal Mines

Coal mine methane (CMM) and other gases naturally exist within coal seams and are released to the atmosphere under suitable conditions. Of these gases, CH_4 is of greatest concern, while other releases, such as CO_2, are considered small and are not reported since the IPCC provides no method for estimating these emissions (IPCC, 2006).

As noted in A3.2.1.1, structural disturbance exposes the coal to lower atmospheric pressures, allowing the release of fugitive emissions during mining and post-mining operations, including handling, crushing and transportation. Once an underground mine closes and active venting stops, emissions may continue for decades. After production ceases, all subsequent emissions are estimated using the model described in this section.

Methodology

CMM is influenced by many factors, including geological seam structure, coal rank and characteristics, mining activities, pressure gradients, mine flooding and post-mining venting and capping. Though no Canadian data is available on post-mining venting and capping, provincial regulations require all recently abandoned mines to be capped for safety.

The IPCC Tier 2 equation for abandoned mines takes the general form in Equation A3.2–3.

Equation A3.2–3 **IPCC Tier 2**

$$\textit{CH}_4\ \textit{Emissions} = \textit{Unflooded Mines} \times \textit{Fraction Gassy} \times \textit{Average Emission Rate} \times \textit{EF} \times \textit{Conversion Factor}$$

$\textit{CH}_4\ \textit{Emissions}$	=	yearly emissions (Gg/year)
$\textit{Unflooded Mines}$	=	number of unflooded mines
$\textit{Fraction Gassy}$	=	% of mines defined as gassy
$\textit{Average Emission Rate}$	=	(m^3/year)
$\textit{EF}$	=	emission factor, dimensionless, of the form (1+aT)·b
$\textit{Conversion Factor}$	=	converts CH_4 volume to mass (0.67 kg/m^3, at 20°C and 1 atmosphere pressure)

The IPCC Tier 3 equation for abandoned mines takes the general form in Equation A3.2–4.

Equation A3.2–4 **IPCC Tier 3**

$$CH_4\ Emissions = Emission\ rate\ at\ closure \times EF \times Conversion\ Factor$$

$CH_4\ Emissions$	=	yearly emissions (Gg/year)
$Emission\ rate\ at\ closure$	=	known emission rate for specific mine (m^3/year)
EF	=	emission factor, dimensionless, of the form (1+aT)·b
$Conversion\ Factor$	=	converts CH_4 volume to mass (0.67 kg/m^3, at 20°C and 1 atmosphere pressure)

Detailed data on mine CH_4 emission rates during production years was only available for five mines in Nova Scotia (King 1994). This data allowed the use of Equation A3.2–4, following the IPCC Tier 3 approach, to estimate abandoned mine emissions in this region. For all other regions of Canada, known production data for abandoned mines was averaged over the life of the mines, and the EFs in Table A3.2–1 were used to estimate emissions in the final year of production. Based on this estimate, Equation A3.2–3 was used to calculate emissions. Calculations were done using, the five periods seen in Table A3.2–2, and a Tier 2 approach to determine the percent gassy mines for each time interval. Mines abandoned before 1900 are assumed to be non-emitting (IPCC, 2006).

Following the end of mining activities, CH_4 emissions have been shown empirically to drop off following a hyperbolic decline curve. This is modelled using the IPCC Tier 2/3 EF equation (1+aT)·b, where a and b are mine- or basin-specific constants and T is the time since abandonment (IPCC, 2006). See Table A3.2–3 for a list of constants applied to Canadian data. This IPCC EF formula was used for all provincial estimates.

CH_4 emissions from flooding mines decrease dramatically once active pumping ceases. Water pressure inhibits CH_4 from being emitted due to reduced relative permeability. U.S. EPA empirical studies (U.S. EPA, 2004) based on U.S. mines indicate that mine flooding occurs within eight years. The 2006 IPCC Guidelines (IPCC, 2006) indicate that fully flooded mines be assigned zero emissions but be explicitly listed.

For the purposes of calculating emissions, mines are assumed unflooded unless specific data exists. Provincial experts in Alberta indicated that most mines are flooded but had knowledge of flooding at only the Bellevue Mine Museum. Therefore, only the 12 abandoned mines in the near vicinity of the Bellevue Mine Museum, which closed over 20 years ago, were assumed flooded. For Nova Scotia, provincial experts at Nova Scotia Environment confirmed that underground mines started flooding immediately after pumps were turned off and that all mines were flooded by end of summer 2013.[1] Table A3.2–4 characterizes the condition of abandoned mines by flooded and non-flooded, for all regions of Canada that have underground coal mines.

The IPCC defaults in Table A3.2–2, are used to estimate the percentage of gassy mines in each region and time interval. For all regions of Canada, except for Saskatchewan, the default high values for gassiness were assumed.

The lower IPCC default percentage of gassy mines was chosen for Saskatchewan mines based on time since abandonment, lignite rank, small mine size and shallow depth—often dug from a riverbed into a slight hill. Additionally, during a public safety review, all mine entrances were either capped or sealed. The non-gassy nature of these mines was previously reported in Hollingshead (1990).

Table A3.2–2 **IPCC Tier 2, % Gassy Mines per Time Interval**

Period	Low	High
1900–1925	0%	10%
1926–1950	3%	50%
1951–1975	5%	75%
1976–2000	8%	100%
2001–present	9%	100%

Table A3.2–3 **IPCC Tier 2/3 – Emission Factor Coefficients**

Coal Rank	a	b
Anthracite	1.72	-0.58
Bituminous	3.72	-0.42
Sub-bituminous	0.27	-1.00

1 Nova Scotia Environment. 2015. Personal communication (email from Miller M, Policy Analyst, Nova Scotia Environment to Baker W, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada, dated November 16, 2015).

Table A3.2–4 **IPCC Tier 2/3 – Abandoned Underground Coal Mines, 2024**

Province	Number of Abandoned Coal Mines[a]	Number of Abandoned Mines Flooded[b]
NS[c]	282	281
SK[d]	245	0
AB	854	13
BC	51	0
CA	**1 432**	**294**

Notes:
a. Only mines that produced more than 0.5 kilotonnes are included.
b. When no data is available, mines are assumed to be non-flooded.
c. Tier 2 and 3 estimates used for Nova Scotia.
d. Saskatchewan lignite mine estimate uses IPCC Tier 2 sub-bituminous emissions factor calculated for each time band (see IPCC 2006 4.27, Equation 4.1.12).

Activity Data

This model uses data obtained from industry and from provincial and federal government sources. The general lack of detailed data sources affected the choice of estimation methods, preventing the incorporation of likely but unconfirmed flooding and mine-specific emissions measurements. Conservative assumptions were made when accurate data was unavailable for mine gassiness, flooded status and EFs. As previously noted, in 2018, the Donkin mine in Nova Scotia temporarily returned to production and was not included in the data for abandoned mines during that period.

Emissions

The results of emission calculations, for select years, are presented in Chapter 3. Abandoned mines in Nova Scotia have historically contributed the largest proportion of emissions; the two emission peaks in 1993 and 2000 correspond to closures of large mines in that province. There were two recent mine abandonments in Western Canada and the effect of these closures on the model's decline curves are visible in the latest reporting years.

A3.2.2. Oil and Natural Gas

Fugitive emissions from the oil and natural gas industry are estimated using the following methods depending on the emission source and data availability in the province or territory. Figure A3.2–1 presents a breakdown of 2024 fugitive oil and gas emissions by estimation method.

- **Direct estimation / Reported**: where possible, facility reported volumetric data and detailed gas composition data are used to directly estimate emissions. This applies to Alberta, British Columbia, and Saskatchewan reported venting and Alberta, British Columbia, Saskatchewan, and Newfoundland and Labrador flaring emissions (see section A3.2.2.1.2). Reported emissions for the natural gas transmission, storage, and distribution sectors are used directly in the inventory (see sections A3.2.2.2 and A3.2.2.4) as well as flaring emissions for the Petroleum Refining industry (see section A3.2.2.3). Additionally, reported quantities of CO_2 captured at oil and gas facilities and injected into storage are subtracted from emission estimates.
- **Modelled**: when facility reported data is not available, emissions are modelled using annual activity data and EFs. This applies to emissions from pneumatic devices, compressor seals, and equipment leaks in British Columbia, Alberta, Saskatchewan, and Manitoba (see section A3.2.2.1.3), Alberta and British Columbia surface casing vent flow emissions (see section A3.2.2.1.4), as well as abandoned oil and gas wells (see section A3.2.2.6) and post-meter fugitives (see section A3.2.2.7).
- **Aerial measurements**: source-resolved methane emission inventories derived from aerial measurements are used as the basis to estimate emissions from storage tanks, compressor buildings, and unlit flares in British Columbia, Alberta and Saskatchewan, engine sheds in Alberta and Saskatchewan, and wellheads in Saskatchewan (see section A3.2.2.1.5).
- **Interpolated/Extrapolated**: detailed inventory studies for specific years are used as the basis to interpolate/extrapolate emissions for years without detailed inventory data based on changes in activity data. This applies to the Oil Sands and Heavy Oil Upgrading industry (see section A3.2.2.5) and venting and other fugitive emissions from the Petroleum Refining sector (see section A3.2.2.3). It also includes all other fugitive emission sources and provinces and territories not mentioned above (see section A3.2.2.1.1).

Table A3.2–5 lists the oil and gas industry segments and fugitive sources estimated and the allocation of these emissions according to the Common Reporting Tables (CRT) categories.

Figure A3.2–1 **Breakdown of Fugitive Oil and Gas Emissions by Estimation Method, 2024**

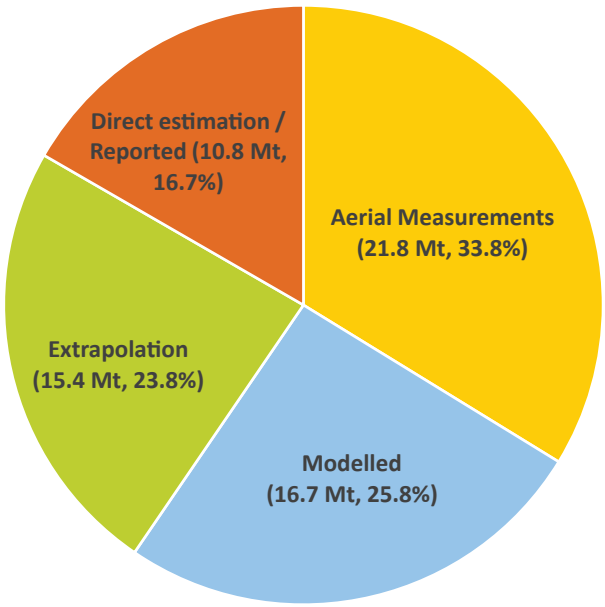


Table A3.2–5 **Allocation of Fugitive Oil and Gas Emissions to CRT Categories**

CRT Category	Industry Segment	Emission Source Categories
1.B.2.a.ii Oil – Production and upgrading	Light/Medium Crude Oil Production	Fugitive Equipment Leaks; Loading/Unloading; Surface Casing Vent Flow
	Heavy Crude Oil Cold Production	Fugitive Equipment Leaks; Loading/Unloading; Surface Casing Vent Flow
	Well Servicing	Fugitive Equipment Leaks; Loading/Unloading
	Heavy Crude Oil Thermal Production	Fugitive Equipment Leaks; Loading/Unloading; Surface Casing Vent Flow
	Disposal and Waste Treatment	Fugitive Equipment Leaks
	Oil Sands Liquids Extraction	Fugitive Equipment Leaks
	Oil Sands Mining and Ore Processing	Fugitive Equipment Leaks; Exposed Mine Face; Tailings Ponds; Other Fugitive
	Oil Sands and Heavy Oil Upgrading	Fugitive Equipment Leaks; Other Fugitive
	Accidents and Equipment Failures	Gas Migration; Surface Casing Vent Flow
1.B.2.a.iii Oil – Transport	Petroleum Liquids Transportation	Fugitive Equipment Leaks
1.B.2.a.iv Refining / storage	Petroleum Refining	Other Fugitive
1.B.2.a.vi.1 Oil – Other – Abandoned Wells	Abandoned Oil Wells	Other Fugitive
1.B.2.a.vi.2 Oil – Other – Accidents and Equipment Failures	Oil Sands Upgrading	Spills/Pipeline Ruptures
1.B.2.b.ii Natural Gas – Production and gathering	Natural Gas Production	Fugitive Equipment Leaks; Loading/Unloading; Surface Casing Vent Flow
	Well Testing	Fugitive Equipment Leaks; Loading/Unloading
1.B.2.b.iii Natural Gas – Processing	Natural Gas Processing	Fugitive Equipment Leaks; Loading/Unloading
1.B.2.b.iv Natural Gas – Transmission and Storage	Gas Transmission	Fugitive Equipment Leaks; Spills/Pipeline Ruptures
	Gas Storage	
1.B.2.b.v Natural Gas – Distribution	Gas Distribution	Fugitive Equipment Leaks; Spills/Pipeline Ruptures
1.B.2.b.vi.1 Natural Gas – Other – Gas post-meter	Post-meter Fugitives	Fugitive Equipment Leaks
1.B.2.b.vi.2 Natural Gas – Other – Abandoned wells	Abandoned Gas Wells	Other Fugitive
1.B.2.b.vi.3 Natural Gas – Other – Accidents and Equipment Failures	Accidents and Equipment Failures	Spills/Pipeline Ruptures

Table A3.2–5 **Allocation of Fugitive Oil and Gas Emissions to CRT Categories** (cont'd)

CRT Category	Industry Segment	Emission Source Categories
1.B.2.c.i.1 Venting – Oil	Light/Medium Crude Oil Production	Glycol Dehydrator Off-Gas; Reported Venting; Storage Losses; Unreported Venting[a]
	Heavy Crude Oil Cold Production	Glycol Dehydrator Off-Gas; Reported Venting; Storage Losses; Unreported Venting[a]
	Heavy Crude Oil Thermal Production	Glycol Dehydrator Off-Gas; Reported Venting; Storage Losses; Unreported Venting[a]
	Petroleum Liquids Transportation	Reported Venting; Storage Losses; Unreported Venting[a]
	Oil Sands Liquids Extraction	Venting
	Oil Sands Mining and Ore Processing	Storage Losses; Venting
	Oil Sands and Heavy Oil Upgrading	Hydrogen production process venting; Storage Losses; Venting; CO_2 captured
	Petroleum Refining	Venting; CO_2 captured
1.B.2.c.i.2 Venting – Natural Gas	Natural Gas Production	Glycol Dehydrator Off-Gas; Reported Venting; Storage Losses; Unreported Venting[a]
	Natural Gas Processing	Glycol Dehydrator Off-Gas; Formation CO_2; Reported Venting; Storage Losses; Unreported Venting[a]
	Gas Transmission	Reported Venting
	Gas Distribution	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting[a]
	Gas Storage	Reported Venting; Unreported Venting[a]
1.B.2.c.i.3 Venting – Combined	Well Drilling; Well Servicing	Reported Venting; Storage Losses
	Well Testing	Glycol Dehydrator Off-Gas; Reported Venting; Storage Losses; Unreported Venting[a]
	Disposal and Waste Treatment	Unreported Venting[a]
1.B.2.c.ii.1 Flaring – Oil	Light/Medium Crude Oil Production	Flaring
	Heavy Crude Oil Production	
	Heavy Crude Oil Thermal Production	
	Petroleum Liquids Transportation	
	Oil Sands Liquids Extraction	
	Oil Sands Mining and Ore Processing	
	Oil Sands and Heavy Oil Upgrading	
	Petroleum Refining	
1.B.2.c.ii.2 Flaring – Natural Gas	Natural Gas Production	Flaring
	Natural Gas Processing	
	Gas Transmission	
	Gas Storage	
	Gas Distribution	
1.B.2.c.ii.3 Flaring – Combined	Well Drilling	Flaring
	Well Servicing	
	Well Testing	
	Disposal and Waste Treatment	

Note:
a. Depending on the emission sector category and province/territory, unreported venting can include emissions from pneumatic controllers, pneumatic pumps, compressor fugitives, compressor start gas, unlit flares, engine sheds, wellheads, and well drill-stem tests.

A3.2.2.1. Upstream Oil and Natural Gas Industry

A3.2.2.1.1. Upstream oil and gas and Canadian Association of Petroleum Producers Studies

Except where otherwise noted, fugitive emissions from the upstream oil and gas (UOG) industry are based on two separate studies: a study titled *A National Inventory of Greenhouse Gas, Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emissions by the Upstream Oil and Gas Industry* (CAPP, 2005a), prepared by Clearstone Engineering Ltd. for the Canadian Association of Petroleum Producers (CAPP) and referred to hereafter as the CAPP study, and an update to the inventory that was completed in 2014 for Environment Canada by Clearstone Engineering Ltd. and referred to hereafter as the UOG study (EC, 2014). Both inventories used an IPCC Tier 3 bottom-up assessment to estimate all GHG emissions from the UOG sector, with the exclusion of oil sands mining, extraction and upgrading. The CAPP study provided a detailed emission inventory for the year 2000, while the UOG study produced inventories for the years 2005 and 2011.

In general, the emission inventories for the years 2000, 2005 and 2011 were used directly, except for a few special cases. If a specific source did not exist in one of the inventory years (e.g., the 2000 inventory) due to insufficient data, but did exist in another inventory year (e.g., the 2005 inventory), then emissions for that source were extrapolated from the known year and included in the inventory that was missing data to ensure completeness. A brief description of the methodology used in the CAPP and UOG studies follows, along with the methodology used to estimate the emissions for 1990–1999, 2001–2004, 2006–2010 and from 2012 onwards.

Methodology for the 2000, 2005 and 2011 Estimates

The emission estimates contained in the CAPP and UOG studies were developed using a bottom-up approach, beginning at the individual facility and process unit level and aggregating the results to provide emission estimates by facility and geographic area. The Canadian UOG sector's assets and operations are vast: the 2011 inventory included over 300 000 capable oil and gas wells, 14 100 batteries producing gas into more than 5000 gathering systems delivering to almost 750 gas plants, and 24 000 oil batteries delivering to 150 tank terminals, all of which are interconnected by tens of thousands of kilometres of pipeline carrying hydrocarbons from wells to batteries to plants and finally to markets.

Emissions from flaring, venting, equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses and accidental releases were estimated. The basic methods used to estimate GHG emissions were:

- emission monitoring results
- emission source simulation results
- emission factors
- destruction and removal efficiencies

To estimate emissions, large amounts of data were collected including:

- measured volumes of natural gas taken from the process
- vented and flared waste gas volumes
- fuel purchases (propane, diesel fuel, etc.)
- fuel analyses
- emission monitoring results
- process operating conditions that may be used to infer the work being done by combustion devices (gas compositions, temperatures, pressures and flows, etc.)
- spill and inspection reports

Other required data included the following:

- types of processes used
- equipment inventories
- emission source control features
- sulphur content of the fuels consumed and waste gas flared
- composition of the inlet and outlet streams

Refer to the CAPP study (CAPP, 2005a) and UOG study (EC, 2014) for further details.

Methodology for Extrapolating Emission Estimates

The method for extrapolating emissions from a known inventoried year to other non-inventoried years was developed by Clearstone Engineering Ltd. (CAPP, 2005b). This method was used to backcast the 2000 emission estimates for the 1990–1999 period, to extrapolate the 2011 inventory for 2012 onwards and, in conjunction with other curve fitting methods, to interpolate the 2001–2004 and 2006–2010 time periods.

Equation A3.2–5 is used to estimate emissions for non-inventoried years by multiplying base year emissions data for a given source and sector by the ratio of activity data for the non-inventoried year to that of the base year. Various types of activity data for each province/territory and year were used, such as natural gas and crude oil production volumes, fuel, flare and vent volumes, number of wells drilled, number of spills, ruptures and blowouts, total capable oil and gas wells, and shrinkage. Not all activity data is available for all years or all regions. Emission sources for specific sectors and regions were extrapolated using the most appropriate activity data. Where activity data was not available for the entire time series, the methodology to interpolate intermediate years, which is described later in this section, was used to provide one consistent time series.

Table A3.2–6 lists the publicly available activity data used to extrapolate emissions along with the corresponding data source.

Table A3.2–7 contains a list of the activity data used to estimate flaring emissions for each region, sector category and period while Table A3.2–8 contains the same information for reported venting. Table A3.2–9 displays the activity data that is used to extrapolate emissions for all other UOG fugitive sources such as fugitive equipment leaks, unreported venting,[2] storage losses, etc.

Equation A3.2–5

$$ER_{i,j}^{k} = ER_{i,j}^{baseYr} \times \left(\frac{AF_{j}^{k}}{AF_{j}^{baseYr}} \right)$$

$ER_{i,j}^{k}$ = emission rate of compound i, source j, and year k, t/year

$ER_{i,j}^{baseYr}$ = base year (e.g., 2011) emission rate for compound i and source j, t/year

AF_{j}^{k} = activity factor for source j and year k

AF_{j}^{baseYr} = base year (e.g., 2011) activity factor for source j

The emissions for 1990–1999 were backcast by sector and source at the provincial level based on the year 2000 emission estimates from the CAPP study (CAPP, 2005a). The only exception to this was the province of Nova Scotia, which from 1992 to 1999 was an oil-only producing province. In 2000, it switched to a gas-only producing province. As such, the year 2000 data could not be used to estimate emissions for the 1990–1999 period, and Nova Scotia's fugitive emissions were extrapolated based on CAPP's 1995 UOG study data (CAPP, 1999). Refer to the UOG study (CAPP, 2005a) for further details.

The emissions from 2012 onwards were extrapolated using emissions by sector and source at the provincial/territorial level based on the year 2011 emission estimates from the UOG study (EC, 2014).

Methodology for 2001–2004 and 2006–2010

To estimate emissions for the 2001–2004 and 2006–2010 time periods, all three base year inventories (2000, 2005 and 2011) were extrapolated for the 2000–2011 period using the method described previously. This resulted in three curves which were used to interpolate the intermediate years by using either a "wedging" or "proportional adjustment" method, depending on the circumstance. The "wedging" method was used unless it resulted in negative emission estimates for any year in the period. Less than 0.3% of cases required the use of the "proportional adjustment" method.

2 Unreported venting includes venting from processes or equipment that is not typically included in reported venting volumes. Depending on the industry sector and province/territory, it can include pneumatic devices (e.g., chemical injection pumps, natural gas operated instrumentation), compressor vents, compressor start gas, unlit flares, engine sheds, wellheads, purge gas and blanket gas that is discharged directly to the atmosphere and gas vented from drill-stem tests.

Table A3.2–6 **Required Activity Data and Their Sources**

Publisher	Publication	Activity Data
Alberta Energy Regulator (AER)	ST60B: Upstream Petroleum Industry Flaring and Venting Report (AER, 2000–)	Reported venting and flaring volumes
	ST3: AER Industries Monthly Statistics, Gas Supply and Disposition (AER, n.d. [b])	Shrinkage
	Alberta's Energy Reserves and Supply/Demand Outlook (AER, n.d. [c])	Thermal in-situ bitumen production Cold crude bitumen production
	AER Compliance Dashboard (AER, n.d. [d])	Number of incidents
British Columbia Government	Production and distribution of natural gas (BC, n.d. [a])	Reported venting volumes Shrinkage
British Columbia Energy Regulator	Drilling Kicks and Blowouts by Area (BCER, n.d. [b])	Sum of kicks and blowouts
	Air Summary Report (BCOGC, 2019)	Reported flaring volumes
	Petrinex Volumetric data (BCER, n.d. [c])	Reported venting and flaring volumes Shrinkage
Canada Energy Regulator (CER)	Canada's Energy Future (CER, 2025)	Non-associated gas production
Canada–Newfoundland and Labrador Offshore Energy Regulator (C-NLOER)	Development Wells – Hebron (C-NLOER, 2017–)	Number of capable wells
	Development Wells – Hibernia (C-NLOER, 1997–)	Number of capable wells
	Development Wells – North Amethyst (C-NLOER, 2010–)	Number of capable wells
	Development Wells – Terra Nova (C-NLOER, 2002–)	Number of capable wells
	Development Wells – White Rose (C-NLOER, 2005–)	Number of capable wells
	Environment Statistics – Spill Frequency and Volume Annual Summary (C-NLOER, n.d. [a])	Number of spills
Canadian Association of Petroleum Producers (CAPP)	Statistical Handbook for Canada's Upstream Petroleum Industry (CAPP, n.d. [a]; [b])	Total wells drilled (including dry and service) (Tables 1.2b–1.2f)
		Sum of Operated Oil Wells (Table 3.17a) and Operated Gas Wells (Table 3.18a)
Manitoba Economic Development, Investment, Trade and Natural Resources	Petroleum Industry Spill Statistics (MB EDITNR, n.d. [a])	Number of spills
New Brunswick Natural Resources and Energy Development	Monthly Production Statistics (NB NRED, n.d.)	Light/medium crude oil production Natural gas production
Petrinex	Saskatchewan Volumetric data (Petrinex, n.d. [a])	Thermal heavy oil production
Saskatchewan Ministry of Energy and Resources	Crude Oil Volume and Value Summary (SK MER, 2012– [a])	Light/medium crude oil production Heavy crude oil production
	Natural Gas Volume and Value Summary (SK MER, 2012– [b])	Non-associated gas production
	Saskatchewan Upstream Oil and Gas IRIS Incident Report (SK MER, n.d.)	Number of spills
	Saskatchewan Annual Petroleum Statistics (SK MER, 2009–2011)	Shrinkage
	Saskatchewan Mineral Statistics Yearbook, Petroleum and Natural Gas. (SK MER, 1990–2008)	Shrinkage
Statistics Canada	Table 25-10-0047-01 Natural gas, monthly supply and disposition (Statistics Canada, n.d. [c])	Gross production Field flared and waste Field disposition and usage Gathering system disposal and use Plant uses Shrinkage
	Table 25-10-0055-01 Supply and disposition of natural gas, monthly (Statistics Canada, n.d. [d])	Gross withdrawals
	Table 25-10-0014-01 Crude oil and equivalent, monthly supply and disposition (Statistics Canada, n.d. [e])	Heavy crude oil production Light/medium crude oil production Synthetic crude oil production Crude bitumen production
	Table 25-10-0063-01 Supply and disposition of crude oil and equivalent (Statistics Canada, n.d. [f])	Heavy crude oil production Light/medium crude oil production Synthetic crude oil production Non-upgraded production of crude bitumen
	Report on Energy Supply and Demand in Canada (Statistics Canada, n.d. [b])	Total RPP Retail Pump Sales

Table A3.2–7 **Activity Data Used to Extrapolate Flaring Emissions by Region and Year**

Province / Territory	Emission Sector Category	Period	Activity Data	Period	Activity Data
AB	Light/Medium Crude Oil Production	1990–1999	Field flared and waste	2000–2009	Flaring – Oil batteries
	Heavy Crude Oil Cold Production				Flaring – Oil batteries + Bitumen batteries
	Heavy Crude Oil Thermal Production				Flaring – Bitumen batteries
	Natural Gas Production				Flaring – Gas batteries + Gas gathering systems
	Natural Gas Processing				Flaring – Gas plants
	Well Testing				Flaring – Well testing
	Petroleum Liquids Transportation				Flaring – Total
	Disposal and Waste Treatment				Flaring – Total
BC	Light/Medium Crude Oil Production	1990–1995	Field flared and waste	-	NA
	Natural Gas Production				
	Natural Gas Processing				
	Well Testing		Wells Drilled	1996–2024	Flaring – Well Cleanup and Testing
	Well Drilling				Flaring – Underbalanced Drilling
MB, NB, NT	Light/Medium Crude Oil Production	1990–2024	Light/medium crude production	-	NA
NB, NS, ON, YT	Natural gas production	1990–2024	Natural gas production	-	NA
NT	Natural gas processing	1990–2024	Field flared and waste	-	NA
NS, ON	Natural gas processing	1990–2024	Natural gas production	-	NA
BC, ON, SK	Petroleum Liquids Transportation	1990–2024	Total crude production	-	NA
AB	Well Servicing	1990–2024	Wells Drilled	-	NA
SK	Well Testing	1990–2024	Wells Drilled	-	NA

Note:
NA = Not applicable

Table A3.2–8 **Activity Data Used to Extrapolate Reported Venting Emissions by Region and Year**

Province / Territory	Emission Sector Category	Period	Activity Data	Period	Activity Data
AB	Light/Medium Crude Oil Production	1990–1999	Light/medium crude production	2000–2009	Heavy Crude Oil Thermal Production
	Heavy Crude Oil Cold Production		Heavy crude production		Venting – Oil batteries + Bitumen batteries
	Heavy Crude Oil Thermal Production	1990–2004	In-situ thermal production	2005–2009	Venting – Bitumen batteries
	Natural Gas Production	1990–1999	Natural gas production	2000–2009	Venting – Gas batteries + Gas gathering systems
	Natural Gas Processing		Natural gas production		Venting – Gas plants
	Well Testing		Wells drilled		Venting – Well testing
	Petroleum Liquids Transportation		Total crude production		Venting – Total
BC	Light/Medium Crude Oil Production	1990–2010	Light/medium crude production	2011–2018	Field vented
	Natural Gas Production		Natural gas production		Field vented
	Natural Gas Processing		Natural gas production		Natural gas production
MB	Light/Medium Crude Oil Production	1990–2024	Light/medium crude production	-	NA
NT	Natural gas processing	1990–2024	Natural gas production	-	NA
AB, SK, BC	Well Servicing, Well Drilling	1990–2024	Wells Drilled	-	NA

Note:
NA = Not applicable

Table A3.2–9 **Activity Data Used to Extrapolate Other Fugitive Emission Sources by Region for All Years**

Emission Sector Category	Emission Source Category	Province / Territory	Activity Data
Accidents and Equipment Failures	Spills/Pipeline Ruptures	All	Total number of spills, ruptures and blowouts
Accidents and Equipment Failures	Gas Migration	All	Total number of capable oil and gas wells
Accidents and Equipment Failures	Surface Casing Vent Flow	MB, NL, NS, NT, ON, YT	Total number of capable oil and gas wells
Light/Medium Crude Oil Production	Fugitive Equipment Leaks Unreported Venting – pneumatics Unreported Venting – compressor seals Storage Losses Glycol Dehydrator Off-Gas	NB, NL, NS, NT, ON	Light/medium crude oil production
	Loading/Unloading Other Unreported Venting	All	Light/medium crude oil production
Heavy Crude Oil Cold Production	Glycol Dehydrator Off-Gas Loading/Unloading Other Unreported Venting	AB, SK	Cold crude bitumen / heavy oil production
Heavy Crude Oil Thermal Production	Fugitive Equipment Leaks Glycol Dehydrator Off-Gas Loading/Unloading Storage Losses Unreported Venting	AB	Thermal in-situ bitumen production
		SK	Thermal heavy oil production
Natural Gas Production	Fugitive Equipment Leaks Unreported Venting – pneumatics Unreported Venting – compressor seals Storage Losses Glycol Dehydrator Off-Gas	NB, NL, NS, NT, ON, YT	Natural gas production
	Loading/Unloading	AB, BC, SK	Non-associated gas production
		All other provinces	Natural gas production
Natural Gas Processing	Fugitive Equipment Leaks Unreported Venting – pneumatics Unreported Venting – compressor seals Storage Losses Glycol Dehydrator Off-Gas	NL, NS, NT, ON, YT	Natural gas production
	Loading/Unloading Other Unreported Venting	All	Natural gas production
	Formation CO_2	All	Shrinkage[a]
Disposal and Waste Treatment	Fugitive Equipment Leaks Storage Losses Unreported Venting	AB	Total crude production
Petroleum Liquids Transportation	Fugitive Equipment Leaks Storage Losses Unreported Venting	PE and QC	Total RPP Retail Pump Sales
		All other provinces	Total crude production
Well Servicing Well Testing	Fugitive Equipment Leaks Glycol Dehydrator Off-Gas Storage Losses Loading/Unloading Unreported Venting	All	Wells drilled
Gas Storage	Fugitive Equipment Leaks Unreported Venting	All	Natural gas delivered to and received from storage
Gas Transmission Gas Distribution	Fugitive Equipment Leaks Glycol Dehydrator Off-Gas Spills/Pipeline Ruptures Unreported Venting	All	Kilometres of pipeline

Note:
a. British Columbia shrinkage volumes are adjusted from 2012 onwards to reflect the CO_2 content of produced natural gas. The calculated annual volume is multiplied by the ratio of CO_2 mass fractions between the reported year and 2012. This ensures the activity factor accounts for real changes in the natural gas produced in B.C. when extrapolating emissions.

Wedging

The “wedging” method evenly distributes the difference in emissions for a given source and sector in a given province between an inventoried year and an extrapolated year to maintain the emissions trend using Equation A3.2–6.

Equation A3.2–6

$$ER_{i,j}^{k} = ER_{i,j}^{k,k1_exp} + \frac{\left(ER_{i,j}^{k2_inv} - ER_{i,j}^{k2,k1_exp}\right)}{(k2 - k1)} \times (k - k1)$$

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k
$ER_{i,j}^{k,k1_exp}$	=	emission rate of compound i and source j from extrapolated year k1 data
$ER_{i,j}^{k2_inv}$	=	emission rate of compound i and source j from inventoried year k2 data
$ER_{i,j}^{k2,k1_exp}$	=	emission rate of compound i, source j and year k2 from extrapolated year k1 data
k	=	year between k1 and k2
$k1$	=	base year 1 (e.g. 2000 or 2005)
$k2$	=	base year 2 (e.g. 2005 or 2011)

If k1 is equal to 2005, k2 is equal to 2011, and k is equal to k1, then the result of Equation A3.2–6 is the emission rate from the 2005 inventoried year. This occurs since the 2005 extrapolated data uses the 2005 inventoried year as is for the year 2005. If k is equal to k2, then the result is the emission rate from the 2011 inventoried year. This shows that this method will maintain the emission estimates for the inventoried years, while interpolating the intermediate years and maintaining the emissions trend.

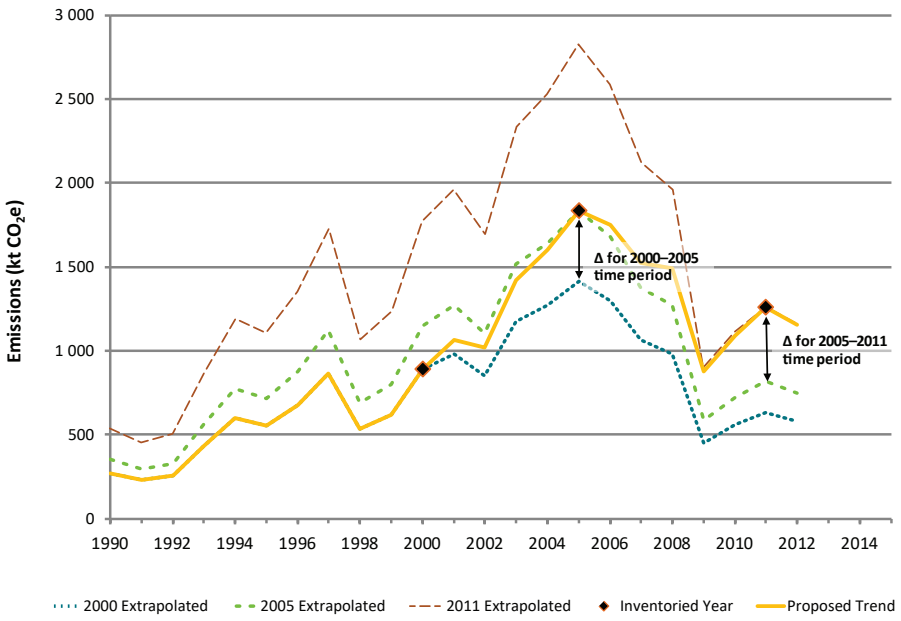
Figure A3.2–2 shows the results of the “wedging” method in graphical form. In general, the 2000 and 2005 inventory years are used to interpolate emissions by sector, source and province/territory for the 2001–2004 period, while the 2005 and 2011 inventory years are used to interpolate emissions for the 2006–2010 period. However, there are a few special cases where the 2000 and 2011 inventory years are used to interpolate emissions for the 2001–2010 period. This occurs when data was missing or incomplete for the 2005 data year and, as a result, specific sector, source and province/territory combinations were not able to be estimated for the 2005 inventory. In addition, based on conversations with the contractor and the province of Saskatchewan, the Saskatchewan venting emissions for the cold heavy oil production sector in the 2005 inventory were determined to be unreliable. As a result, emissions for this source and sector were interpolated using the 2000 and 2011 data as end points with the 2005 data point being omitted.

Issues with Saskatchewan and Alberta thermal heavy oil production reported venting emission estimates in the 2000 inventory were also identified. Analysis of the 1990 to 2004 estimates, developed by extrapolating 2000 emissions back to 1990 and using the wedging method between 2000 and 2005, suggested that approximately 40-70% of produced gas was being vented at thermal facilities in Saskatchewan and 7-9% was being vented in Alberta. This is in sharp contrast to the Saskatchewan and Alberta Petrinex reported data for 2013 onwards which show <0.1% to 0.4% of produced gas being vented. In addition, CAPP (1999) states that, based on a survey of heavy oil producers, 4.08% of produced gas was vented at thermal heavy oil operations in 1995.

As a result, reported venting emissions from Alberta and Saskatchewan thermal heavy oil facilities for 1990 to 2004 are estimated using the Gas-to-Oil Ratio (GOR) of 62.2 from CAPP (1999) to first estimate the volume of produced gas. The produced gas volume is multiplied by the vent rate of 4.08% (CAPP, 1999) for the 1990 to 1995 period. From 1996 to 2004, the vent rate is linearly interpolated between 4.08% and the calculated vent rate for the year 2005 in each province, respectively. Lastly, emissions are estimated using Equation A3.2–11 and the relevant gas composition.

Finally, if any specific source and sector in each province/territory only existed in one of the inventoried years, then the inventoried data was extrapolated for the entire time series. All of this was done to ensure time-series consistency.

Figure A3.2–2 **Graphical Representation of the "Wedging" Method**



Proportional Adjustment

As stated previously, if the "wedging" method resulted in negative emissions in any year of the interpolation period, then the method was abandoned for that given sector, source and province/territory and the "proportional adjustment" method was used, as shown in Equation A3.2–7.

Equation A3.2–7

$$ER_{i,j}^{k} = ER_{i,j}^{k,k1_exp} \times \frac{\left(ER_{i,j}^{k2_inv}\right)}{\left(ER_{i,j}^{k2,k1_exp}\right)}$$

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k
$ER_{i,j}^{k,k1_exp}$	=	emission rate of compound i and source j from extrapolated year k1 data
$ER_{i,j}^{k2_inv}$	=	emission rate of compound i and source j from inventoried year k2 data
$ER_{i,j}^{k2,k1_exp}$	=	emission rate of compound i, source j and year k2 from extrapolated year k1 data
k	=	year between k1+1 and k2
$k1$	=	base year 1 (e.g. 2000 or 2005)
$k2$	=	base year 2 (e.g. 2005 or 2011)

If k1 is equal to 2005, k2 is equal to 2011 and k is equal to k2, then the result of Equation A3.2–7 is the emission rate of the inventoried year for 2011. Otherwise, the emission rate of the extrapolated data is modified by the same percentage for each year in the interpolated period. This method was required in less than 0.3% of all cases and was generally only required for sources with very low emissions.

A3.2.2.1.2. Direct Estimation of Reported Venting and Flaring

Methodology

Reported venting and flaring emissions from 2010 onwards for the province of Alberta and from 1990 onwards for the province of Saskatchewan are estimated directly instead of extrapolated from the CAPP and UOG studies (CAPP, 2005a; EC, 2014). Similarly, British Columbia reported venting (2019 onwards) and flaring (1996 onwards) emissions, as well as Newfoundland and Labrador offshore flaring (1997 onwards) emissions are estimated directly.

Reported volumes of gas flared and vented by operator and facility from the Petrinex reporting system (Petrinex, n.d. [b]) are used in conjunction with gas composition data by Alberta township (Tyner and Johnson, 2020) to estimate emissions for Alberta. However, the public Petrinex data (n.d. [b]) does not include confidential facilities, which generally account for about 1-2% of reported flare and vent volumes. *ST60B: Upstream Petroleum Industry Flaring and Venting Report* (AER, 2000–) is published annually by the Alberta Energy Regulator (AER) and summarizes reported venting and flaring volumes including those volumes reported by facilities not available in the public Petrinex data. Therefore, to accurately reflect the complete volume of gas vented and flared, gas volumes and associated emissions calculated using Petrinex data are adjusted so that volumes match those reported in ST60B.

From 2020 onwards, vent volumes reported to the Alberta OneStop reporting system (AEPA, 2022; AER, 2000–) are used to adjust the emissions calculated from Petrinex reported vent volumes. See section A3.2.2.1.6 for more details.

Flare and vent volumes by operator and facility reported to Petrinex from 2012 onwards (SK MER, 2012– [c]; Petrinex, n.d. [a]) and available from alternate publications (SK MER, 1990–2008; 2009–2011) for years prior to 2012 are used in conjunction with gas composition data by production class (SK MER, 2021) to estimate flare and vent emissions for Saskatchewan.

In British Columbia, facility-level flare and vent volumes reported by operators to Petrinex are available from 2019 onwards (BCER, n.d. [b]). Reported venting and flaring emissions are calculated directly by combining the reported volumetric data with location-specific natural gas compositions. The produced natural gas compositions were derived by ECCC using tens of thousands of gas sample analyses from production wells in British Columbia (BCER, n.d. [c]; [d]).

Newfoundland and Labrador flare volumes by offshore production facility (C-NLOER, n.d. [b]) are reported to the Canada-Newfoundland and Labrador Offshore Energy Regulator (C-NLOER) and shared with Environment and Climate Change Canada as part of a data-sharing agreement. Monthly flare volumes are available from first production in November 1997. Where possible, annual CO_2 and CH_4 facility-level flaring EFs are calculated using flaring emissions by facility reported to the GHG Reporting Program (ECCC, n.d.) and annual flare volumes. When GHGRP data is not available, EFs from CAPP (2005a) are used.

Activity Data

The Petrinex reporting system collects various volumetric production accounting data for the primary purpose of collecting royalties. Oil and gas facilities in Alberta, Saskatchewan, and British Columbia must report various data to Petrinex monthly. This data includes tombstone data for each facility such as FacilityID, subtype classification, facility name, operator, geographic location, etc. as well as volumetric data corresponding to a specific ProductID (e.g. crude oil, crude bitumen, heavy oil, water, gas, etc.) and ActivityID (e.g. flare, vent, fuel, production, receipts, disposition).

The Alberta Township Survey (ATS) system follows the Dominion Land Survey (DLS) method, whereby any parcel of land in Western Canada can be located by its legal land description. In the ATS, land is designated as being west of the 4th, 5th, or 6th Meridians (110°, 114°, 118° west longitude, respectively). Six-mile-wide columns between meridians are called ranges and are numbered consecutively from east to west. Townships are six-mile-wide rows that intersect ranges and are numbered consecutively from south to north. The term township also describes the six-by-six mile square formed by the intersection of ranges and townships. Townships are further sub-divided into 36 sections, and sections are then divided into quarters (northeast, northwest, southeast, southwest), or into 16 legal subdivisions (LSD), as indicated in Figure A3.2–3.

The province of Saskatchewan also uses the DLS method to define parcels of land. Saskatchewan townships are aggregated into four main petroleum and natural gas production areas: AREA I − Lloydminster, AREA II − Kindersley, AREA III − Swift Current, and AREA IV − Estevan (see Figure A3.2–4).

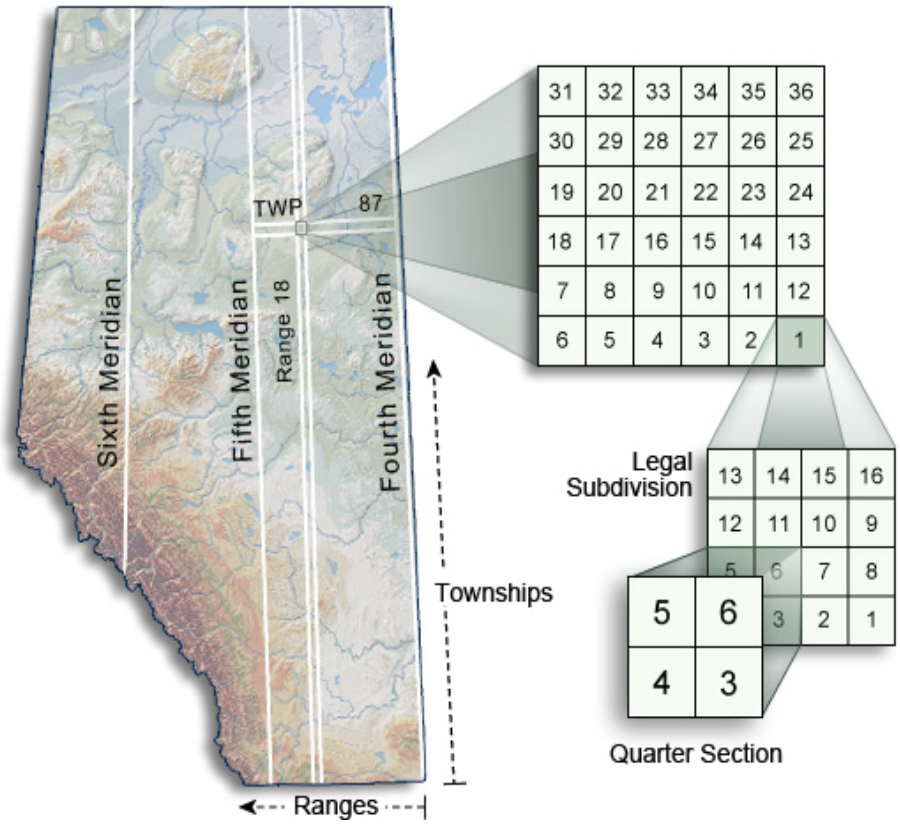
While detailed Saskatchewan facility-level flare and vent volumes are available from 2012 onwards (SK MER, 2012– [c]; Petrinex, n.d. [a]), data from 1990 to 2011 is provided as aggregate provincial totals (SK MER, 1990–2008; 2009–2011). However, to utilize the detailed composition data, the aggregated flare and vent volumes must be disaggregated to the four production areas. This was done by calculating the ratio of flare and vent volumes to production volumes for the years with detailed data (i.e., 2012–2020) and then applying those ratios to the reported production volumes by year and production area (SK MER, 1990–2008; 2009–2011) in the earlier part of the time series. The resultant flare and vent volumes were then normalized to the reported provincial flare and vent volume totals to ensure the estimated volumes were not above or below the reported data.

Vent volumes for gas gathering and gas processing were not reported until 2012. Therefore, the estimated volumes were not normalized to the reported volumes between 1990 and 2011 since they did not exist. Similarly, reported vent volumes at oil facilities were unrealistically low in comparison to production volumes from 1990 to 2006. As such, estimated volumes were not normalized to the reported volumes for this period.

Additionally, historical heavy oil production volumes do not delineate between thermal production and cold production. However, a time series of thermal heavy oil production volumes was developed using Petrinex reported data (Petrinex, n.d. [a]) and pieces of information taken from archived annual reports for heavy oil operators in Saskatchewan (e.g. Husky Energy). The estimated thermal production time series was then used to separate thermal and cold heavy oil production which was then used to proportionally allocate flare and vent volumes to the specific production sector (i.e. non-heavy oil, cold heavy oil, thermal heavy oil) as applicable.

Facility-level Petrinex flare and vent volumes for British Columbia are provided directly to ECCC by the BCER (n.d. [b]). Covering each year since 2019, the detailed Petrinex data contains similar facility location information to the data reported in Alberta and Saskatchewan, with one key difference. In British Columbia, the locations of oil and gas infrastructure within the Peace River region are identified using the DLS system, but outside of this region the Petroleum and Natural Gas Grid is used instead. The Petroleum and Natural Gas Grid Regulation sets out its application, essentially following the National Topographic System (NTS) and divides the province into “blocks”, “units”, and “quarter units” (BC, 2020b). Figure A3.2–5 explains how well and facility locations are assigned and interpreted using the Petroleum and Natural Gas Grid. For the purpose of estimating flaring and venting emissions, Petrinex volumetric data are aggregated by township within the Peace River region, and by block in the remainder of the province.

Figure A3.2–3 **Alberta Township System (ATS)**

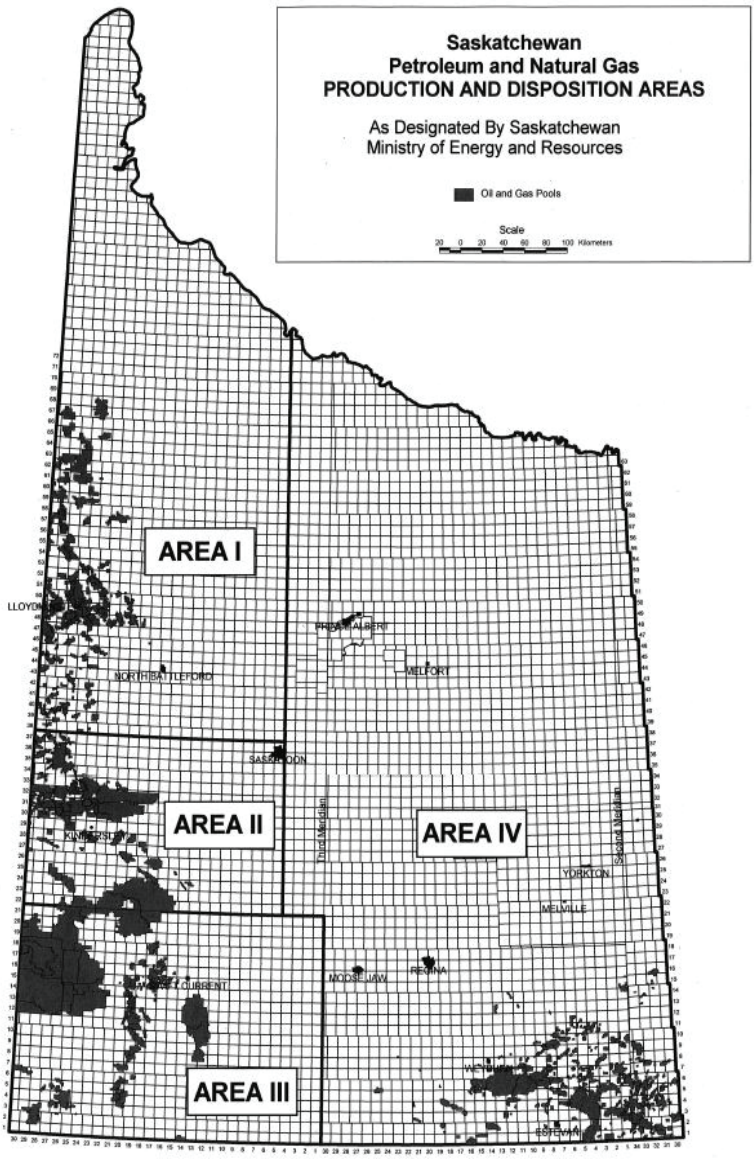


Notes:
TWP = Townships
Source: Government of Alberta (2021)

Flare gas volumes for the period from 1996 to 2018 are taken from the Air Summary Report (BCOGC, 2019), which provides aggregated flare volumes at the provincial subsector level.

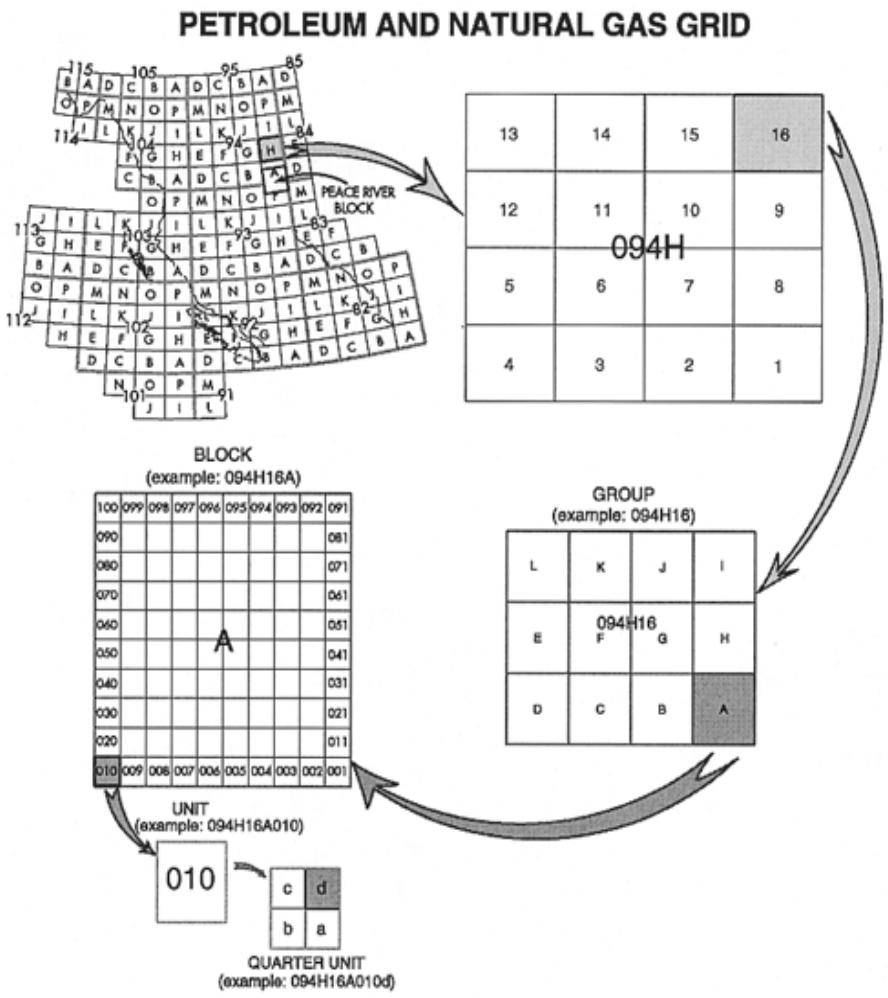
Newfoundland and Labrador monthly flare volumes reported by each offshore facility, including Hibernia, Terra Nova, Sea Rose, and Hebron, were used when calculating emissions.

Figure A3.2–4 **Saskatchewan Oil and Natural Gas Production Areas**



Note:
Source: Government of Saskatchewan (2021)

Figure A3.2–5 **British Columbia Petroleum and Natural Gas Grid**



Note:
Source = Government of British Columbia (2020b)

Emission Factors

To reflect the regional variability in gas composition, emissions for flaring and reported venting in Alberta are estimated using natural gas composition data for the UOG industry in Alberta analyzed by the Energy and Emissions Research Laboratory (EERL) of Carleton University (Tyner and Johnson, 2020) (hereafter referred to as EERL study). The EERL study uses measured gas composition data from approximately 400 000 wells in Alberta taken over a span of several decades across the province's many oil and gas producing regions to generate gas compositions by Alberta township (see Figure A3.2–6).

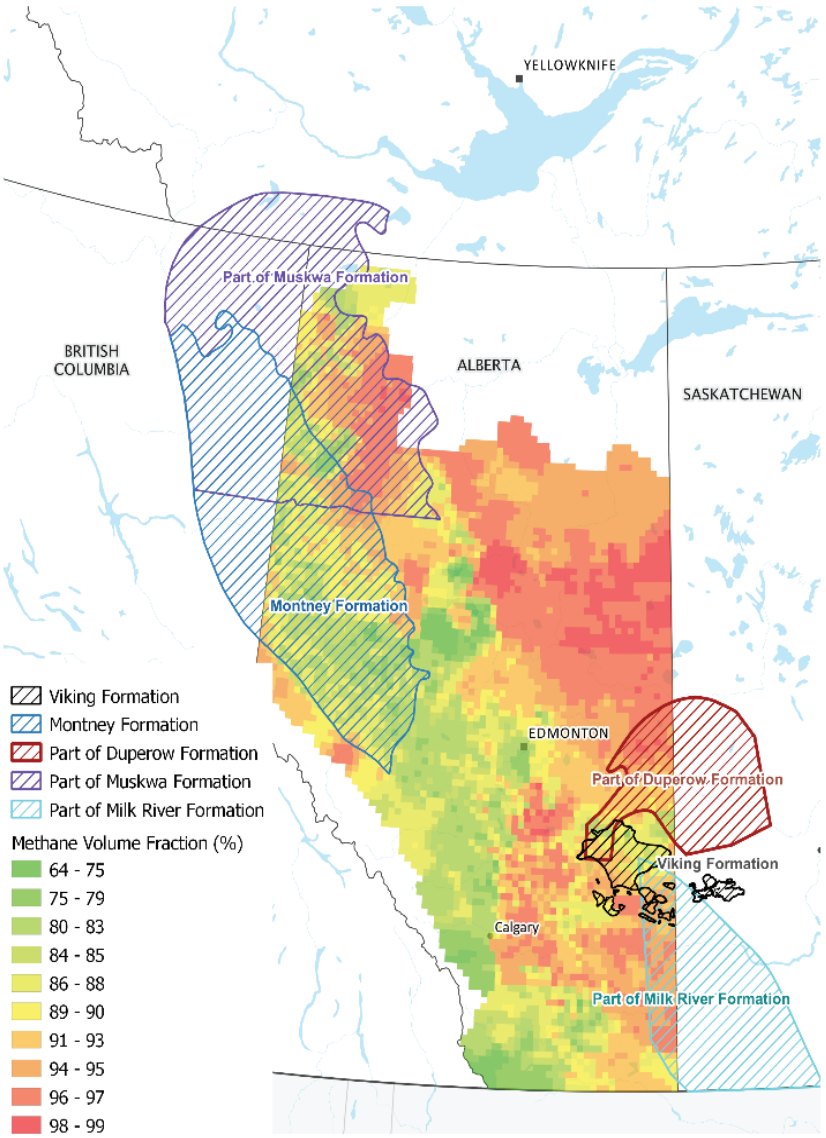
Gas composition data for Saskatchewan was provided directly by the Saskatchewan Ministry of Energy and Resources (SK MER, 2021). Compositions are broken down by production class as presented in Table A3.2–10.

Gas compositions for British Columbia were derived by ECCC from well-level gas samples and production data reported to the provincial regulator (BCER, n.d. [c]; [d]). To the extent it was practical, the composition dataset was compiled following the EERL (2020) approach, which included filtering the raw sample data to remove outliers. For wells without produced gas composition sample data (roughly 40% of the oil and gas wells reporting production as of 2024), mole fractions of each component were assigned using a 2-D inverse distance weighted (IDW) average of the 20 nearest wells within the same pool, or simply the 20 nearest neighbours, if fewer than 20 other wells were located in the pool (i.e. wells with matching

Table A3.2–10 **Average Natural Gas Compositions by Saskatchewan Production Class**

Saskatchewan Production Class	CH_4	CO_2	H_2S	C_2H_6	VOC	Density (kg/m³)
	Mass Percent					
AREA I – Lloydminster	87.98	4.56	0.02	1.31	0.95	0.7233
AREA II – Kindersley Heavy	82.72	2.04	0.54	3.82	7.84	0.7559
AREA II – Kinderlsey Non-Heavy	67.22	0.33	0.00	3.15	24.23	0.8597
AREA III – Swift Current	66.68	2.50	0.42	2.47	17.98	0.8512
AREA IV – Estevan	35.55	2.55	1.82	17.59	36.17	1.1037

Figure A3.2–6 **Methane Content by Alberta Township with Select Oil and Gas Producing Formations**

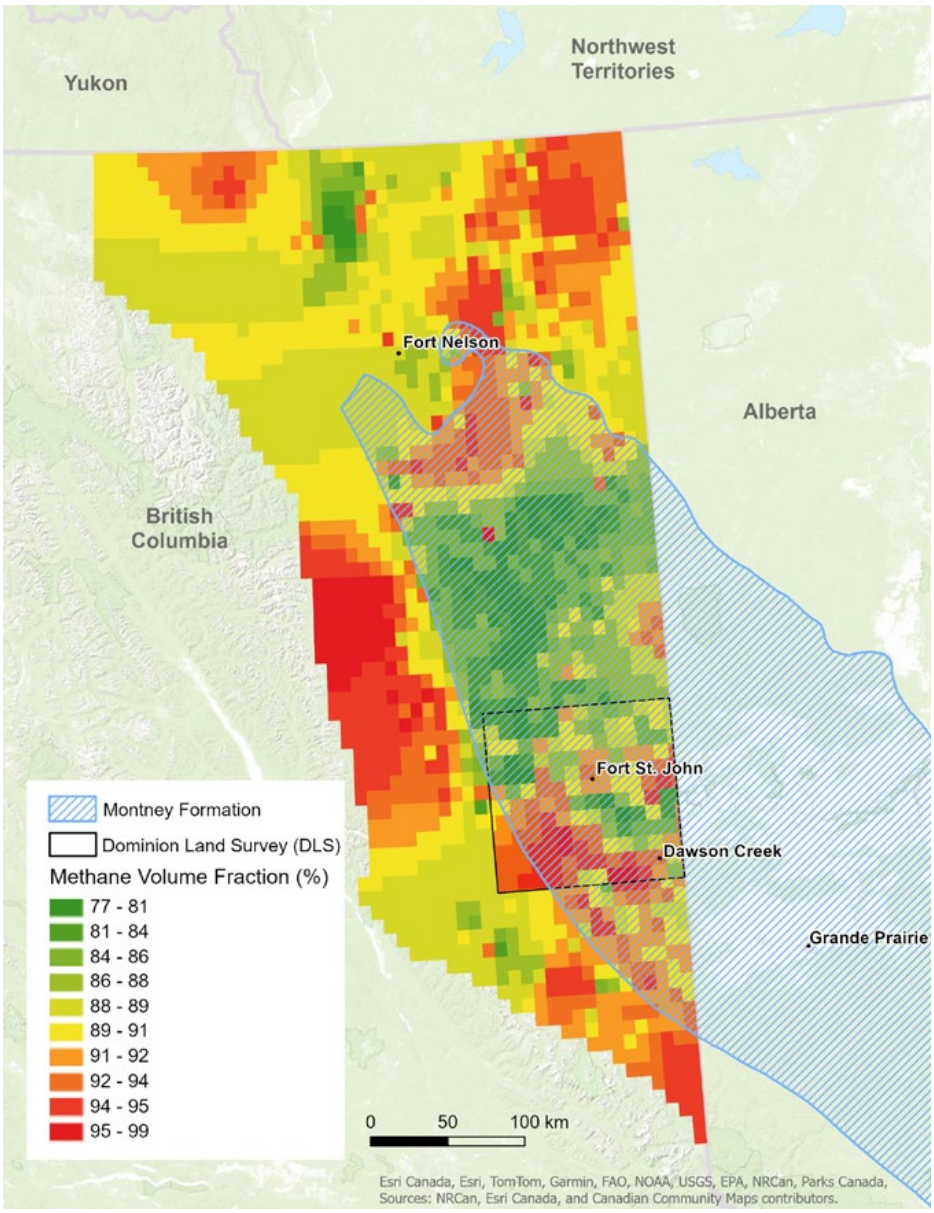


"area" and "formation" codes in the reported data). Although the EERL study used a 3-D IDW approach, analysis conducted by Natural Resources Canada has demonstrated that a simpler 2-D IDW approach provides a similar level of accuracy to 3-D IDW when assigning well-level gas compositions for British Columbia (Naseri and Vena, 2025).

Gas production volumes by well were then linked to the final well-level composition dataset in order to calculate production-weighted average gas compositions by block/township in British Columbia. See ECCC (2026) for a detailed explanation of the procedure used to develop annual and gridded production-weighted gas composition values for British Columbia.

The gridded gas composition dataset developed by ECCC is used to estimate flaring and reported venting emissions from 2019 onwards. Average methane content by location in northeastern British Columbia is presented in Figure A3.2–7. Township-specific composition profiles are used within the boundary of the Peace River area (denoted as DLS), while in the remainder of the province block-specific values are applied following the Petroleum and Natural Gas Grid. Flaring emissions calculations for 1996–2018 use provincial production-weighted average compositions, as the BCOGC (2019) data is not disaggregated by facility.

Figure A3.2–7 **Location-Specific Methane Content of Natural Gas Produced in British Columbia**



CO_2, CH_4 and nitrous oxide (N_2O) EFs for flaring are calculated using the gas composition data as shown in Equation A3.2–8, Equation A3.2–9, and Equation A3.2–10, respectively. The calculated EFs are then multiplied by the volumetric data (Petrinex, n.d. [a]; SK MER, 2012− [c]; Petrinex, n.d. [b]; BCER, n.d. [b]) to estimate emissions. Similarly, CO_2 and CH_4 emissions from reported venting are estimated using Equation A3.2–11.

Equation A3.2–8

$$EF_{CO2,i} = \sum_j \frac{y_{i,j} \times n_{c,j} \times MW_{CO2}}{V_{STP}} \times g_c$$

$EF_{CO2,i}$ = CO_2 emission factor for flaring in designated area i (g/m³)
$y_{i,j}$ = mole fraction of component j in designated area i
$n_{c,i}$ = number of carbon atoms per molecule of component j
MW_{CO2} = molecular weight of CO_2 (g/mol) = 44.010 g/mol
V_{STP} = volume of gas at standard conditions (101.325 kPa and 15°C) = 23.6444813 m³/kmol
g_c = constant of proportionality = 1000 mol/kmol

Equation A3.2–9

$$EF_{CH4,i} = \sum \frac{y_{CH4,i} \times MW_{CH4} \times (1 - CE)}{V_{STP}} \times g_c$$

$EF_{CH4,i}$ = CH_4 emission factor for flaring in designated area i (g/m³)
$y_{CH4,i}$ = mole fraction of CH_4 in designated area i
MW_{CH4} = molecular weight of CH_4 (g/mol) = 16.04206 g/mol
CE = combustion efficiency = 0.98 (EC, 2014)
V_{STP} = volume of gas at standard conditions (101.325 kPa and 15°C) = 23.6444813 m³/kmol
g_c = constant of proportionality = 1000 mol/kmol

Equation A3.2–10

$$EF_{N2O,i} = ER_{N2O} \times HHV_i$$

$EF_{N2O,i}$ = N_2O emission factor for flaring in designated area i (g/m³)
ER_{N2O} = flaring emission rate for N_2O (g/MJ) = 0.0000952 g/MJ (WCI.363(k) 2012)
HHV_i = higher heating value for township i (MJ/m³)

Equation A3.2–11

$$Emis_{i,j} = y_{i,j} \times Vol_i \times \rho_j$$

$Emis_{i,j}$ = vented emissions of component j in designated area i (kt)
$y_{i,j}$ = mole fraction of component j in designated area i
Vol_i = volume of gas vented in designated area i (10^6 m³)
ρ_j = density of component j at standard conditions (101.325 kPa and 15°C) (kg/m³)

Facility-specific CO_2 and CH_4 EFs are calculated annually from 2004 onwards for each Newfoundland and Labrador offshore facility using GHGRP reported emissions (ECCC, n.d.) and reported flare volumes (C-NLOER, 2024b). Since GHGRP data is not available prior to 2004, the CAPP (2005a) EFs were used from 1997 to 1999. From 2000 to 2003, the EFs were linearly interpolated between the GHGRP-derived EFs for 2004 and the CAPP (2005a) EFs used for the year 1999.

A3.2.2.1.3. Pneumatics, Compressor Seals and Fugitive Equipment Leaks

Methodology

The UOG Fugitive Emissions Model (FEM) estimates annual emissions from pneumatic devices (controllers and pumps), compressor seals and equipment leaks from 1990 onwards using a facility-based approach. The model utilizes the number of active UOG facilities and well sites along with average numbers of components per facility type (or asset ratios), component-level EFs, gas composition data and other source specific parameters to estimate emissions by province and industry segment for these sources.

The FEM is currently limited to the Western Canadian provinces of Alberta, Saskatchewan, British Columbia and Manitoba. These provinces generally account for greater than 95% of total natural gas production and greater than 90% of total crude oil production in Canada in a given year (StatCan, n.d.[d], n.d.[f]).

The scope of the modelling work focusses on specific facility types including batteries, compressor stations and gas plants. The facilities are further broken down by subtype (e.g., single-well battery, multi-well group battery, etc.) and product type (e.g., light/medium crude oil, heavy crude oil, natural gas, etc.). All active well sites are also part of the FEM.

This approach facilitates continuous improvements via revisions to source data or model parameters, such as asset ratios or EFs for specific facility subtypes, product types or regions as new information becomes available. Given reliable data, changes to industry practices or government policy can also be reflected annually.

A summary of the FEM methodology is provided in the following sections. For complete documentation of the methodology including facility counts and modelling parameters, please refer to the *Upstream Oil and Gas Fugitive Emissions Model: Methodology and Documentation* (ECCC, 2026).

FEM emission estimates for pneumatics, compressor seals and equipment leaks replace emissions for the same sources estimated using the methodology described in section A3.2.2.1.1 with some notable exceptions. Starting in 2020, Alberta compressor seal emissions are not included separately in final emission totals. Similarly, Saskatchewan estimates for pneumatics and compressor seals at all facilities, and fugitive equipment leaks at gas production and gas processing facilities are not included in final emission totals starting in 2020. Estimates for pneumatics and compressor seals are also omitted from 2021 onwards for British Columbia. In each case, this is due to revisions to provincial definitions of what operators are to include in reported vent gas volumes. As a result of these definition changes, estimates for these sources are not included separately in the final emission totals to avoid double counting as they are included in emission estimates from reported venting. Please refer to section A3.2.2.1.6 for a more complete discussion of these changes.

Activity Data

Emission estimates in the FEM are built up from the annual number of active facilities and wells in British Columbia, Alberta, Saskatchewan, and Manitoba. The FEM relies on several data sources, as described in Table A3.2–11, to determine the number of active facilities in the Western provinces. Where available, facility counts and well counts are derived directly from production accounting data (e.g., Petrinex, n.d. [a], n.d. [b]; BCER, n.d. [b]; MB EDITNR, n.d. [b]) or from data provided by provincial regulators (e.g., BCOGC, 2018). However, since complete production accounting data for each province back to 1990 is unavailable, it is necessary to estimate facility counts for years without data using other methods and data sources. For a complete description of how the available data sources are combined to provide the numbers of UOG facilities in these provinces from 1990 onwards and a listing of facility counts used in the FEM, please refer to the FEM methodology document (ECCC, 2026).

Table A3.2–11 **Data Sources Used to Determine Facility and Well Counts**

Province	Years	FEM Facility Types	Data Source	Source Description
AB	2014–2024	All except Satellite Batteries (SatBat)	Petrinex (n.d. [a])	Petrinex monthly volumetric data
	2010–2013	All except Compressor Stations (CS) and SatBat	Alberta Energy Regulator (AER)	Petrinex annual volumetric data (preprocessed and provided by AER)
	2000–2009	All except CS, Gas Plants (GP), Gas Gathering Systems (GGS) and SatBat	AER	Annual data provided by AER
	1990–2009	GP	AER (2020)	AER ST50A: Gas Processing Plants in Alberta
	1990–2024	SatBat	Petrinex (n.d. [c])	Alberta facility licence
	1990–2009	Well Sites	CAPP (n.d. [a])	Number of operating oil and gas wells (tables 3.17 and 3.18)
BC	2010–2017	All except GP	BCOGC (2018)	BCOGC derived facility counts and production volumes
	2019–2024	All except SatBat	BCER (n.d. [b])	Petrinex monthly volumetric data
	2004–2018	GP	BC (2020a)	BC Gas Plant Report
	2020-2024	SatBat and CS	BCER (n.d. [e])	Leak, Detection and Repair Data for Wells and Facilities
	1990–2009, 2018	Well Sites	CAPP (n.d. [a])	Number of operating oil and gas wells (tables 3.17 and 3.18)
SK	2013–2024	All except CS and SatBat	Petrinex (n.d. [b])	Petrinex monthly volumetric data
	2013–2024	GP	SK MER (2013–)	SK Gas Plant Reports
	2013–2024	SatBat and CS	Petrinex (n.d. [d])	Saskatchewan facility infrastructure
	1990–2020	Well Sites	CAPP (n.d. [a])	Number of operating oil and gas wells (tables 3.17 and 3.18)
MB	2020–2024	All	MB EDITNR (n.d. [b])	Petrinex monthly volumetric data
	1990–2024	Well Sites	MB EDITNR (n.d. [c])	Production reports by well

Emission Factors and Other Parameters

Asset ratios representing the average number of each type of pneumatic device, compressor, and equipment component per facility subtype are determined from the studies presented in Table A3.2–12. Other parameters such as the proportion of pneumatics powered by gas per facility subtype are also derived from these studies. For a complete listing of all asset ratios used in the FEM, please refer to ECCC (2026).

Provincial data sources have also been leveraged to calculate EFs and other FEM parameters. The Alberta Energy Regulator started publishing facility reported data from its OneStop reporting system for the 2020 reference year, including vent gas volumes from pneumatic instruments, pneumatic pumps, and compressor seals, as well as estimated volumes released from unintentional equipment leaks (AER, 2000–). Additionally, the British Columbia GHG Industrial Reporting program collects emissions data and supporting information from UOG facilities operating in the province. Facility reported source-level emissions data are supplemented by detailed reports, which contain key information including the number of emitting pneumatic devices and equipment counts (BC, 2024). The information available from these provincial datasets enables ECCC to update model parameters and assumptions, ensuring the FEM accurately tracks emissions trends in the years since the studies presented in Table A3.2–12 were conducted.

Emissions from pneumatic devices are estimated using Equation A3.2–12 and the EFs presented in Table A3.2–13.

Table A3.2–12 **Upstream Oil and Gas Fugitive Emissions Model Asset Ratio Data Sources**

Emission Source	Province	Author	Year Completed	Title of Report
Pneumatics	All	Greenpath Energy Ltd.	2016	*Modelling Inputs for Upstream Oil and Gas Methane Emission Sources*
	AB, MB	Clearstone Engineering Ltd. and Carleton University	2018	*Update of Equipment, Component and Fugitive Emission Factors for Alberta Upstream Oil and Gas*
	SK	Advisian Ltd.	2019	*Oil and gas inventory information enhancement and economic analysis study: Field data gather and interpret report*
	BC	Cap-Op Energy	2019	*British Columbia Oil and Gas Methane Emissions Field Study*
Equipment Leaks	All	Greenpath Energy Ltd.	2016	*Modelling Inputs for Upstream Oil and Gas Methane Emission Sources*
	AB, SK, MB	Clearstone Engineering Ltd. and Carleton University	2018	*Update of Equipment, Component and Fugitive Emission Factors for Alberta Upstream Oil and Gas*
	BC	Cap-Op Energy	2019	*British Columbia Oil and Gas Methane Emissions Field Study*
Compressor Seals	AB, SK, MB	Clearstone Engineering Ltd. and Carleton University	2018	*Update of Equipment, Component and Fugitive Emission Factors for Alberta Upstream Oil and Gas*
	BC	Cap-Op Energy	2019	*British Columbia Oil and Gas Methane Emissions Field Study*

Table A3.2–13 **Pneumatic Device Emission Factors by Province**

Province(s)	AB, SK, MB	BC[b]				
Years Applied	1990–2024	1990–2014	2015	2016	2017	2018–2024
Pneumatic Device Type	Release Rate (m^3 /hr)					
Intermittent	0.00314	0.00314	0.00314	0.00314	0.00314	0.00314
Level	0.378[a]	0.22	0.202	0.183	0.165	0.147
Positioner	0.247	0.719	0.71	0.701	0.692	0.683
Pressure	0.43	0.644	0.634	0.623	0.613	0.602
Temperature	0.00543	0.00543	0.00543	0.00543	0.00543	0.00543
Transducer	0.42	0.391	0.388	0.385	0.382	0.379
Methanol Pump	0.636	0.553	0.553	0.553	0.553	0.553
Other Chemical Pump	0.55	0.25	0.25	0.25	0.25	0.25

Notes:
Unless otherwise indicated, emission factors were derived internally by the Oil, Gas and Alternative Energy Division (OGAED) at ECCC using Prasino (2013), Cap-Op (2019), Clearstone (2018) and Spartan Controls (2018).
a. Clearstone (2019)
b. ECCC EF calculations for level controllers, positioners, pressure controllers, and transducers incorporate aggregated pneumatics counts provided by BC MECS (2024).

British Columbia provided summarized pneumatic device counts grouped by industry subsector and bleed rate (BC, 2024), which was used to refine calculated EFs, asset ratios, and the proportions of pneumatics driven by gas. The BC EFs shown in Table A3.2–13 for certain pneumatic controllers in 2014 and 2018 were calculated using these device counts, with EFs for each device type in 2015–2017 estimated by linear interpolation. ECCC (2026) provides a full description of how the aggregated pneumatics data is used in the model.

Alberta Environment and Protected Areas has previously provided ECCC with a registry of pneumatic device conversions that took place from 2012 to 2020. This registry includes conversions from gas-driven pneumatic pumps and controllers to electric and compressed air pneumatics (i.e., non-emitting devices), from high-bleed to low-bleed devices, and to vent gas capture systems. Similarly, the British Columbia Clean Infrastructure Royalty Credit Program and the CleanBC Industry Fund log pneumatic device conversions within British Columbia.

Data from these programs is used to reduce pneumatic device emission estimates in Alberta and B.C. to reflect the impact of these emission reduction activities. This reduction occurs from 2018 onwards as the field studies used to derive asset ratios occurred in the 2017/2018 period and are expected to capture device conversions that occurred prior to the field studies. B.C. device conversions only impact inventory estimates prior to 2021, since pneumatics are instead included in reported venting from then onwards as described in section A3.2.2.1.6.

Other data are also leveraged to estimate further emissions reductions from pneumatics. OneStop data covers the period from 2020 onwards and enables annual pneumatic venting volumes to be grouped by UOG sector. The year-to-year changes in sector-level venting from pneumatics are calculated as a percentage, which is then used to adjust modelled emissions from 2021 onwards in Alberta.

Equation A3.2–12

$$Emis_{i,j,k,l,m} = \frac{FC_{j,k} \times PPF_{j,k,l} \times GDprop_{j,k} \times EF_{l,m} \times \rho \times x_i \times 8760}{10^6}$$

$Emis_{i,j,k,l,m}$	=	Emissions for gas species i, facility type j, product type k, pneumatic device l and scenario m (kt)
$FC_{j,k}$	=	Facility count for facility type j and product type k
$PPF_{i,k,l}$	=	Average number of pneumatic devices l, per facility type j and product type k
$GDprop_{j,k}$	=	Proportion of gas driven pneumatic devices per facility type j and product type k
$EF_{l,m}$	=	Emission factor for pneumatic device type l and pneumatic scenario m (m^3/hr)
P	=	density of released gas (kg/m^3)
x_i	=	mass fraction of species i
8760	=	number of hours per calendar year (24 h/d × 365 d/yr)
10^6	=	kg per kt

Emissions from reciprocating and centrifugal compressor seals are estimated using Equation A3.2–13 and the EFs presented in Table A3.2–14.

Equation A3.2–13

$$Emis_{i,j,k} = \frac{FC_{j,k} \times CPF_{j,k} \times SPC_{j,k} \times Util_{j,k} \times SRF_m \times EF_m \times \rho \times x_i \times 8760}{10^6}$$

$Emis_{i,j,k}$	=	Compressor seal emissions for gas species i, facility type j and product type k (kt)
$FC_{j,k}$	=	Facility count for facility type j and product type k
$CPF_{i,k}$	=	Average number of compressors per facility type j and product type k
$SPC_{j,k}$	=	Average number of seals per compressor by facility type j and product type k
$Util_{j,k}$	=	Compressor utilization rate per 24-hour period per facility type j and product type k
SRF_m	=	Fraction of facilities using seal replacement frequency m
EF_m	=	Compressor seal emission factor for seal replacement frequency m (m^3/hr/cylinder)
P	=	density of released gas (kg/m^3)
x_i	=	mass fraction of species i
8760	=	number of hours per calendar year (24 h/d × 365 d/yr)
10^6	=	kg per kt

Lastly, the emissions from equipment leaks are calculated using Equation A3.2–14 and the EFs presented in Table A3.2–15. The EFs are broken down by the type of production (i.e. natural gas or crude oil), type of service for the component (i.e. components under pressurized process gas service or process liquid service), component type and by leak detection and repair (LDAR) frequency. The LDAR frequency is represented by the corresponding LDAR scenarios as presented in Table A3.2–16. The LDAR scenarios differentiate between the frequency of LDAR activities occurring at the various oil and gas facility subtypes over the course of the time series.

Table A3.2–14 Compressor Seal Emission Factors

FEM Compressor Type	Seal Replacement Frequency Scenario	Emission Factor (m^3/hr)[a]
Reciprocating	30 month	0.65
Reciprocating	60 month	1.17
Centrifugal – Wet Seal	NA	14.25
Centrifugal – Dry Seal	NA	6.34

Notes:
NA = not applicable
Reciprocating emission factors are per compressor seal, while centrifugal EFs are per compressor.
a. Emission factors adapted from Carbon Limits (2017) for reciprocating compressors, and from API (2017) for centrifugal compressors.

Table A3.2–15 Fugitive Equipment Leak Emission Factors by LDAR Scenario

Production Type	Service Type	Component Type	LDAR Scenario Emission Factor (g THC/hr)					
			No LDAR[a]	Industry Measure 1[b]	Industry Measure 2[b]	Policy 1[b]	Policy 2[b]	Policy 3[b]
Natural Gas	Process gas	Connector	0.820	0.635	0.567	0.513	0.267	0.185
		Valve	2.810	1.042	0.690	0.603	0.314	0.218
		OEL	467.000	120.210	75.960	66.249	35.764	25.082
		PRV	17.000	2.400	1.485	1.287	0.671	0.465
		Control Valve	16.200	4.604	2.830	2.452	1.285	0.892
		Meter	3.270	2.614	1.758	1.535	0.806	0.560
		Pump Seal	23.200	3.862	2.405	2.086	1.099	0.765
		Regulator	8.110	1.650	1.173	1.033	0.539	0.374
	Process liquid	Connector	0.550	0.111	0.106	0.098	0.051	0.035
		Valve	3.520	0.651	0.640	0.583	0.304	0.211
		OEL[c]	467.000	120.210	75.960	66.249	35.764	25.082
		PRV[c]	17.000	2.400	1.485	1.287	0.671	0.465
		Control Valve[c]	16.200	4.604	2.830	2.452	1.285	0.892
		Meter[c]	3.270	2.614	1.758	1.535	0.806	0.560
		Pump Seal[c]	23.200	3.862	2.405	2.086	1.099	0.765
		Regulator[c]	8.110	1.650	1.173	1.033	0.539	0.374
Crude Oil	Process gas	Connector	2.460	0.443	0.334	0.297	0.155	0.107
		Valve	1.510	0.199	0.143	0.126	0.066	0.045
		OEL	308.000	16.874	10.696	9.294	4.877	3.387
		PRV	16.300	11.318	6.797	5.872	3.065	2.125
		Control Valve	14.600	11.842	7.305	6.347	3.381	2.360
		Meter	1.300	1.042	0.810	0.720	0.375	0.260
		Pump Seal	35.880	28.702	17.514	15.184	8.028	5.590
		Regulator	6.680	1.880	1.309	1.150	0.600	0.416
	Process liquid	Connector	0.190	0.110	0.106	0.096	0.050	0.035
		Valve	1.210	0.688	0.590	0.531	0.276	0.192
		OEL[c]	308.000	16.874	10.696	9.294	4.877	3.387
		PRV[c]	16.300	11.318	6.797	5.872	3.065	2.125
		Control Valve[c]	14.600	11.842	7.305	6.347	3.381	2.360
		Meter[c]	1.300	1.042	0.810	0.720	0.375	0.260
		Pump Seal[c]	35.880	28.702	17.514	15.184	8.028	5.590
		Regulator[c]	6.680	1.880	1.309	1.150	0.600	0.416

Notes:
LDAR = Leak Detection and Repair; THC = Total Hydrocarbons; PRV = Pressure Relief Valve; OEL = Open Ended Line
a. CAPP (2005a)
b. Developed internally by the Oil, Gas and Alternative Energy Division (OGAED) at ECCC utilizing data or information from CAPP (2005a), CAPP (2014), Clearstone (2018, 2019) and Cap-Op (2019).
c. Assumed same emission factor as equivalent component in process gas service.

Prior to the release of the CAPP *Best Management Practices for the Management of Fugitive Emissions at Upstream Oil and Gas Facilities* (CAPP, 2007), the 'No LDAR' EFs, which assume no formal LDAR activities, are applied to all facilities except gas processing plants, where 'Industry Measure 1' EFs are applied, which assumes LDAR activities approximately every 2 years. Starting in 2007, the 'No LDAR' EFs are phased out for other facilities and the 'Industry Measure 1' EFs are phased in. Similarly, 'Industry Measure 2' EFs are phased in starting in 2015 to reflect more frequent LDAR activities of approximately every 16 months. Note that for most facility subtypes, a small fraction has the 'No LDAR' EFs applied in each year, which decreases each year starting in 2007. This fraction represents the facilities of that subtype that handle small amounts of fluids and are unlikely to have formal LDAR activities in place.

Finally, the 'Policy' scenario EFs are used starting in 2020 to reflect the implementation of both federal (ECCC, 2018) and provincial regulations (AB, 2018–; BC, n.d. [b]; SK, n.d.) to reduce CH_4 emissions from oil and gas operations. The federal methane regulations apply to all provinces except Alberta, British Columbia and Saskatchewan. All three of these provinces have their own regulations which are expected to produce equivalent CH_4 emissions reductions as the federal rules.

The LDAR portion of the federal regulations require LDAR surveys at most facility subtypes three times per year or every four months. Therefore, the 'Policy 3' EFs are applied to Manitoba starting in 2020. Similarly, the Saskatchewan regulations require LDAR surveys twice a year, or every 6 months, at gas production and processing facilities. Therefore, the 'Policy 2' EFs are applied to Saskatchewan starting in 2020. In the Alberta regulations, LDAR surveys are required annually at all facilities except sweet gas plants and compressor stations receiving gas with low H_2S content (<0.01 mol/kmol), where a frequency of three times per year is required, meaning that 'Policy 1' EFs are used at all facilities except the subset of gas plants and compressor stations where the 'Policy 3' EFs are used. Lastly, the British Columbia regulations require LDAR surveys three times per year at most facilities and once per year at smaller facilities.

The applicability criteria from the federal and provincial regulations were used to determine the proportions of facilities under each LDAR scenario in the years after the regulations came into force. These proportions represent the fractions of facilities by subtype that should be conducting LDAR programs according to the regulations (i.e., the fraction of facilities under each LDAR scenario). While the regulations may have required specific annual LDAR frequencies, annual reports provided to ECCC under the federal-provincial equivalency agreements have shown actual compliance levels to be less than 100% (AEPA, 2022; BCOGC, 2022). To reflect realistic levels of operator non-compliance, information from these equivalency reports and equivalent information published in AER ST60B (AER, 2000–) has been used to calculate or adjust the LDAR proportions where possible (ECCC, 2026).

Refer to the FEM methodology document (ECCC, 2026) for a complete listing of the proportions of each LDAR scenario that are applied to each facility subtype in each year and region.

Equation A3.2–14

$$Emis_{i,j,k,l,m} = \frac{FC_{j,k} \times CPF_{j,k,l} \times LDAR_{j,k,m} \times EF_{l,m} \times x_i \times 8760}{THC_k \times 10^9}$$

$Emis_{i,j,k,l,m}$	=	Emissions for gas species i, facility type j, product type k, component l and LDAR scenario m (kt)
$FC_{j,k}$	=	Facility count for facility type j and product type k
$CPF_{j,k,l}$	=	Number of components l, per facility type j and product type k
$LDAR_{j,k,m}$	=	LDAR proportion per facility type j, product type k and LDAR scenario m
$EF_{l,m}$	=	Emission factor for component l and LDAR scenario m (g THC/hr)
x_i	=	mass fraction of species i
THC_k	=	Mass fraction of Total Hydrocarbons per product type k (g THC/g total gas)
8760	=	number of hours per calendar year (24 h/d × 365 d/yr)
10^9	=	g per kt

Table A3.2–16 **Frequency of LDAR Activities by LDAR Scenario**

LDAR Scenario	LDAR Frequency (months)
No LDAR	no formal LDAR program
Industry Measure 1	24
Industry Measure 2	16
Policy 1	12
Policy 2	6
Policy 3	4

Note:
LDAR = Leak Detection and Repair

Table A3.2–17 **Average Natural Gas Compositions used in the Upstream Oil and Gas Fugitive Emissions Model**

Province	FEM Product Type	CH_4	CO_2	H_2S	C_2H_6	VOC	Density (kg/m^3)
		Mass Percent					
AB	All Gas Types	73.32	2.86	1.25	10.00	10.48	0.8016
	CHOPS	91.56	2.12	0.00	1.66	0.90	0.7096
	Gas Processing	72.25	2.88	0.14	11.14	11.89	0.8089
	Heavy Oil	89.44	6.62	0.02	1.06	1.60	0.7252
	Light/Med Oil	67.33	2.53	0.69	11.01	15.67	0.8393
MB	Light/Med Oil	78.89	0.97	0.01	4.24	10.97	0.7745

Note:
CHOPS = Cold Heavy Oil Production with Sand

The FEM also uses gas composition data from the EERL study (see A3.2.2.1.2) to determine the CO_2 and CH_4 emissions resulting from pneumatic devices, compressor seals and equipment leaks. For the years from 2010 onwards, where detailed production accounting data for Alberta is available, the township-level Alberta gas composition data is used in conjunction with township-level facility counts to estimate emissions. As detailed production accounting data required to determine facility counts by Alberta township is not available for 1990–2009, average gas compositions, derived from the EERL study data and presented in Table A3.2–17 are used.

The gas composition data broken down by production class (SK MER, 2021) and presented in Table A3.2–10 was used for Saskatchewan. To utilize this data, facility and well counts by production class were derived from Petrinex data for 2013 onwards and backcasted for the 1990–2012 period.

The location-specific gas composition data derived for British Columbia shown in Figure A3.2–6 was used to model emissions by block/township from 2019 onwards. Emissions for 1990–2018 were estimated using annual production weighted gas compositions for the entire province.

The detailed analysis of gas composition data completed for Alberta in the EERL study has not taken place for Manitoba. In lieu of province-specific data, average gas compositions were developed. All average gas compositions used in the FEM are summarized in Table A3.2–17.

For a full description of the methodology, data sources, EFs and parameters used in the FEM please refer to the FEM methodology document (ECCC, 2026).

A3.2.2.1.4. Surface Casing Vent Flows

Methodology

Surface casing vent flow (SCVF) emissions for the provinces of Alberta and British Columbia are modelled instead of extrapolated from the CAPP and UOG studies (CAPP, 2005a; EC, 2014) as outlined in section A3.2.2.1.1. Both provinces have regulatory measures (EUB, 2003; BC, 2021) that dictate how operators detect, report, and resolve SCVFs at wells within their provincial boundaries. The reported data collected by Alberta and British Columbia (AER, n.d. [e]; BCER, n.d. [f]) is used to better represent the variability of this source by location and industry subsector.

The methodology described in section A3.2.2.1.1 is applied in all other provinces and territories where onshore oil and gas extraction occurs.

Activity Data

Reported SCVF data collected by Alberta and British Columbia is publicly available (AER, n.d. [e]; BCER, n.d. [f]). The information contained in these reports is used to model annual SCVF emissions. Although the regulations for SCVF repair came into force in 2003 in Alberta and 2010 in British Columbia, records of detected vent flows exist in the provincial databases prior to 1990 for Alberta and 1993 for B.C. This enables estimates to be prepared for the entire time series, when other relevant well information is included (Petrinex, n.d. [e]; BCER, n.d. [g]; [h]).

Under both Alberta and British Columbia regulations, the deadline to resolve detected SCVFs depends on whether they are classified as “serious” or “non-serious”. The definition of a serious SCVF is the same in both provinces and applies if any of the criteria in Table A3.2–18 are observed at a well. Table A3.2–18 summarizes other components of the provincial requirements used in estimating emissions.

An important aspect of the method is to determine when a SCVF occurred and its duration, which requires several pieces of reported information. For Alberta, the duration is based on the records in the *Well Vent Flow/Gas Migration Report* (AER, n.d. [e]), as well as the *Well Infrastructure Report* from the Petrinex reporting system (Petrinex, n.d. [e]). A similar process is used for British Columbia, where reports of wells with SCVF are linked to the *Well Index* and *Well Surface Abandonment* databases made available by the BCER (n.d. [g]; [h]). Table A3.2–19 highlights the required information from each data source.

When these key dates are known for a reported vent flow, along with the well status and reported resolution, the leak duration is estimated directly. Interpretation of the report dates, resolution dates, and well status dates in the records requires assumptions based on the regulatory requirements in each province, as they are currently the best available source of information on SCVF mitigation practices. These simplifying assumptions are stated in Table A3.2–20.

Table A3.2–18 Provincial Requirements for Surface Casing Vent Flow Testing, Reporting, and Repair

Regulatory Component	Alberta	British Columbia
Regulation Name	Interim Directive ID 2003-01	B.C. Reg. 282/2010 – Drilling and Production Regulation
Testing Requirements	• Within 90 days of drilling rig release • Annually for five years after detection	• At rig release, or immediately after any completion • As part of lifetime routine maintenance • Before suspension, abandonment, or permit transfer
Serious SCVF Definition	Serious SCVFs meet one or more of these criteria: • Hydrogen sulfide (H_2S) is present • Gas flowrate is greater than or equal to 300 cubic metres per day (m^3/d) • Stabilized shut-in pressure is greater than one half the formation leak-off pressure at the surface casing shoe or 11 kPa/m times the surface casing setting depth • Hydrocarbon liquid (oil) vent flow is present • Vent flow occurred due to wellhead seal failures or casing failure • Water vent flow is present, if the water contains substances that could cause soil or groundwater contamination • Any usable water zone is not covered by cemented casing • Vent flow constitutes a fire, public safety, or environmental hazard	
Reporting Requirements	• Within 30 days of detection • Annual test results are not reported	**Serious**: Immediately after discovery **Non-Serious**: Within 30 days of discovery • Regular test results are reported
Repair Requirements	**Serious**: 90 days from discovery **Non-Serious**: prior to well abandonment	**Serious**: "Immediately" after discovery **Non-Serious**: prior to well abandonment

Table A3.2–19 Key Information Extracted from Surface Casing Vent Flow Data Sources

Province	Name of Data Source	Key Information
AB	AER Vent Flow and Gas Migration Report	Report Date, Resolution Date, Reported Resolution, Classification (Serious or Non-Serious)
	Well Infrastructure Report (from Petrinex)	Finished Drill Date, Well Status (active, abandoned, etc.), Well Status Date
BC	BCER Surface Casing Vent Flow Database (BCOGC-2883)	Test Date, Classification (Serious or Non-Serious), Well Mode Code (active, abandoned, etc.)
	BCER Well Index Report (BCOGC-2555)	Rig Release Date, Last Production Date
	BCER Well Surface Abandonment Report (BCOGC-41437)	Abandonment Date (if applicable)

Table A3.2–20 Assumptions Based on Regulatory Requirements for Different Surface Casing Vent Flow Reporting Scenarios

Province	Scenario	Assumptions by Surface Casing Vent Flow Classification	
		Serious	Non-Serious
AB	Report Date before Resolution Date	SCVF starts 90 days before Report Date; ends at Resolution Date	SCVF starts at Finished Drill Date; ends at Resolution Date OR Abandonment OR continues to present (if leak is not resolved or well is not abandoned)
	Report Date equals Resolution Date		
	Report Date after Resolution Date	SCVF starts 90 days before Resolution Date	SCVF starts at Finished Drill Date
	Well Status is Abandoned at Test Date	SCVF starts at Abandonment Date; ends at Resolution Date	N/A
	No resolution reported	SCVF ends 90 days after Report Date	SCVF continues to present
BC	Test Date before Rig Release Date	SCVF starts at Test Date; ends at Repair Date	SCVF starts at Rig Release Date; ends at Abandonment Date OR Repair Date OR continues to present
	Well Mode is Abandoned at Test Date	SCVF starts at Abandonment Date; ends at Repair Date	
	Other	SCVF starts at Rig Release Date; ends at Repair Date	

Note:
For British Columbia, Repair Date is any subsequently reported Test Date where gas flowrate is zero. If no subsequent test is reported, Repair Date is based on B.C. Reg. 282/2010 requirements.

Emission Factors

Reported surface casing vent flowrates are applied for the estimated duration associated with each record in the provincial databases. While AER data contains one record for each occurrence, BCER data contains records of follow-up tests on wells with SCVF, meaning emission rates for each source reflect any reported changes over time, whether due to an attempted repair or natural fluctuations in the vent flow. For records where SCVF is reported without a gas flow rate, the average flow rate is applied based on the location (AER sub-region in Alberta; provincially in British Columbia) and reported severity (serious or non-serious).

Geographic information is also considered, as the composition of the natural gas emitted depends on the location of the source. Gas compositions from Tyner and Johnson (2020) are assigned to the reported surface casing vent flowrate in the same manner as described for the fugitive sources in section A3.2.2.1.3. Township-specific compositions are applied in Alberta, and location-specific values derived from provincial data (BCER, n.d. [c]; [d]) and presented in Figure A3.2–7 are used to estimate the gas composition from wells in British Columbia. While the natural gas in vent flows may originate from formations other than those being produced by the well, the Tyner and Johnson (2020) gas composition data remains the most comprehensive location-specific information presently available to ECCC. These limitations also apply to the production-weighted compositions used for British Columbia, which were similarly derived. Should more representative speciation data for SCVFs in Canada become available, the methodology is designed such that it could be readily adopted.

Emissions from SCVFs are allocated to the correct oil and gas production subsector using detailed well information from Petrinex (n.d. [e]) and BCER (n.d. [f]) databases. As with key dates, provincial vent flow databases are linked to these data sources to extract the necessary well categorizations. Depending on the information available, either the associated facility subtype, production type, or production fluid density is used to allocate SCVF emissions from each well to the appropriate industry subsector, such as natural gas production, light/medium crude oil production, heavy crude oil cold production and heavy crude oil thermal production.

Annual SCVF emissions of CH_4 and CO_2 from individual wells are calculated directly using Equation A3.2–15:

Equation A3.2–15

$$Emis_{i,w} = y_{i,t} \times \rho_{i,t} \times LR_w \times LD_w$$

$Emis_{i,w}$	=	SCVF emissions for component i and well w
$y_{i,t}$	=	mole fraction of component i and location t
$\rho_{i,t}$	=	density (kg/m^3) of component i and location t
LR_w	=	surface casing vent gas flowrate (m^3/day) from well w
LD_w	=	number of days per year where vent flow occurs at well w

A3.2.2.1.5. Source-resolved Aerial Measurements of Methane

The Energy and Emissions Research Laboratory (EERL) at Carleton University published detailed CH_4 emissions inventories for the UOG sector in 2021 for Alberta (Conrad et al., 2023a) and British Columbia (Johnson et al., 2023) and 2020 and 2021 for Saskatchewan (Conrad et al., 2023b). As part of an informal data sharing agreement, EERL provides ECCC with the latest data as new annual inventories are developed and previous inventories are revised.

Aerial Survey Methodology

The EERL approach is based on aerial measurements and the protocol described in Johnson et al. (2023). This protocol utilizes Gas Mapping LiDAR (Light Detection And Ranging) (GML) from aircraft flying at low altitude to identify CH_4 emissions sources within UOG facilities. The aircraft and GML equipment used to conduct the measurement campaigns are operated by Bridger Photonics. Individual plumes of CH_4 observed using the GML technology are quantified as emission rates on a mass basis and assigned to specific equipment using high-resolution, geolocated images and facility plans. The source-level resolution of this approach means emissions can be quantified without introducing the need to subtract background emissions from agriculture, landfills, or non-anthropogenic sources (Johnson et al., 2023).

To develop complete inventories for the UOG sector, EERL planned its aerial measurement campaigns to cover a broad sample of active facilities and wells within each study region. Sites chosen for measurements provided representative samples of facility sizes, subtypes, and locations to account for the heterogeneity of the UOG sector in Canada. Measurements were repeated at sampled sites to capture temporal variability and to determine the detection limits of the technology under different atmospheric conditions (Johnson et al., 2023). The results from all flights were then aggregated to provide annual measurement-based emissions estimates for relevant facility types, grouped by subtype based on common attributes (Conrad et al., 2023a, 2023b; Johnson et al., 2023).

Table A3.2–21 provides a summary of the GML measurement campaigns conducted by EERL. The level of coverage achieved by the aerial surveys far exceeds that of typical field studies, which generally cover dozens of facilities over the course of a campaign, and usually do not include repeat site visits. Ground surveys are also constrained by limited site access, cost, and human resources.

Table A3.2–21 **Details of aerial measurement surveys**

Province	Survey Year	Estimated Population		EERL Sample Size		Coverage		Reference
		Active Facilities	Active Wells	Active Facilities	Active Wells	Active Facilities	Active Wells	
AB	2021	21 785	133 017	3 415	5 205	16%	4%	Conrad et al. (2023a)
	2023	21 761	131 963	11 395	16 438	52%	13%	EERL (2025)
	2024	21 140	130 167	11 445	16 891	54%	13%	
SK	2020	11 625	36 320	2 351	1 832	20%	5%	Conrad et al. (2023b)
	2021	11 818	32 588	3 104	1 865	26%	6%	
	2023	11 511	37 063	5 166	5 496	45%	15%	EERL (2025)
	2024	11 419	37 044	4 031	3 759	35%	10%	
BC	2021	950	8 672	581	705	61%	8%	Johnson et al. (2023)
	2023	912	8 608	685	4 499	75%	52%	EERL (2025)
	2024	880	8 625	703	4 834	80%	56%	

Uncertainty Considerations

Quantifying uncertainties is key to the EERL approach to measurement-based CH_4 inventories. Johnson et al. (2023) sets out the main factors that contribute to the uncertainty associated with aerial GML CH_4 estimates. Broadly speaking, these factors are:

- **Coverage**: the surveyed facilities are a representative sample of the population in each province or sub-provincial production region; distinct production regions within a province are represented in the sample for each facility type.
- **Measurement error**: accuracy and precision errors resulting from bias in the calibration of the measurement technology (accuracy), meteorological conditions, inversion techniques, and other factors.
- **Finite detection sensitivity**: accounting for the measurable and unmeasurable contributions to the total CH_4 emissions inventory.

Each of these factors are considered in the design of the EERL survey methodology. As noted in the previous section, EERL designs its GML surveys to cover key oil and gas production regions in each of the studied provinces. Each province where aerial measurements have been conducted is somewhat heterogeneous, but Alberta, and to a lesser extent Saskatchewan, pose particular challenges due to the variety of operations and the vast areas to cover. EERL has been able to collect measurements within virtually all major oil and gas subregions in western Canada. Complete coverage is virtually impossible owing to the high cost and logistics involved, but when informed by provincial facility data (i.e. from Petrinex), it is entirely feasible to sample a representative subset of the UOG sector within a single campaign using aerial GML (Johnson, 2025).

Intermittency of oil and gas CH_4 releases also contributes to measurement-based inventory uncertainties. The coverage of EERL's measurements helps address this issue, since large sample sizes mitigate the impact of significant short-lived releases (Johnson, 2025). Importantly, because EERL's protocol sees Bridger's aircraft revisiting sites where emissions are detected, the intermittency of measured releases is also quantified. This allows EERL to account for the persistence of releases when producing its CH_4 estimates and the associated uncertainties (Conrad et al., 2023c).

Measurement error and finite detection sensitivity are also addressed in EERL's statistical approach. In partnership with Bridger Photonics, EERL has developed methods to estimate the accuracy and precision of the GML technology when quantifying detected CH_4 plumes, which included leveraging the results of blinded and semi-blinded controlled releases during aerial surveys (Conrad et al., 2023c). This enables EERL to establish the probability of detection for CH_4 releases within a sampled site based on release rate, altitude, and wind speed near ground-level. Because the probability of detection at surveyed sites is well defined, EERL can also estimate the "unmeasured/unmeasurable" contribution of sources that are not captured by GML measurements, as discussed in the following subsection.

The EERL approach addresses the variation between different facility configurations by grouping oil and gas facilities into distinct strata. EERL determines these strata using the facility subtypes as defined in the Petrinex reporting system for each province. EERL groups Petrinex subtypes where appropriate based on common facility characteristics. For example, gas processing plants handling sour natural gas that report to Petrinex under subtypes 402 (gas plant acid gas flaring <1 tonne/day sulphur), 403 (gas plant acid gas flaring >1 tonne/day sulphur), 404 (gas plant acid gas injection), or 405 (gas plant sulphur recovery) are grouped together under the stratum "Gas Plants (Sour)". Similarly, off-site oil and gas wells are grouped into strata by production type (gas, crude oil, heavy crude oil) or other primary activity (injection, etc.). By dividing the upstream oil and gas sector into these categories, EERL can effectively produce a measurement-based CH_4 estimate for the subset of facilities/wells within each stratum, then simply sum the estimates for each stratum to produce a complete inventory.

EERL CH_4 Inventories

The final EERL inventories include both measured and unmeasured sources, with the latter including sources below the GML detection limit, such as pneumatics and equipment leaks. Similar to the approach described in section A3.2.2.1.3, EERL estimates emissions using a bottom-up approach based on component counts, facility/well populations, and EFs (Johnson et al., 2023). The modelled emissions that are below the GML detection limit during the aerial survey (accounting for wind speeds, emission rates, probability of detection, etc.) are added to the measurement-based estimates to complete the final inventory for each group of facility subtypes or wells (Conrad et al., 2023a, 2023b; Johnson et al., 2023). The EERL inventories include estimates for the following GML measured sources: compressor buildings, dehydrators, flares/combustors (lit), unlit flares/combustors, heaters, piping, power generators, separators, tanks, wellhead, other sources, and unknown sources.

EERL conducted additional measurement campaigns in 2023 and 2024 and provided equivalent source-resolved CH_4 estimates for these years directly to ECCC (EERL, 2025), covering British Columbia, Alberta, and Saskatchewan. The 2020 and 2021 Saskatchewan and British Columbia measurement-based inventories have also been revised (EERL, 2025) to incorporate regional wind uncertainty models, improve the rationalization of strata informed by previous campaigns, and improve the consideration of detected but unquantified sources within multi-pass / multi-flight data. In each case, EERL followed the established process (Johnson et al., 2023) to develop provincial inventories, with results presented by grouped facility subtypes or well type for each measured emissions source.

Methodology

The availability of robust, source-resolved CH_4 emissions estimates for Alberta, British Columbia and Saskatchewan UOG sectors in the published literature has allowed comprehensive measurement data to be integrated into the inventory estimates.

Overview

The CH_4 estimates produced by EERL are directly applicable to the years when measurements were conducted. That is, 2020 (for SK only), 2021, 2023, and 2024. However, to have a consistent time series, it is necessary to estimate emissions for 1990-2020 (1990-2019 for SK) and for 2022. To do this, emissions by facility subtype and source were used to derive EFs for each province using two distinct surrogate approaches:

1. on a per facility/well basis (Facility Count Method) and
2. on a volumetric activity basis (Activity Data Method).

The EFs for each method were calculated with facility counts and volumetric activity data, respectively, from the same year emissions were measured, and for each group of facility subtypes and wells in the EERL measurement-based inventories. These two methods were chosen in part because of the availability of facility counts and volumetric activity data (e.g. production volumes, flare volumes, etc.) for the entire time series. The results from both the Facility Count and Activity Data surrogate approaches are then averaged to produce the final estimates for each facility subtype by source for all years. The rationale for this custom approach is discussed in more detail later in this section.

Equation A3.2–16 and Equation A3.2–17 present the formulas used for the Facility Count Method and Activity Data Method, respectively. Both surrogate methods were used to estimate emissions for aerial-based sources for all years before 2021 for Alberta and B.C. and before 2020 for Saskatchewan, (i.e., annual facility counts and volumetric activity data were multiplied by the derived EFs from the earliest published EERL inventory). Estimates for 2022 were calculated using the wedging interpolation method described in section A3.2.2.1.1. 2022 emission rates were derived as defined in Equation A3.2–6 using both Facility Count and Activity Data approaches, again following Equation A3.2–16 and Equation A3.2–17, and the EERL estimates from the base years 2021 and 2023. This approach resulted in two distinct estimates for each source and subtype for 2022. Final estimates for each subtype-source combination were calculated as the average of the “wedged” Facility Count and Activity Data estimates.

Equation A3.2–16

$$Emis_{FC,i,j,k,l} = \left(\frac{Emis_{base_yr,j,k,l}}{FC_{base_yr,j,k}}\right) \times FC_{i,j,k} = EF_{FC,j,k,l} \times FC_{i,j,k}$$

$Emis_{FC,i,j,k,l}$	=	Facility Count Method CH_4 emissions for year i, province j, subtype k, and source l
$Emis_{base_yr,j,k,l}$	=	EERL measurement-based CH_4 emissions for base year, province j, subtype k, and source l
$FC_{base_yr,j,k}$	=	Facility/well count for base year, province j and subtype k
$FC_{i,j,k}$	=	Facility/well count for year i, province j and subtype k
$EF_{FC,j,k,l}$	=	Facility Count Method emission factor for province j, subtype k, and source l

Equation A3.2–17

$$Emis_{AD,i,j,k,l} = \left(\frac{Emis_{base_yr,j,k,l}}{AD_{base_yr,j,k}}\right) \times AD_{i,j,k} = EF_{AD,j,k,l} \times AD_{i,j,k}$$

$Emis_{AD,i,j,k,l}$	=	Activity Data Method CH_4 emissions for year i, province j, subtype k, and source l
$Emis_{base_yr,j,k,l}$	=	EERL measurement-based CH_4 emissions for base year, province j, subtype k, and source l
$AD_{base_yr,j,k}$	=	Volumetric activity for base year, province j and subtype k
$AD_{i,j,k}$	=	Volumetric activity for year i, province j and subtype k
$EF_{AD,j,k,l}$	=	Activity Data Method emission factor for province j, subtype k, and source l

Source Selection

Although EERL estimated annual emissions for all identified CH_4 sources, specific sources were selected for integration into the emission estimates where aerial measurements were expected to better characterize emissions than was previously possible using other inventory methods. The selected sources are listed in Table A3.2–22.

To select a subset of source-level aerial measurement-based CH_4 estimates, it was important to consider the limitations of the techniques used to develop "bottom-up" Tier 2 and Tier 3 methodologies for oil and gas fugitive emissions in Canada. These methods also rely on established procedures and field measurements, but accuracy issues arise due to technical and methodological limitations. For example, reported volumes of vented gas at conventional oil production sites frequently rely on estimated gas-to-oil ratios (GORs) based on steady-state measurements. This approach only produces accurate results if measured GORs are up to date and do not fluctuate significantly throughout the productive lifetime of a well. Modelled equipment leak estimates utilize average EFs developed using screening and measurement techniques that require technicians to have access to the source of the leaks for reliable detection and accurate quantification. Inspections for leaking equipment at oil and gas facilities are typically completed using optical gas imaging (OGI) cameras, where most ground-level components are screened at a distance of 1 to 2 metres. While OGI screenings reliably detect leaks under favourable conditions, conditions are not always ideal, and screening distances increase for elevated components (Clearstone, 2019).

Specific considerations that informed the selection of sources from EERL's CH_4 inventories are as follows:

- **Tanks**: tanks in the UOG sector across North America have been shown to emit CH_4 at higher rates than in traditional bottom-up inventories (Rutherford et al., 2021; Festa-Bianchet et al., 2023). Indeed, prior to its adoption, the EERL measurement data suggested large underestimates in all three Western Provinces (factors of 10, 9 and 7 for AB, BC and SK, respectively) when compared to emissions derived using traditional bottom-up approaches. Tank venting is generally based on engineering estimates and models of flashing losses from infrequently measured or modelled gas in solution (GIS). This approach has been shown to lead to accuracy issues in Western Canada, particularly at cold heavy oil production sites, where gas-to-oil ratios are known to fluctuate, and in many cases pockets of entrained gas are vented from production tanks at rates much higher than would be predicted using steady-state GIS values (Festa-Bianchet et al., 2023). Additionally, ground-based field studies face access limitations when it comes to accurately quantifying tank emissions, as vents, thief hatches, and other potentially leaking components are often several metres above field technicians. Considering these issues, ECCC determined that adopting an aerial measurement-based method for tanks would improve inventory accuracy.

Table A3.2–22 **Aerial Measurement Data Integrated into Fugitive CH_4 Estimates**

Province	Integrated Sources	Year(s)	Reference
BC	Compressor Buildings Tanks Unlit Flares	2021	Johnson et al. (2023)[a]
		2023, 2024	EERL (2025)
AB	Compressor Buildings Engine Sheds Tanks Unlit Flares/Combustors	2021	Conrad et al. (2023a)
		2023, 2024	EERL (2025)
SK	Compressor Buildings Engine Sheds Tanks Unlit Flares/Combustors Wellheads	2020, 2021	Conrad et al. (2023b)[a]
		2023, 2024	EERL (2025)

Note:
a. Estimates revised by EERL and provided to ECCC (EERL, 2025) to reflect methodological improvements, primarily more precise meteorological data.

- **Compressor building fugitives**: these are a significant source in the EERL inventories. Vented emissions from compressor rod packing and casings based on modelling were significantly lower than aerial GML results and relied on EFs derived from manufacturer specifications or from ground-based field studies. As compressors are generally located within buildings in Canada, it is difficult to delineate combustion exhaust and fugitive or vent emissions from compressor buildings. OGI screening and field measurement equipment like high-flow samplers cannot quantify methane released alongside other pollutants in hot combustion exhaust, whereas such emissions are readily detected and quantified using aerial GML. Given the discrepancy between measured top-down and estimated bottom-up emissions for this source and considering the issues related to accurately quantifying compressor fugitives and combustion exhaust, ECCC determined the aerial measurement estimate was more accurate than alternative approaches.
- **Engine Sheds**: another significant CH_4 source in the EERL inventories, particularly at cold heavy oil production sites. Similar challenges to quantifying and disaggregating combustion exhaust from vents and fugitive leaks exist for engine sheds as for compressor buildings. Festa-Bianchet et al. (2023) showed that there are significant discrepancies between reported venting and measured CH_4 at cold heavy oil production sites, indicating that emissions from equipment and components typically housed within engine sheds were not well characterized using traditional inventory methods.
- **Unlit flares/combustors**: unlit flares were not included as a source category prior to the adoption of measurement-based CH_4 emissions. Given empirical and scientific evidence showed that unlit flares/combustors occurred in Canada (Conrad et al., 2023a, 2023b; Johnson et al., 2023), EERL data for this source was incorporated into the inventory methodology to address this completeness issue.
- **Wellheads (SK)**: compared to prior ECCC estimates for wellhead emissions (modelled equipment leaks at well-sites and estimates for surface casing vents), EERL estimates for 2020 and 2021 were less than half of the existing wellhead estimates before adopting the measurement-based approach. Saskatchewan estimates for SCVF CH_4 had previously been based on Alberta data, which Government of Saskatchewan experts had highlighted as an issue given lower incidence of SCVF in the province. Therefore, the EERL wellhead CH_4 emissions were incorporated to address this accuracy issue.

Tanks, compressor buildings, and unlit flares were identified previously as key contributors to the historical discrepancy between bottom-up and measurement-based CH_4 estimates in British Columbia (Tyner and Johnson, 2021). The five sources selected from the aerial-based inventories for incorporation into the National Inventory Report (NIR) were also expected to have been impacted minimally by the targeted measures to reduce CH_4 under provincial regulations first implemented in 2020 (AB, 2018–; BC, n.d. [b]; SK, n.d.). Given these considerations, the EERL data is expected to more accurately quantify CH_4 from the selected sources, improving the overall accuracy of the NIR. This is not to suggest EERL estimates for other sources were omitted due to accuracy concerns, but the selected sources impact the overall emissions level most significantly and are complementary to other inventory methods as they are readily incorporated alongside bottom-up estimates while avoiding overlap. In fact, these sources accounted for 40%, 46%, and 81% of total CH_4 emissions in the 2023 EERL inventories for Alberta, British Columbia and Saskatchewan, respectively, demonstrating the relative importance of these sources in quantifying total CH_4 emissions from the UOG sector.

Integrating Aerial Measurement-based Sources with Other Estimates

Aerial measurement-based CH_4 emissions either replace or are reconciled with other UOG estimates to avoid double counting to the extent possible given available information. CH_4 from stationary combustion is estimated separately (as described in Annex 3.1) and removed from the source-level estimate for compressor buildings, as the measurement based EFs include both fugitive and combustion CH_4 emissions. Similarly, bottom-up emission estimates of storage losses from tanks are removed along with equipment leaks associated with tanks. The “bottom-up” fugitive sources reconciled with or directly replaced by aerial “top-down” measurement-based estimates are described in Table A3.2–23.

Table A3.2–23 **Integration of "Top-Down" Measurement-Based and "Bottom-Up" CH_4 Estimates by Source**

Measured Source	Reconciliation of CH_4 Sources	
	Included	"Bottom-Up" Estimate Removed
Compressor Buildings	Total Measured CH_4 minus Estimated CH_4 emissions from combustion of natural gas in compressors	Fugitive Equipment Leaks,[a] Unreported Venting – Compressor Seals
Engine Sheds	Total Measurement-based CH_4	Fugitive Equipment Leaks[a]
Tanks	Total Measurement-based CH_4	Fugitive Equipment Leaks,[a] Storage Losses
Wellheads[b]	Total Measurement-based CH_4	Fugitive Equipment Leaks,[a] Surface Casing Vent Flow

Note:
a. Includes only equipment leak CH_4 estimates for the associated "measured source."
b. Measurement based estimates for Wellheads are included for Saskatchewan only.

For unlit flares specifically, emissions on a mass basis are converted to a volume of gas using the composition data and densities described in section A3.2.2.1.2. The calculated unlit flare volume is subtracted from reported flare gas volumes with the resulting volume used to estimate flaring emissions for all GHGs as outlined in section A3.2.2.1.2 for Alberta and Saskatchewan, and as in section A3.2.2.1.1 for British Columbia. Similarly, CO_2 emissions from unintentional venting by unlit flares/combustors are calculated based on the unlit flare volume. This step also constrains the volume of gas vented by unlit flares/combustors to not exceed reported flare gas volumes.

Activity Data

For consistency between methodologies, the facility counts used to estimate fugitive emissions from pneumatics, compressor seals, and equipment leaks are also used in the Facility Count Method (Equation A3.2–16) to calculate annual estimates for measurement-based sources. Minor regrouping of facility subtypes used in existing UOG facility counts for British Columbia, Alberta, and Saskatchewan allows direct alignment with EERL facility subtype groupings. See section A3.2.2.1.3 for details on how annual facility and well counts are compiled for the UOG sector.

Volumetric activity data used in the Activity Data Method (Equation A3.2–17) is mapped to the appropriate source depending on their characteristics and those of the UOG sector where the emissions occur. Source to activity mapping follows similar logic for each province, but there are slight differences due to the types of activity data available. The mapping used to generate a consistent time series for each source is shown in Table A3.2–24.

Annual facility reported volumetric activity data is available for Alberta (2010 onward) and for Saskatchewan (2013 onward) from the Petrinex reporting system (Petrinex, n.d. [a]; [b]). Crude oil production, natural gas production, gas receipts, and flaring volumes from Petrinex are aggregated by reporting facility subtype, which allows direct alignment with the measurement-based CH_4 estimates from EERL once subtypes are grouped accordingly. For earlier years where subtype-level activity data is not available, corresponding sector-level activity data are used to extrapolate subtype-level activity back to 1990. This ensures the extrapolated activity by subtype values agree with known annual total activity data. Sector-level activity data used to complete the time series are extracted from the sources listed in Table A3.2–6 to maintain consistency between measurement-based estimates and other fugitive sources.

2019 was the first full year of Petrinex facility reporting in British Columbia with subsequent definitional changes occurring in 2020 (see section A3.2.2.1.6 for details). As such, sector-level volumetric activity data is used to estimate annual emissions to ensure emissions trends in the years immediately prior to the aerial measurement studies reflect real UOG activity in British Columbia, and not artifacts of reporting changes that may have outsized impacts when extrapolating at the subtype level.

Table A3.2–24 **Volumetric Activity Data Mapping for Extrapolating Aerial Measurement-Based CH_4 Emissions by Source**

Province(s)	UOG Sector(s)	EERL Sources	Activity Data
AB and SK	Heavy Crude Oil Cold Production Light/Medium Crude Oil Production	Tanks, Wellheads	Crude Oil Production
		Compressor Buildings, Engine Sheds	Natural Gas Production
		Unlit Flares/Combustors	Reported Flaring Volumes
	Natural Gas Production	Compressor Buildings, Tanks, Wellheads[a]	Natural Gas Production
		Unlit Flares / Combustors	Reported Flaring Volumes[b]
	Natural Gas Processing	Compressor Buildings Tanks	Gas Receipts
		Unlit Flares / Combustors	Reported Flaring Volumes
BC	Light/Medium Crude Oil Production	Compressor Buildings	Natural Gas Production
		Tanks	Crude Oil Production
		Unlit Flares	Reported Flaring Volumes
	Natural Gas Production	Compressor Buildings	Natural Gas Production
		Tanks	Condensate Production
		Unlit Flares	Reported Flaring Volumes
	Natural Gas Processing	Compressor Buildings	Gas Receipts
		Tanks	Condensate Production
		Unlit Flares	Reported Flaring Volumes

Notes:
a. EERL wellhead emissions incorporated for Saskatchewan only.
b. Saskatchewan Unlit Flares / Combustors in the Natural Gas Production sector are extrapolated using gas production volumes.

Emission Factors

The CH_4 EFs for the subset of sources listed in Table A3.2–22 were calculated for each group of facility or well subtypes included in the measurement-based estimates for British Columbia, Alberta, and Saskatchewan. The Facility Count Method EFs used EERL CH_4 emissions and corresponding facility counts estimated in-house for the measurement inventory year. Annual active facility and well counts for 1990 onwards were derived as described in section A3.2.2.1.3. Activity Data Method EFs for each province were calculated using the same CH_4 estimates grouped by facility type and source, but were calculated using the activity data values for the inventory year as highlighted in Equation A3.2–17, mapped as shown in Table A3.2–24.

The derived provincial EFs used to backcast measurement-based emissions to 1990 are shown in Table A3.2–25 for Alberta, Table A3.2–26 for Saskatchewan, and Table A3.2–27 for British Columbia.

Table A3.2–25 **CH_4 EFs Derived from 2021 EERL Aerial Measurement-based Inventory for Alberta**

Emissions Source	EERL Stratum	Associated Petrinex Subtype(s)	ECCC Derived EFs		Activity Data EF Denominator
			Facility Count EF (tonnes CH_4 / facility)	Activity Data EF (tonnes CH_4 / AD)	
Compressor Buildings	CRUDE OIL SINGLE-WELL BATTERY	311	1.40E-02	3.55E-02	10^6 m^3 gas production
	CRUDE OIL MULTIWELL GROUP BATTERY	321	9.32E-01	3.64E-01	
	CRUDE OIL MULTIWELL PRORATION BATTERY	322	7.52E+00	8.33E-01	
	CRUDE BITUMEN (HEAVY OIL) SINGLE-WELL BATTERY	331	2.30E+00	1.77E+01	
	CRUDE BITUMEN MULTIWELL GROUP BATTERY	341	4.10E+00	6.45E+00	
	CRUDE BITUMEN MULTIWELL PRORATION BATTERY	342	1.02E+01	6.90E+00	
	GAS SINGLE WELL BATTERY	351	5.51E-01	2.18E-01	
	GAS MULTI-WELL GROUP BATTERY	361	3.67E+00	1.81E-01	
	GAS MULTIWELL EFFLUENT MEASUREMENT BATTERY	362	5.39E+00	5.08E-02	
	GAS MULTI-WELL PRORATION BATTERY (IN SOUTHEAST ALBERTA)	363	6.24E-01	5.18E-02	
	GAS MULTI-WELL PRORATION BATTERY (OUTSIDE SOUTHEAST ALBERTA)	364	6.42E-01	4.67E-02	
	GAS PLANT SWEET	401	1.08E+02	4.45E-01	10^6 m^3 gas receipts
	GAS PLANT ACID GAS FLARING < 1T/D SULPHUR	402	5.25E+01	4.25E-01	
	GAS PLANT ACID GAS FLARING > 1T/D SULPHUR	403	2.24E+02	8.01E-01	
	GAS PLANT ACID GAS INJECTION	404	1.19E+03	1.59E+00	
	GAS PLANT SULPHUR RECOVERY	405	2.47E+02	2.85E-01	
	GAS PLANT MAINLINE STRADDLE	406	1.78E+02	1.51E-02	
	GAS PLANT FRACTIONATION	407	1.78E+02	4.37E+00	
	ENHANCED RECOVERY OR CONCURRENT PRODUCTION/CYCLING SCHEME[a]	501, 502, 508	4.29E+00	2.87E-02	10^6 m^3 gas production
	COMPRESSOR STATION[a]	601	2.75E+01	1.91E-01	
	GAS GATHERING SYSTEM[a]	621, 622	1.36E+01	2.41E-01	
	CRUDE OIL WELL	311, 321, 322	8.09E-02	1.28E-01	
	GAS WELL	351-364	6.33E-02	6.16E-02	
Engine Sheds	CRUDE OIL MULTIWELL PRORATION BATTERY	322	4.81E-02	5.33E-03	10^6 m^3 gas production
	CRUDE BITUMEN (HEAVY OIL) SINGLE-WELL BATTERY	331	4.27E+00	3.30E+01	
	CRUDE BITUMEN MULTIWELL GROUP BATTERY	341	3.29E+00	5.17E+00	
	CRUDE BITUMEN MULTIWELL PRORATION BATTERY	342	3.08E+00	2.08E+00	
Flares/Combustors (unlit)	CRUDE OIL SINGLE-WELL BATTERY	311	2.34E-01	1.13E+01	10^6 m^3 flare gas
	CRUDE OIL MULTIWELL GROUP BATTERY	321	2.41E-01	3.92E+00	
	CRUDE OIL MULTIWELL PRORATION BATTERY	322	5.55E-01	4.01E+00	
	GAS SINGLE WELL BATTERY	351	5.36E-02	2.48E+01	
	GAS MULTI-WELL GROUP BATTERY	361	4.80E-01	4.53E+01	
	GAS MULTIWELL EFFLUENT MEASUREMENT BATTERY	362	2.98E+00	2.29E+01	
	GAS PLANT SWEET	401	1.54E+01	5.45E+01	
	GAS PLANT SULPHUR RECOVERY	405	1.29E+01	2.68E+00	
	GAS PLANT MAINLINE STRADDLE	406	1.89E+01	9.14E+00	
	GAS PLANT FRACTIONATION	407	1.89E+01	2.28E+02	

Table A3.2–25 **CH_4 EFs Derived from 2021 EERL Aerial Measurement-based Inventory for Alberta** (cont'd)

Emissions Source	EERL Stratum	Associated Petrinex Subtype(s)	ECCC Derived EFs		Activity Data EF Denominator
			Facility Count EF (tonnes CH_4 / facility)	Activity Data EF (tonnes CH_4 / AD)	
Flares/Combustors (unlit) (cont'd)	COMPRESSOR STATION[a]	601	4.09E+00	4.93E+00	
	GAS GATHERING SYSTEM[a]	621, 622	2.16E+00	6.50E+01	
	GAS WELL	351-364	2.92E-01	3.75E+02	
	CRUDE OIL WELL	311, 321, 322	1.87E-02	1.54E+00	
Tanks	CRUDE OIL SINGLE-WELL BATTERY	311	1.08E+01	2.12E+01	10^3 m^3 crude oil production
	CRUDE OIL MULTIWELL GROUP BATTERY	321	3.33E+00	1.22E+00	
	CRUDE OIL MULTIWELL PRORATION BATTERY	322	2.55E+01	2.21E+00	
	CRUDE BITUMEN (HEAVY OIL) SINGLE-WELL BATTERY	331	4.60E-01	4.83E-01	
	ENHANCED RECOVERY OR CONCURRENT PRODUCTION/CYCLING SCHEME[a]	501, 502, 508	1.11E+01	5.87E-02	
	GAS SINGLE WELL BATTERY	351	1.31E+00	5.21E-01	10^6 m^3 gas production
	GAS MULTI-WELL GROUP BATTERY	361	1.16E+01	5.71E-01	
	GAS MULTIWELL EFFLUENT MEASUREMENT BATTERY	362	2.02E+00	1.90E-02	
	GAS MULTI-WELL PRORATION BATTERY (IN SOUTHEAST ALBERTA)	363	1.27E+00	1.05E-01	
	GAS MULTI-WELL PRORATION BATTERY (OUTSIDE SOUTHEAST ALBERTA)	364	1.09E+00	7.96E-02	
	GAS PLANT SWEET	401	3.62E+01	1.49E-01	10^6 m^3 gas receipts
	GAS PLANT ACID GAS FLARING < 1T/D SULPHUR	402	9.02E+00	7.30E-02	
	GAS PLANT ACID GAS FLARING > 1T/D SULPHUR	403	7.62E+00	2.72E-02	
	GAS PLANT ACID GAS INJECTION	404	1.60E+03	2.14E+00	
	GAS PLANT SULPHUR RECOVERY	405	9.90E+01	1.14E-01	
	GAS PLANT MAINLINE STRADDLE	406	5.69E+01	4.83E-03	
	GAS PLANT FRACTIONATION	407	5.69E+01	1.40E+00	
	ENHANCED RECOVERY OR CONCURRENT PRODUCTION/CYCLING SCHEME[a]	501, 502, 508	1.11E+01	5.87E-02	10^6 m^3 gas production
	DISPOSAL FACILITY[a]	503, 504, 507, 509	2.61E+00	5.17E-03	
	COMPRESSOR STATION[a]	601	4.53E+00	3.15E-02	
	GAS GATHERING SYSTEM[a]	621, 622	8.13E+00	1.44E-01	
	GAS WELL	351-364	1.30E+00	1.26E+00	
	CRUDE OIL WELL	311, 321, 322	2.84E-01	3.55E-01	10^3 m^3 crude oil production
Tanks (CHOPS)	CRUDE BITUMEN (HEAVY OIL) SINGLE-WELL BATTERY	331	3.08E+00	3.23E+00	10^3 m^3 crude oil production
	CRUDE BITUMEN MULTIWELL GROUP BATTERY	341	7.23E+00	2.76E+00	
	CRUDE BITUMEN MULTIWELL PRORATION BATTERY	342	2.81E+00	1.41E-01	
	HEAVY OIL WELL	331, 341, 342	3.11E-01	2.08E-01	

Notes:
Derived by ECCC from the results of Conrad et al. (2023a). Only non-zero EFs are presented.
a. These facilities do not directly produce natural gas or generally do not report natural gas production, therefore total annual gas production was used as activity data.

Table A3.2–26 **CH_4 EFs Derived from 2020 EERL Aerial Measurement-based Inventory for Saskatchewan**

Emissions Source	EERL Stratum	Associated Petrinex Subtype(s)	ECCC Derived EFs		Activity Data EF Denominator
			Facility Count EF (tonnes CH_4 / facility)	Activity Data EF (tonnes CH_4 / AD)	
Compressor Buildings	Crude Oil Single Well Battery	311	1.18E-02	1.68E-01	10^6 m^3 gas production
	Crude Oil Multiwell Group Battery	321	2.10E-01	4.33E+00	
	Crude Oil Multiwell Proration Battery	322	4.75E-01	1.83E-01	
	Heavy Crude Oil Multiwell Battery	326, 327	1.76E+00	8.72E-01	
	Gas Single-well Battery	351	3.94E-01	1.20E+00	
	Gas Multiwell Battery	361, 363, 364	1.53E-01	1.50E-02	
	ENHANCED RECOVERY SCHEME[a]	501	1.58E+01	4.39E-02	
	Compressor Station[a]	601	9.16E+00	5.95E-01	
	GAS GATHERING SYSTEM[a]	621	5.33E+00	2.15E-01	
	CRUDE OIL WELL	311, 321, 322	1.84E-02	1.79E-01	
	GAS WELL	351, 361, 363, 364	5.38E-03	6.24E-02	
	Gas Plant Sweet	401	1.03E+02	1.62E+00	10^6 m^3 gas receipts
	Gas Plant – Sour	402-405	1.64E+00	2.46E-02	
	Gas Plant	406	1.03E+02	3.22E-01	
Engine Sheds	Crude Oil Single Well Battery	311	4.52E-01	6.46E+00	10^3 m^3 crude oil production
	Heavy Oil Single-well Battery	325	4.27E+01	4.26E+02	
Flares/Combustors (unlit)	Crude Oil Single Well Battery	311	8.73E-01	3.74E+01	10^6 m^3 flare gas
	Crude Oil Multiwell Group Battery	321	7.06E-03	6.25E-01	
	Crude Oil Multiwell Proration Battery	322	2.73E+01	7.20E+01	
	Heavy Crude Oil Multiwell Battery	326, 327	3.21E+01	1.08E+02	
	Gas Plant Sweet	401	2.25E+01	1.97E+01	
	Gas Single-well Battery	351	3.51E-02	1.07E-01	10^6 m^3 gas production
	Gas Multiwell Battery	361, 363, 364	4.08E-03	4.00E-04	
	GAS GATHERING SYSTEM[a]	621	7.24E-01	2.92E-02	
Tanks	Crude Oil Single Well Battery	311	2.32E+01	5.50E+01	10^3 m^3 crude oil production
	Crude Oil Multiwell Group Battery	321	1.56E+00	2.46E+00	
	Crude Oil Multiwell Proration Battery	322	2.58E+01	1.92E+00	
	ENHANCED RECOVERY SCHEME[a]	501	1.91E+02	9.98E-02	
	CRUDE OIL WELL	311, 321, 322	1.21E-01	2.23E-01	
	Satellite Battery – Intermediate MPB facility[a]	347	1.11E+00	1.66E-01	
	Gas Single-well Battery	351	2.87E+00	8.73E+00	10^6 m^3 gas production
	Gas Multiwell Battery	361, 363, 364	1.89E+01	1.85E+00	
	Compressor Station[a]	601	5.94E-02	3.86E-03	
	GAS GATHERING SYSTEM[a]	621	1.37E+01	5.54E-01	
	GAS WELL	351, 361, 363, 364	1.49E-02	1.73E-01	
	Gas Plant Sweet	401	2.13E+01	3.34E-01	10^6 m^3 gas receipts
	Gas Plant – Sour	402-405	6.07E-02	9.12E-04	
	Gas Plant	406	2.13E+01	6.65E-02	
Tanks (CHOPS)	Heavy Oil Single-well Battery	325	9.12E+00	1.26E+01	10^3 m^3 crude oil production
	Heavy Crude Oil Multiwell Battery	326, 327	1.59E+02	6.80E+00	
	HEAVY OIL WELL	325-327	2.50E-01	3.16E-01	
Wellheads	Crude Oil Single Well Battery	311	4.19E-01	9.94E-01	10^3 m^3 crude oil production
	Crude Oil Multiwell Swab Group Battery	314	3.97E+01	7.96E+01	
	Crude Oil Multiwell Group Battery	321	2.93E-03	4.63E-03	
	Crude Oil Multiwell Proration Battery	322	4.56E-03	3.38E-04	
	CRUDE OIL WELL	311, 321, 322	2.41E-01	4.44E-01	
	Gas Single-well Battery	351	3.19E-01	9.72E-01	10^6 m^3 gas production
	Gas Multiwell Battery	361, 363, 364	6.59E-02	6.45E-03	
	GAS WELL	351, 361, 363, 364	4.56E-01	5.29E+00	
Wellheads (CHOPS)	Crude Oil Single Well Battery	311	7.37E-02	1.75E-01	10^3 m^3 crude oil production
	Heavy Oil Single-well Battery	325	1.76E+01	2.43E+01	
	Heavy Crude Oil Multiwell Battery	326, 327	3.78E-03	1.61E-04	
	HEAVY OIL WELL	325-327	2.36E-01	2.98E-01	

Notes:
Derived by ECCC from the results of Conrad et al. (2023b). Only non-zero EFs are presented.
a. These facilities either do not directly produce oil or natural gas, or they generally do not report production, therefore total annual production was used as activity data.

Table A3.2–27 **CH_4 EFs Derived from 2021 EERL Aerial measurement-based Inventory for British Columbia**

Emissions Source	EERL Stratum	Associated Petrinex Subtype(s)	ECCC Derived EFs		Activity Data EF Denominator
			Facility Count EF (tonnes CH_4 / facility)	Activity Data EF (tonnes CH_4 / AD)	
Compressor Buildings	CRUDE OIL SINGLE-WELL BATTERY	311	9.51E-01	8.54E-04	10^6 m^3 gross natural gas production
	CRUDE OIL MULTIWELL GROUP BATTERY	321	9.09E-01	6.92E-05	
	CRUDE OIL MULTIWELL PRORATION BATTERY	322	1.06E+01	5.65E-03	
	GAS SINGLE WELL BATTERY	351	2.63E-01	9.41E-05	10^6 m^3 non-associated natural gas production
	GAS MULTIWELL GROUP BATTERY	361	1.05E+01	1.50E-02	
	GAS MULTIWELL EFFLUENT MEASUREMENT BATTERY	362	4.60E+01	1.01E-01	
	COMPRESSOR STATION	601	1.00E+02	2.38E-01	
	GAS GATHERING SYSTEM	621	4.11E+00	7.60E-03	
	GAS PLANT SWEET	401	2.90E+02	1.11E-01	10^6 m^3 gross natural gas production
	GAS PLANT ACID GAS FLARING < 1T/D SULPHUR	402	9.45E+01	3.45E-02	
	GAS PLANT ACID GAS FLARING > 1T/D SULPHUR	403	9.45E+01	5.75E-03	
	GAS PLANT ACID GAS INJECTION	404	9.45E+01	5.75E-03	
	GAS PLANT SULPHUR RECOVERY	405	9.45E+01	5.75E-03	
	ENHANCED RECOVERY SCHEME	501	6.27E+00	4.77E-04	
Flares (Unlit)	CRUDE OIL MULTIWELL GROUP BATTERY	321	3.16E+00	1.58E+00	10^6 m^3 flaring – oil batteries
	CRUDE OIL MULTIWELL PRORATION BATTERY	322	5.16E+00	1.81E+01	
	OIL WELL	311, 321, 322	3.13E-02	2.47E+00	
	GAS MULTIWELL GROUP BATTERY	361	1.39E+01	2.81E+01	10^6 m^3 flaring – gas production
	GAS MULTIWELL EFFLUENT MEASUREMENT BATTERY	362	1.08E+00	3.36E+00	
	DISPOSAL	503	4.30E+00	2.17E+00	
	COMPRESSOR STATION	601	1.79E+01	6.00E+01	
	GAS WELL	351, 361, 362	3.12E-02	6.23E+00	
	GAS PLANT SWEET	401	2.02E+01	3.66E+00	10^6 m^3 flaring – gas plants
	GAS PLANT ACID GAS FLARING < 1T/D SULPHUR	402	2.12E+00	3.68E-01	
	GAS PLANT ACID GAS FLARING > 1T/D SULPHUR	403	2.12E+00	6.14E-02	
	GAS PLANT ACID GAS INJECTION	404	2.12E+00	6.14E-02	
	GAS PLANT SULPHUR RECOVERY	405	2.12E+00	6.14E-02	
Tanks	CRUDE OIL SINGLE-WELL BATTERY	311	8.34E-01	7.27E-02	10^3 m^3 light/medium crude oil production
	CRUDE OIL MULTIWELL GROUP BATTERY	321	2.80E-01	2.07E-03	
	CRUDE OIL MULTIWELL PRORATION BATTERY	322	1.08E+01	5.56E-01	
	ENHANCED RECOVERY SCHEME	501	1.93E+00	1.43E-02	
	OIL WELL	311, 321, 322	7.46E-01	8.66E-01	
	GAS SINGLE WELL BATTERY	351	3.91E+00	2.37E-02	10^3 m^3 condensate production
	GAS MULTIWELL GROUP BATTERY	361	7.97E+00	1.93E-01	
	GAS MULTIWELL EFFLUENT MEASUREMENT BATTERY	362	1.04E+01	3.87E-01	
	DISPOSAL	503	1.63E+00	9.90E-03	
	COMPRESSOR STATION	601	4.40E+01	1.77E+00	
	GAS WELL	351, 361, 362	1.78E-02	4.29E-02	
	GAS PLANT SWEET	401	1.33E+02	8.78E-01	
	GAS PLANT ACID GAS FLARING < 1T/D SULPHUR	402	4.10E+01	2.60E-01	
	GAS PLANT ACID GAS FLARING > 1T/D SULPHUR	403	4.10E+01	4.33E-02	
	GAS PLANT ACID GAS INJECTION	404	4.10E+01	4.33E-02	
	GAS PLANT SULPHUR RECOVERY	405	4.10E+01	4.33E-02	

Notes:
Derived by ECCC from the results of Johnson et al. (2023). Only non-zero EFs are presented.

Rationale for Backcast Approach

The aerial measurement-based CH_4 emissions methodology uses a custom approach to produce a consistent time series. The Facility Count Method and the Activity Data Method are both considered surrogate approaches as defined in Volume 1, Chapter 5, Section 5.3 of the IPCC Guidelines, which presents potential approaches for resolving data gaps when developing a consistent time series (IPCC, 2006). When there are multiple available activity datasets that are suitable candidates for the surrogate approach, the Guidelines suggest that it may be possible to compare the correlation strengths of the available surrogates with known emissions values, then select the surrogate that correlates most strongly with emissions. However, the Guidelines also acknowledge that relating emissions to more than one statistical parameter may be more accurate than using a single surrogate.

ECCC has compared the correlation strengths between the selected surrogate data and the aerial measurement-based CH_4 estimates using linear regression. However, it should be noted that there are limitations to such a comparison. ECCC does not have access to process or equipment-level activity data for the facilities sampled during the EERL campaigns, so a regression analysis of measured emissions with source-level activity is not possible. Instead, we have compared the strength of correlations between annual methane emissions by source and the total annual volumetric activity data and facility counts aggregated at the subtype level by province. As such, this comparison analysis is inherently limited due to the nature of the measurement data and the necessary aggregation of available surrogate data.

The heterogeneity of the oil and gas sector presents a further challenge, as facilities differ widely in their physical characteristics, varying from individual well pads to more complex multi-well batteries to gas processing plants. Facility counts and activity levels for different facility types range by orders of magnitude. The impacts of this variation were partially mitigated when conducting the linear regression analyses by grouping emissions and surrogate data based on the sector-source-activity mapping presented in Table A3.2–24. Annual surrogate data used in this analysis were taken from 2020 (for SK only) and 2021, corresponding to the annual CH_4 estimates from EERL. The analysis treated each CH_4 estimate and related surrogate (subtype-level facility count or volumetric activity) as individual data points such that correlation strength between emissions and the two surrogate approaches could be directly compared for each activity grouping in Table A3.2–28 and Table A3.2–29.

Linear regression analyses were performed to calculate R^2 values with the y-intercept set to 0. The analysis was repeated two ways. In Table A3.2–28, the presented R^2 values were derived from emissions and surrogate data without modification. In Table A3.2–29, both emissions and surrogate data were normalized to values between 0 and 1 where the maximum value for each source in a given province was set to 1. The purpose of using normalized values in the second regression analysis was to further mitigate the effects of the wide variation in facility populations and activity levels. Since the normalized values generally produced stronger correlations overall, additional regression analyses were conducted using this approach for emissions and surrogate data grouped by individual sources, with the resulting R^2 values also shown in Table A3.2–29.

In most cases presented in Table A3.2–28 and in Table A3.2–29, one R^2 value is larger than the other. However, the differences are generally marginal, and nearly all the calculated values indicate weak to moderate correlation strength. This makes it difficult to conclude that one surrogate should be preferred to the other based on its correlation to CH_4 emissions, even on a case-by-case basis.

The R^2 values presented in Table A3.2–28 and Table A3.2–29 correspond to the data shown in Figure A3.2–8, where CH_4 emissions are plotted against both surrogates. The challenge of comparing linear regression analyses using the unmodified data is evident in plots (a) and (b)– even when grouped by activity type, clear linear trends do not materialize. Plots (c) and (d) present the same data after normalization and include a dashed line representing a perfect linear correlation for reference. Any normalized dataset with a strong positive correlation between the two variables would be expected to cluster closely around this line.

Table A3.2–28 **Summary of Regression Analysis – Correlation Strength of Measurement-based CH_4 versus Surrogate Data**

Activity	Source	# of Data Points	R^2 (Surrogate vs. CH_4)	
			Facility Counts[a]	Volumetric Activity[b]
Flare Volume	All Measurement-Based	38	0.13	0.36
Gas Production		71	0.19	0.13
Oil Production		49	0.05	0.09
Gas Receipts		32	0.54	0.40

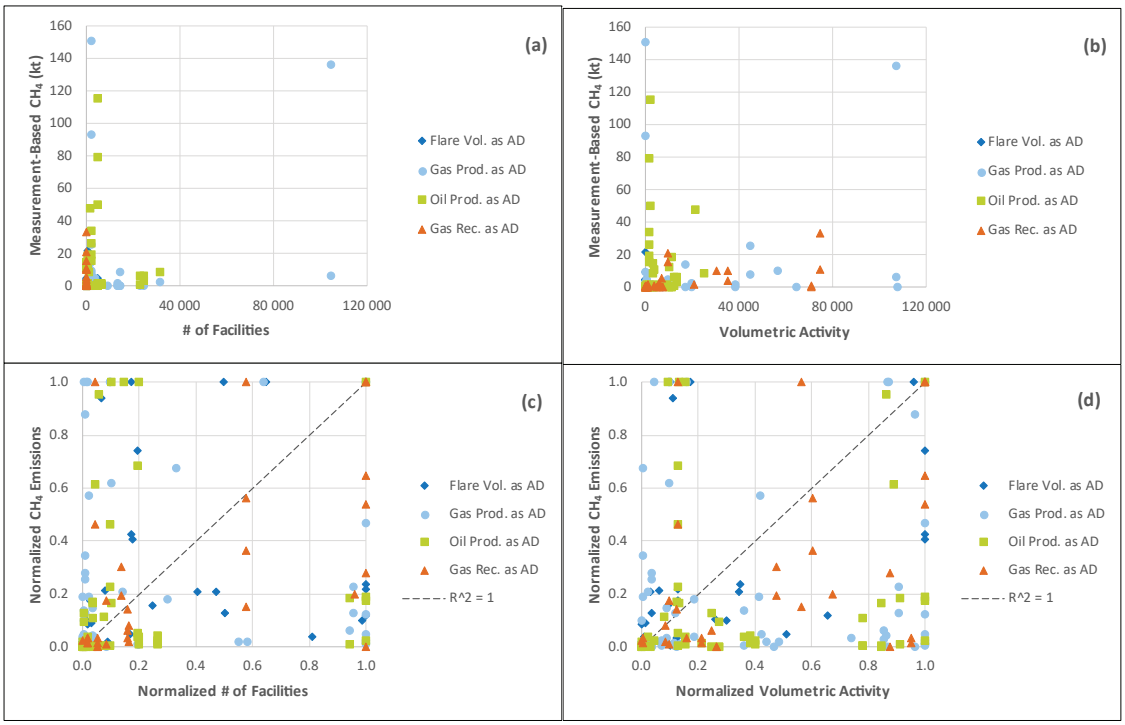
Notes:
Measurement-based estimates by source are grouped according to the activity-source mapping defined in Table A3.2–24.
a. R^2 values derived from regression analysis using data shown in Figure A3.2–8 plot (a).
b. R^2 values derived from regression analysis using data shown in Figure A3.2–8 plot (b).

Table A3.2–29 Summary of Regression Analysis – Correlation Strength of Normalized Measurement-based CH_4 versus Normalized Surrogate Data

Activity	Source	# of Data Points	R^2 (Normalized Surrogate vs. Normalized CH_4)[a]	
			Facility Counts[b]	Volumetric Activity[c]
Flare Volume	All Measurement-Based	38	0.23	0.42
Gas Production		71	0.15	0.21
Oil Production		49	0.15	0.19
Gas Receipts		32	0.58	0.54
Flare Volume	Unlit Flares	38	0.23	0.42
Gas Production	Compressor Buildings	43	0.04	0.15
	Engine Sheds	9	0.16	0.01
	Tanks	13	0.19	0.54
	Wellheads	6	0.74	0.40
Oil Production	Tanks	31	0.17	0.25
	Wellheads	18	0.11	0.07
Gas Receipts	Compressor Buildings	19	0.73	0.70
	Tanks	13	0.39	0.36

Notes:
Measurement-based estimates by source are grouped according to the activity-source mapping defined in Table A3.2–24.
a. Surrogates and CH_4 emissions were normalized to the maximum values in each activity-source grouping.
b. R^2 values derived from regression analysis using data shown in Figure A3.2–8 plot (c).
c. R^2 values derived from regression analysis using data shown in Figure A3.2–8 plot (d).

Figure A3.2–8 Measurement-based CH_4 Emissions versus Selected Surrogates used in Regression Analyses to Test Correlation Strength



Notes:
Each point represents measurement-based CH_4 emissions for a different stratum-source combination (ex. Crude oil single well battery – Tanks).
All data points are grouped by associated activity (ex. CH_4 for Crude oil single well battery – Tanks is grouped under "Oil Prod. As AD").

(a) = CH_4 plotted versus estimated facility/well populations in 2020 (SK) or 2021.

(b) = CH_4 plotted versus reported annual volumetric activity (10^6 m^3 for gas, 10^3 m^3 for oil) for 2020 (SK) or 2021.

(c) = CH_4 plotted versus normalized estimated facility/well populations.

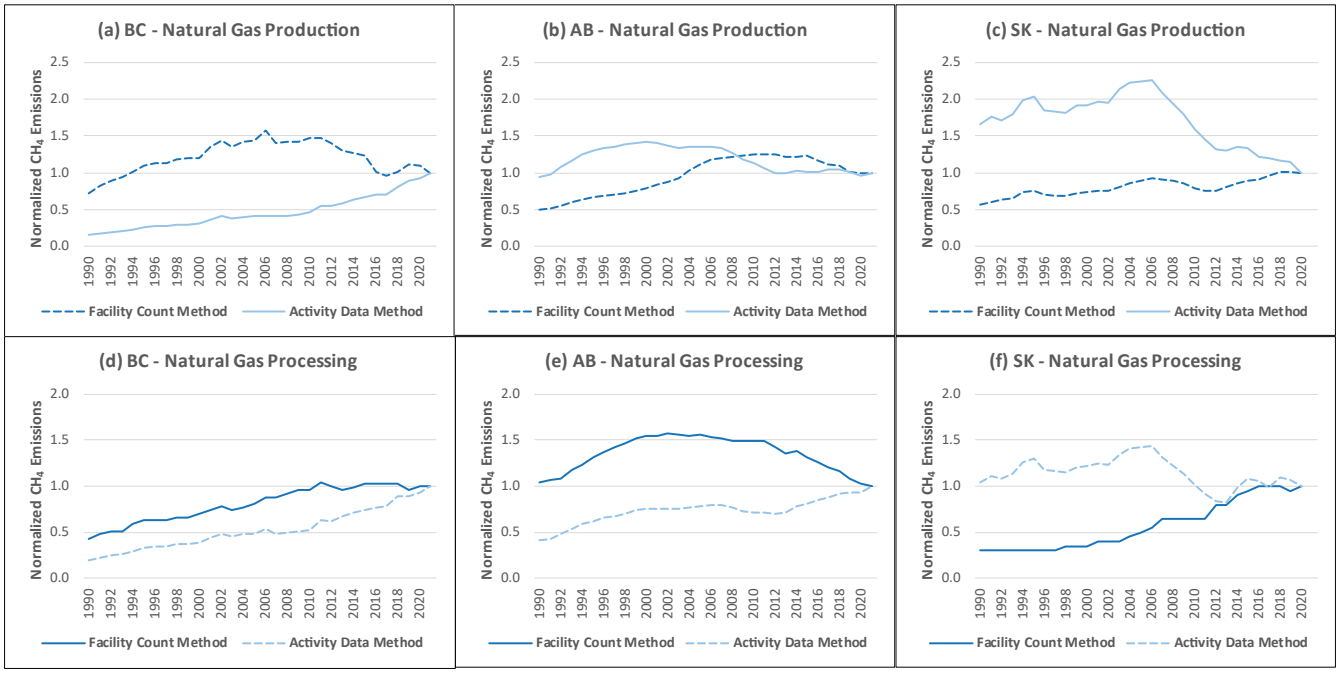
(d) = CH_4 plotted versus normalized reported annual volumetric activity.

Comparisons of the regression analysis results are considered inconclusive when considering the calculated R^2 values and visual comparisons of the plotted data. While single surrogates could be chosen based on the result of either the unmodified correlation comparison (Table A3.2–28, Figure A3.2–8 [a] and [b]) or the normalized version (Table A3.2–29, Figure A3.2–8 [c] and [d]), in many cases the results do not indicate one surrogate explains the variation in emissions significantly better than the other. For the gas production grouping, opposite conclusions could even be drawn from the results of the two correlation strength comparisons. Overall, the evidence is not strong enough to justify selecting a single surrogate for all cases.

ECCC has also compared the results of the two backcast methodologies for each facility subtype and measurement-based emission source. The results of both approaches are generally similar for recent periods, but historical estimates can diverge significantly between the Facility Count and Activity Data methods. Notably, in certain cases the results for comparable facility subtypes demonstrate diverging trends when looking back towards 1990. The results of this comparison show that a universal approach where one backcast method is selected over the other could have contrasting results for otherwise similar facilities. This would result in somewhat arbitrary emissions trends that in many cases would not be readily explainable by the physical characteristics of the UOG sector.

For example, Figure A3.2–9 presents the trends in backcasted CH_4 emissions for compressor buildings in the natural gas production and processing sectors. Emissions are normalized to the earliest base year (i.e., 2021 for BC and AB; 2020 for SK) for direct comparison between trends for each province and sector.

Figure A3.2–9 **Natural Gas Production and Processing Compressor building CH_4 Normalized to Backcast Base Year**



Notes:
Compressor building CH_4 time series as shown reflect the backcast emissions trends prior to reconcilation with combustion estimates.
BC, AB compressor building emissions are normalized relative to 2021 levels, while SK emissions are normalized to 2020.

Figure A3.2–9 makes clear that trends for equivalent emissions sources could have completely different time series estimates depending on the selected surrogate. If one surrogate was chosen based on the strength of the respective correlations for gas production and gas processing categories in Table A3.2–29 (as indicated by the "Gas Receipts" activity), the result would be the emissions plotted as a solid line in each subplot within Figure A3.2–9. The R^2 values for the gas production group in Table A3.2–29 indicate a stronger correlation between CH_4 emissions and gas production volumes (R^2 = 0.15) than facility counts (R^2 = 0.04), but both correlations are weak. Gas plant populations only show a marginally stronger correlation (R^2 = 0.73) to emissions than gas receipts (R^2 = 0.70) in the equivalent comparison for the gas processing sector. However, selecting one surrogate based on these comparisons alone would have contradictory and significantly different results, despite the shared characteristics of compressor buildings in the natural gas production and processing sector across each province. The difference between trends shown in plots (c) and (f) for Saskatchewan in particular highlight the impact of such a choice.

ECCC has conducted equivalent comparisons for all measurement-based emissions estimates, many of which show similar divergence and/or contradictory results. Essentially, this analysis showed that historical trends are highly sensitive to the selection of either surrogate. Using the average of both approaches limits the impact on emissions trends of selecting one surrogate based on marginally stronger correlation strength alone. ECCC believes the results of such comparisons further support the conclusion that an average of both backcast methods is a suitable approach given the available surrogate data.

The Facility Count and Activity Data methods are both reasonable surrogate approaches under the Guidelines, but each has limitations. In the Facility Count Method, active facility counts are related to overall activity, but this approach does not reflect impact of changes to activity per facility (i.e., increased production or throughput of crude oil and/or natural gas per facility would be expected to result in increased emissions, and vice versa). Conversely, the Activity Data Method does not account for changes in the number of potential emissions sources (i.e., increased population of multi-well crude oil batteries would be expected to result in an increase in emissions, and vice versa).

While facility populations and activity levels in the UOG sector are related, it is a complex relationship. Without access to more granular data, such as equipment counts or throughput data at the source level (e.g., number of tanks by subtype for the entire time series), it is difficult to distinguish whether the number of sources or the volume of hydrocarbons produced and/or processed best explains the variation in CH_4 emissions. The correlation comparison analysis does not suggest that one approach is clearly more suitable overall, or that one surrogate clearly correlates more strongly with emissions on a case-by-case basis. A simple average allows both facility/well population and activity effects to be incorporated in the backcasted estimates.

Quality Assurance (QA) / Quality Control (QC) and Verification

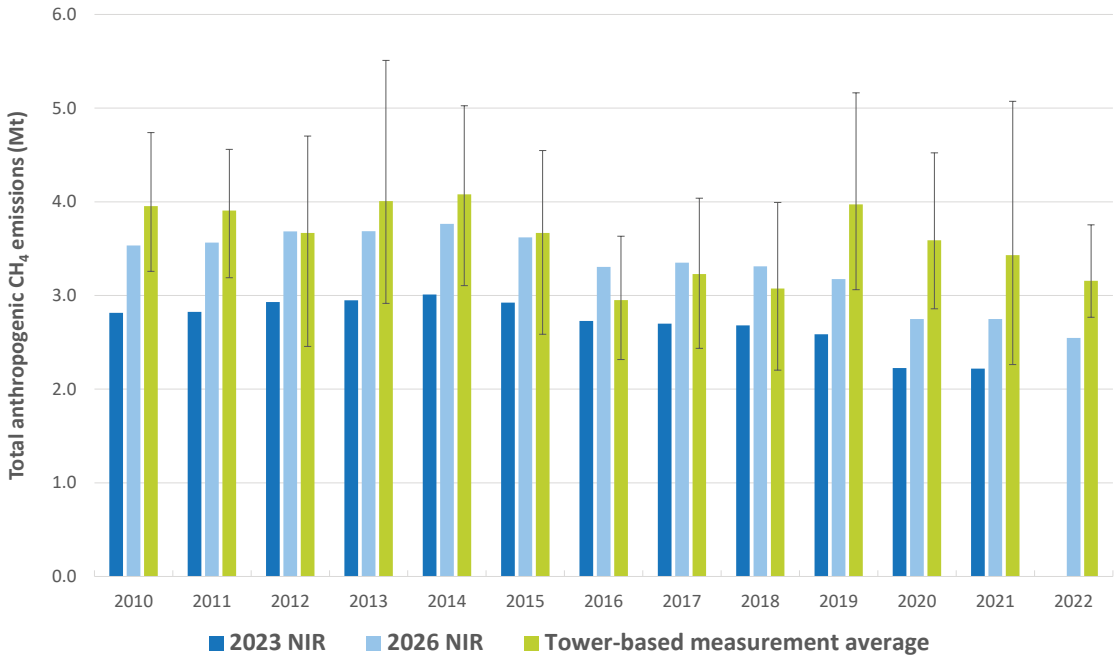
The 2006 IPCC Guidelines (Vol 1, Chapter 6, sections 6.7.1.2 and 6.7.1.3) outline various QC checks that should be used to evaluate the quality of country-specific EFs developed for the inventory, including: QC checks on the background data used to develop the EFs, QC checks on models, comparison with IPCC default factors, and comparisons with other countries.

Checks on the background measurement data were performed by both the operator, Bridger Photonics, as well as EERL, including controlled release experiments to evaluate detection limits and necessary bias corrections. Various activities were undertaken to evaluate the model developed by ECCC to backcast source-specific aerial measurements including detailed completeness checks, the regression analyses presented previously, and importantly, trends comparisons for all sources at the subtype level, equivalent to those presented in Figure A3.2–9. As noted in the previous section, these granular trends comparisons functioned like a sensitivity analysis on the choice of surrogate data. The sensitivity of CH_4 emissions in 1990 to the choice of surrogate informed the decision to use an average of the Facility Count and Activity Data Methods for the final estimates.

Remote measurement studies in Canada, the United States, and even globally have shown that measured emissions are typically substantially higher than estimates developed using traditional bottom-up inventory methods (Atherton et al., 2017; Johnson et al., 2017; Zavala-Araiza et al. 2018; Chan et al., 2020; MacKay et al., 2021; Rutherford et al., 2021; Shen et al., 2022, 2023). Therefore, a comparison of the Canada-specific EFs developed using aerial measurement data with IPCC default EFs or those from other countries is likely to show significant differences. Furthermore, default IPCC Tier 1 EFs are only presented by industry segment (e.g., oil production, natural gas processing, etc.) and do not delineate by emission source. As such, to compare with IPCC defaults, all emissions for a given industry segment in Canada, including those estimated by direct estimation, aerial measurements, modelling, and interpolation/extrapolation methods, would need to be aggregated, negating any verification of the EFs derived from aerial measurements. Finally, although the oil and gas industry uses many of the same equipment and processes world-wide, there are many things that impact a country fugitive oil and gas emissions profile. These include utilized extraction methods, maintenance practices, regulations, age of the infrastructure, gas-to-oil ratios, and the general geography of the country. For the above reasons, it was deemed that a comparison with IPCC or other country's EFs was a futile exercise.

That said, tower-based measurements of total anthropogenic methane emissions in the provinces of Alberta and Saskatchewan were available to compare with inventory estimates (Chan et al. 2024). Figure A3.2–10 presents a comparison of total anthropogenic methane emissions (i.e., combustion, fugitive, industrial processes, agriculture, and waste) from the NIR published in 2023 (2023 NIR), this inventory (2026 NIR), and those developed from the tower-based measurements. The 2023 NIR was chosen as it was the last inventory published prior to the incorporation of the aerial-based measurements. The figure shows that current inventory estimates align better with the tower-based measurements than those from the 2023 NIR, providing evidence that the backcast methodology produces reasonable results.

Figure A3.2–10 **Comparison of Tower-based Measurements of Total Anthropogenic CH_4 in Alberta and Saskatchewan with Inventory Estimates, 2010-2022**



Uncertainty Estimates

EERL includes in its published CH_4 inventories lower (2.5 percentile) and upper (97.5 percentile) bounds representing the 95% confidence intervals for CH_4 emissions by facility subtype (Conrad et al., 2023a, 2023b; Johnson et al., 2023). These values reflect the uncertainties associated with all sources of CH_4 and are derived by combining the estimated uncertainties of the measured and unmeasured portions of each measurement-based inventory (Johnson et al., 2023). EERL does not produce uncertainty estimates for individual CH_4 emissions sources.

ECCC applies uncertainty estimates to the subtotal of measurement-based sources for each facility subtype, rather than at the individual source level. This method is thought to be more appropriate than estimating source-level uncertainties for each subtype, as it is more analogous to the EERL approach. However, it should be noted that applying total subtype-level uncertainties to a subtotal of CH_4 emissions still relies on the assumption that the selected sources contribute an equivalent proportion to the lower and upper percentile estimates as they do to the nominal CH_4 values. Such an assumption is necessary to incorporate the robustly estimated uncertainty bounds from EERL while integrating only a subset of the measured emissions sources.

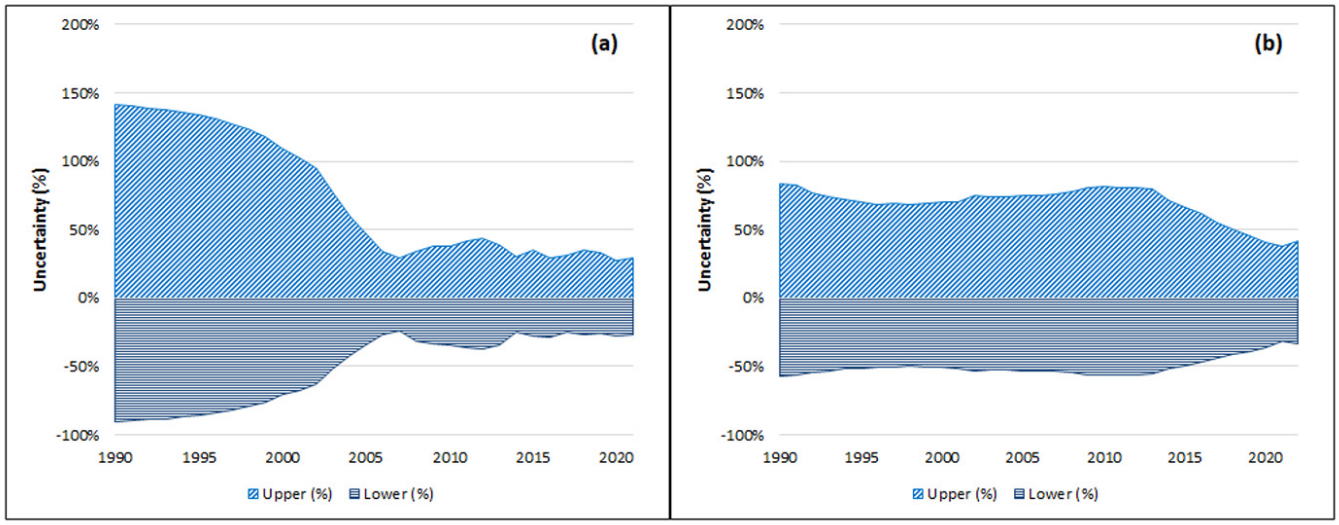
To estimate uncertainties associated with aerial measurement-based emissions, ECCC first calculates the ratio of CH_4 from selected sources to the total by subtype. We then multiply the subtype-level lower and upper percentile CH_4 values from EERL by this ratio. The resulting values are converted from a mass basis to lower and upper bounds as percentages and are used directly in aerial measurement inventory years. To produce a complete time series of annual uncertainty, two sets of upper and lower uncertainty estimates are generated, one for the Facility Count estimates and another for Activity Data estimates. In both cases, facility count and activity data parameter uncertainties are combined with the derived measurement-based emissions uncertainties using an IPCC Tier 1 approach. The overall annual uncertainty is then estimated using the lowest of the estimated lower bounds and the highest of the estimated upper bounds for each subtype. This selection is based on

the comparison of the annual lower and upper bounds for each surrogate method when expressed as CH_4 on a mass basis (i.e., for each subtype, the lower of the Facility Count and Activity Data lower bounds is adopted, and the higher of the two upper bounds is likewise adopted to complete the annual subtype-level uncertainty estimate). Following this selection, the uncertainty values are again converted to percentages relative to the final measurement-based CH_4 estimates aggregated by subtype.

This approach reflects greater uncertainty resulting from the divergence between the two surrogate methods further away from the EERL inventory base years. ECCC believes the resulting uncertainties are more realistic than would be produced by applying constant values or making other arbitrary assumptions about variable uncertainties over time. Figure A3.2–11 provides two relevant examples of this trend, where larger uncertainty ranges in 1990 reflect divergence between Facility Count and Activity Data estimates earlier in the time series.

An IPCC Tier 1 approach is used when aggregating measurement-based CH_4 emissions to the sector-source level and when combining estimates with other methods used for the UOG sector. The parameter level uncertainty estimates for facility counts and activity data (±15% and ±20%, respectively) align with those used in other inventory methods described in sections A3.2.2.1.2 and A3.2.2.1.3.

Figure A3.2–11 **CH_4 Uncertainty Estimates for Measurement-based Sources for Different Facility Subtypes**



Notes:

(a) = Uncertainty bounds for gas single-well batteries in Alberta (Petrinex subtype 351).

(b) = Uncertainty bounds for gas plants (sweet) in Alberta (Petrinex subtype 401).

A3.2.2.1.6. Changes to Alberta, British Columbia, and Saskatchewan Vent Gas Definitions

Effective January 1, 2020, both Saskatchewan and Alberta changed the definitions of fuel gas, flare gas and vent gas in their respective measurement and reporting requirements. Similar changes in British Columbia became effective July 1, 2020. *Directive 017* (AER, 2022) in Alberta defines gas released from pneumatic instruments as vent gas, where it was previously defined as fuel gas, and gas released from compressor seals and glycol dehydrators, which was previously unreported, is also to be reported as vent gas. Saskatchewan's *Directive PNG017* (SK MER, 2020) requires gas released from pneumatic instruments, compressor seals and equipment leaks to be reported as vent gas and British Columbia's *Measurement Guideline* (BCOGC, 2021) made changes to align with the Alberta's *Directive 017*.

Due to gaps in previous measurement and reporting requirements for reported venting, emissions from pneumatics, compressor seals, glycol dehydrators, and equipment leaks were estimated and included separately for the years 1990 to 2019 as unreported venting emission sources. To avoid double-counting emissions, careful consideration must be taken to ensure the sources included in reported vent volumes are also not estimated separately as an unreported vent source. Starting for the year 2021 in British Columbia, separate emission estimates for pneumatics and glycol dehydrators are not included in emission totals as these sources are included in reported vent volumes. Similarly, separate emission estimates for pneumatics and equipment leaks are no longer required for 2020 and beyond in Saskatchewan. Note that since venting from compressor seals is included in the aerial measurements of compressor buildings and included in emission estimates as described in section A3.2.2.1.5, methods have been developed to remove the compressor seal portion from reported venting from 2020 onwards as described later in this section.

In Saskatchewan, the *Oil and Gas Emissions Management Regulations* (OGEMR) (SK, n.d.) only require leak detection and repair (LDAR) at gas production and processing facilities. *Guideline PNG035: Estimating Venting and Fugitive Emissions* (SK MER, 2019) provides guidance to operators on how to quantify gas released from equipment leaks which are identified during LDAR activities. Since LDAR is only required at gas facilities, it is assumed that reported vent volumes include equipment leak emissions at gas facilities in Saskatchewan. However, since LDAR is not required at oil production facilities, it is assumed that equipment leaks are not identified, quantified, or reported as vent gas at these facilities. Therefore, equipment leaks at gas facilities in Saskatchewan are not estimated separately while equipment leaks at oil facilities are estimated separately and included in the emission totals.

Starting in 2020, Alberta collects and reports vent volumes through both Petrinex, which provides total vent volume by individual reporting facility, and the OneStop reporting system (AEPA, 2022; AER 2000–) which provides vent volumes aggregated by facility subtype, but delineated by source, including: defined vent gas (DVG), pneumatic pumps, pneumatic instruments, reciprocating compressors, centrifugal compressors, and glycol dehydrators. DVG includes similar sources to those included in reported vent volumes prior to the 2020 vent gas definition changes. Comparing Petrinex and OneStop data shows unexpected differences in total vent volumes. Petrinex volumes would be expected to be greater than OneStop volumes, since it includes nonroutine venting, which is excluded in OneStop. However, this has not been the case for the four years of OneStop reporting, although the gap between the two datasets has narrowed considerably. OneStop vent volumes were approximately 35% higher in 2020, 46% higher in 2021, 4% higher in 2022, and less than 1% higher in 2023. The reasons for these differences may include operators using different emission management systems; incomplete transition of Petrinex reporting systems to adapt to the change in fuel, flare, and vent definitions; and different estimation methods used for Petrinex and OneStop (AER, 2000–).

To account for these volumetric discrepancies and partly address the methodological inconsistency introduced between 2019 and 2020 due to the vent gas definition changes, Alberta venting emissions are calculated as follows for 2020 onwards. First, vent emissions are calculated using Petrinex reported vent volumes as described in section A3.2.2.1.2. These volumes and the associated emissions are then scaled by facility subtype to the sum of DVG and glycol dehydrators from OneStop. Vent volumes from pneumatic pumps and instruments are excluded since the large difference between OneStop reported and FEM modelled (section A3.2.2.1.3) pneumatics cannot be reconciled. Since OneStop reported vent gas volumes from pneumatics are excluded, modelled pneumatic emissions from the FEM (section A3.2.2.1.3) for Alberta must be included. Similarly, since aerial measurement-based emissions from compressor buildings have been incorporated into estimates (section A3.2.2.1.5), OneStop reported compressor seal volumes are excluded.

The changes in Saskatchewan, British Columbia and Alberta reporting introduced a methodological inconsistency starting in 2020. While the availability of Alberta OneStop data has allowed ECCC to partly address this methodological inconsistency in Alberta, the problem persists for Saskatchewan and British Columbia and to a lesser extent for Alberta. At present, ECCC does not possess reported data with sufficient resolution to completely address the inconsistencies. This issue is further complicated by the oil and gas emissions regulations that came into effect January 1, 2020, in all three provinces,[3] resulting in changes to equipment and industry practice. ECCC is actively investigating potential solutions.

3 Under the Canadian Environmental Protection Act, 1999 (CEPA), the Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector), SOR/2018-66 (the "federal methane regulations") were published in the Canada Gazette, Part II, vol. 152, no. 1 on April 26, 2018. The federal methane regulations came into force on January 1, 2020, except sections 26, 27 and 37 to 41, which came into force on January 1, 2023. Section 10 of CEPA authorizes the Minister of the Environment to enter into an equivalency agreement with a province, territory, or aboriginal government if the provisions within that jurisdiction are equivalent to a regulation made under CEPA.
Equivalency agreements were established for the *federal methane regulations* with Alberta (ECCC, 2020a), British Columbia (ECCC, 2020b), and Saskatchewan (ECCC, 2020c).

A3.2.2.2. Natural Gas Transmission and Storage

Virtually all the natural gas produced in Canada is transported long distances through high pressure, large diameter pipelines from field production and processing areas to the gate of the local distribution systems or large volume customers such as power plants or chemical plants. To increase the reliability of natural gas supply throughout the year, gas is injected into underground storage facilities during the summer months when demand is lower and withdrawn during winter months when demand for space heating increases. Most emissions from natural gas transmission and storage facilities are from equipment leaks and process vents.

Methodology

General

Fugitive emissions for natural gas transmission are based on several documents. The first, *CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP, 1999), was prepared by Clearstone Engineering Ltd. for CAPP in July 1999. The second source is ancillary tables provided by Clearstone Engineering Ltd. that describe the CO_2 emissions. There are no N_2O fugitive emissions from natural gas transmission. The CO_2 and CH_4 emissions for 1990–1996 are taken directly from the two sources for all fugitives except for equipment leaks. The CO_2 and CH_4 emissions from flaring, venting, and spills/pipeline ruptures for 1997–1999 were estimated based on province/territory natural gas transmission pipeline length and release rates, which were developed based on the 1996 emissions from CAPP (1999) and pipeline lengths from StatCan.

For the years 2005 and 2011, emissions are taken from the UOG study (EC, 2014), which followed an IPCC Tier 3 approach that rolled-up the reported GHG emissions from individual natural gas companies. Input data for the natural gas transmission and storage industry was compiled by ORTECH Consulting Inc. (2013) for the Canadian Energy Partnership for Environmental Innovation (CEPEI). CEPEI, a special program under the Canadian Gas Association, is a collaboration of major natural gas transmission and distribution companies operating throughout Canada (Alberta, British Columbia, Manitoba, New Brunswick, Nova Scotia, Ontario, Quebec, and Saskatchewan). Participating companies are expected to account for greater than 99% of GHG emissions from the Canadian natural gas transmission and distribution systems (ORTECH, 2015–). Data for the years 2000–2004, 2006–2010 and 2012 onwards were provided directly by CEPEI (2013–), again following an IPCC Tier 3 approach. To support this process, CEPEI has published optional guidance for its member companies to follow when reporting emissions. This reporting guidance has been regularly updated to incorporate the results of relevant field studies and to ensure the suggested methodologies have reflected the characteristics of the Canadian gas transportation sector.

The emissions are calculated per province/territory and then summed to obtain the total CO_2 and CH_4 emissions for Canada. Newfoundland and Labrador, Prince Edward Island, Yukon, and Nunavut do not have natural gas transmission pipelines. However, natural gas gathering lines were operational in Yukon prior to 2014 when natural gas production was occurring, and fugitive emissions from those lines are accounted for in the 1.B.2.b.2 – Natural Gas – Production category of the CRT.

No natural gas transmission pipelines were operating in Nova Scotia, New Brunswick or the Northwest Territories until 1999.

Similar to natural gas transmission, fugitive emissions from natural gas storage are taken from the UOG study (EC, 2014) for the years 2005 and 2011. Data for the years 2000–2004, 2006–2010 and 2012 onwards was provided directly by CEPEI (2013–).

Equipment Leaks

Between 2004 and 2011 and from 2015 onwards, emissions from equipment leaks, compressor seals, and pneumatic devices are estimated following the general methodology described in the previous section. For the period between 1990 and 2003, adjustments to equipment leak emissions estimates provided by CAPP (1999) and a combination of interpolation and extrapolation approaches were necessary to provide a consistent time series for equipment leaks in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, and Quebec. The CAPP (1999) study presented detailed estimates for the natural gas transmission sector for 1995. Following review and discussion with CEPEI technical experts, equipment leak emissions for 1995 were calculated at a national level using the procedure set out in the CAPP (1999) study, but instead with EFs from CEPEI (2016). The CEPEI (2016) EFs were determined to be more representative of facility configurations in 1995, as the equipment counts used to develop facility average leak rates were based on real-world survey results, whereas the CAPP (1999) EFs relied substantially on engineering assumptions to approximate typical facilities. Provincial equipment leak estimates from CAPP (1999) were then multiplied by the national level ratio of adjusted to original emissions to scale the provincial values accordingly.

To establish a complete time series, the adjusted estimates for 1995 were used as a basis to interpolate emissions for 1996–2003 at the provincial level using the wedging technique (Equation A3.2–6) with pipeline length as the activity factor and 2004 CEPEI data as the second base inventory. Emissions for 1990–1994 were estimated by linearly extrapolating the GHG intensity on an emissions per kilometre of pipeline basis backwards from 1995, then multiplying by the annual provincial pipeline length data from Statistics Canada. This approach was preferred to a linear extrapolation of emissions because the CAPP (1999) study indicated reported emissions declined from 1990 to 1995 (CAPP, 1999), and the resulting trend was consistent with the decrease in emissions from 1995 to 2004.

Following mitigation efforts for pneumatic device and compressor seal emissions, studies co-ordinated by CEPEI resulted in updates to EFs used by a significant share of reporting operators in their emissions for 2015. While this update improved the accuracy of emissions estimates, this led to a discontinuity in the methodology, as estimates for the years prior were not revised. To address the time series consistency issues this reporting change introduced, equipment leaks, pneumatic devices, and compressor seals for British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, and Quebec between 2012 and 2014 were interpolated using the wedging approach (Equation A3.2–6), with UOG study (EC, 2014) estimates for 2011 and CEPEI data for 2015 as the base inventories. 2011 data was determined to have accurately reflected emissions at the time. The extrapolation of equipment leak emissions from 1990 to 1994 and interpolation in 1996–2003 and 2012–2014 allows the most robust available estimates to form the basis of a consistent time series in line with volume 2, section 4.2.2.6 of the IPCC Guidelines (IPCC, 2006).

Activity Data

The activity data required to estimate the fugitive emissions from natural gas transmission for 1990–2003 and 2012–2014 is the annual length of the natural gas transmission pipeline by region. Transmission pipeline lengths were published annually by StatCan in *Natural Gas Transportation and Distribution*. StatCan has discontinued this publication but still collects the data and releases it to ECCC (StatCan, 2024). However, pipeline length data was only available up to and including 2022; pipeline lengths for 2023 and 2024 were therefore estimated. For Quebec, Ontario, Manitoba, Saskatchewan, Alberta, British Columbia and the Northwest Territories, the 2023–2024 pipeline lengths were estimated based on the average annual change in length between 2000 and 2022. The 2023–2024 values were assumed to be the same as 2022 for New Brunswick and Nova Scotia since the natural gas transmission pipeline lengths have not changed since 2003 and 2002, respectively. While the availability of CEPEI emissions data means pipeline lengths are not required to estimate emissions beyond 2014, they are still compiled for analysis purposes and are reported as activity data at the national level for category 1.B.2.b.iv in the CRT.

For natural gas storage, annual volumes of natural gas delivered to storage and withdrawn from storage are taken from *Canadian natural gas storage, Canada and provinces* (StatCan, n.d.[f]) for the 2015 onwards and *Natural gas utilities, monthly receipts and disposition* (StatCan, n.d.[g]) for data prior to 2015.

A3.2.2.3. Petroleum Refining

The refinery model is based on the study *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI, 2004), prepared for the Canadian Petroleum Products Institute (CPPI), Natural Resources Canada (NRCan), Environment Canada and Industry Canada in 2004 by Levelton Consultants Ltd. The study surveyed the refining industry and used this data, along with data collected by the Canadian Industrial Energy End-Use Data and Analysis Centre, to develop GHG emission estimates for 1990 and 1994–2002. In addition, facility-reported data (FRD) available from the Greenhouse Gas Reporting Program (GHGRP) (ECCC, n.d.) for 2005 onwards was used to compiled GHGs associated with flaring activities.

There are three sections in the refinery methodology: fugitive (unintentional releases), process venting and flaring. The combustion methodology for petroleum refining is discussed in Annex 3.1 of the National Inventory Report.

The combustion methodology in Annex 3.1 is also the approach used to estimate venting emissions specific to the combustion of petroleum coke during catalyst regeneration processes. The catalyst in refinery cokers deactivates by petroleum coke formation and must be regenerated by continuous or periodic combustion. Emissions associated with this process are allocated to process venting.

Methodology

Fugitive Emissions

The CO_2 and CH_4 EFs were developed by Levelton Consultants Ltd. and were presented in the refinery study (CPPI, 2004). These EFs are used to estimate the fugitive emissions for the years not included in the study, i.e., 1991–1993 and 2003 onwards.

The fugitive emissions are generated using Equation A3.2–18.

Equation A3.2–18

$$FugitiveGHGEmissions(t) = EmissionFactor(t/GJ) \times RefineryAnnualEnergyConsumption(GJ)$$

Emission factors	=	2.78 t CO_2/GJ for CO_2 and 11.89 t CH_4/GJ for CH_4
Refinery annual energy consumption (in GJ)	=	the sum of the energy of all fuels consumed by refineries in the *Report on Energy Supply and Demand in Canada* (RESD) (StatCan, n.d.[b]), including fuels listed under producer consumption from the refined petroleum products table—the energy consumption value is the same as that in the stationary combustion model for 1.A.1.b Petroleum Refining of the CRT table

The refinery study reported fugitive N_2O emissions for 1990 and 1994–2002 as a constant 100 t N_2O/year; however, there were insufficient data to develop an applicable EF. Therefore, the N_2O emissions were kept constant at 100 t N_2O/year for the years 1991–1993 and 2003 onwards. It is assumed that the reported N_2O emissions from the refinery study are a residual from combustion sources and that the majority of N_2O emissions associated with petroleum refining are correctly reported in the stationary combustion section of the inventory.

Process Emissions (Venting)

Process emissions are mainly associated with venting of CO_2 from the production of hydrogen with natural gas as feedstock.

Hydrogen is used as an input in the production of refined petroleum products (RPPs) such as gasoline and diesel. Using data provided from the refinery study for the years 1990, 1994–1998 and 2000–2002, CO_2 emissions from the production of hydrogen were correlated to refinery annual RPP production. These results were used to estimate CO_2 emissions for the years 1991–1993, 1999 and 2003 onwards.

Flaring Emissions

Flaring emissions have been determined for CO_2, CH_4 and N_2O using the estimates from the refinery study and RPP production by Canadian refineries. The study provided emissions for the years 1990, 1994–1998 and 2000–2002, and these emissions were correlated to refinery annual RPP production. Flaring emissions for the years 1991–1993, 1999 and 2003 were estimated based on this correlation and known RPP production data. For 2005 to 2024 flaring emissions were compiled based on data reported by refineries to Canada's GHGRP (ECCC, n.d.), while an interpolation method was applied for 2004 emissions.

Petroleum refining facilities are required to follow GHGRP reporting requirements along with specified quantification methods, measurements and sampling methods for fuel properties and quantities (ECCC, 2024). These specifications and requirements ensure accurate data are reported. For example, facilities are to follow Canada's Weights and Measures Act (R.S.C., 1985, c. W-6) which is a law that establishes the measurement standards to ensure a certain level of accuracy (e.g., +/- 2%) to protect consumers and purchasers of product by weight, volume, or a unit of energy (e.g., kWh, higher heating value, etc.).

Activity Data

The activity data required to estimate the fugitive emissions from refineries is listed in Table A3.2–30.

Table A3.2–30 **Refinery Method Data Sources**

Publisher	Publication	Activity Data
Statistics Canada	Report on Energy Supply and Demand in Canada (RESD) (Statistics Canada, n.d.[b])	Refinery and producer consumption (by refineries) annual energy consumption. Refinery RPP production
Canadian Petroleum Products Institute (CPPI)	*Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* by Levelton Consultants Ltd. (CPPI, 2004)	Fugitive Emissions Table 3-2 CPPI Regional GHG Inventory – Detailed (kilotonnes) Process Emissions Table 3-2 CPPI Regional GHG Inventory – Detailed (kilotonnes)
		1990–2003 Flaring Emissions Appendix E – Flare Gas
Environment and Climate Change Canada	Greenhouse Gas Reporting Program (GHGRP) (ECCC, n.d.)	Flaring Emissions 2005 to 2024 petroleum refining facility-reported GHGs

A3.2.2.4. Natural Gas Distribution

Natural gas distribution pipelines take high-pressure gas from the natural gas transmission system, reduce the pressure, and distribute the gas through underground gas mains and service lines to individual end-users. Emissions are mainly from fugitive equipment leaks and process vents from pipelines, metering and regulating stations, short-term surface storage, and residential, commercial or industrial meters.

Methodology

General

For the 1990–1999 period, fugitive emissions from venting, flaring, and glycol dehydrators from natural gas distribution are based on the Canadian Gas Association (CGA) report titled *1995 Air Inventory of the Canadian Natural Gas Industry* (CGA, 1997) and the Gas Research Institute (GRI) report titled *Vented Emissions from Maintenance at Natural Gas Distribution Stations in Canada* (GRI, 2000). The CGA study estimated emissions from the Canadian gas pipeline industry for the years 1990 and 1995 using an IPCC Tier 3 approach. Emissions were calculated based on EFs from the U.S. EPA, other published sources and engineering estimates. The activity data was obtained from published sources and specialized surveys of gas distribution system companies. The surveys contained information on equipment schedules, operating parameters of equipment, pipeline lengths used in the Canadian distribution system, etc. The GRI (2000) report is an update to the CGA (1997) study with more accurate and better substantiated data for station vents. An EF was developed for the distribution system based on the study data (CGA, 1997; GRI, 2000) and on gas distribution pipeline distances by province provided by StatCan, which were then used to estimate emissions for the 1990–1999 period.

For 2000 and onwards, emissions are based on data from the UOG study (EC, 2014), following an IPCC Tier 3 approach that rolled up the reported GHG emissions from individual natural gas companies for 2005 and 2011. Input data for the natural gas distribution industry was compiled by ORTECH Consulting Inc. (2013) for CEPEI. Data for the years 2000–2004, 2006–2010 and 2012 onwards was provided directly by CEPEI (2013−), again following an IPCC Tier 3 approach.

The fugitive emissions for natural gas distribution are estimated for each province and then summed to obtain the overall emissions for Canada. At present, no natural gas distribution pipelines exist in the following provinces and territories: Newfoundland and Labrador, Prince Edward Island, Nunavut, and Yukon.

Equipment Leaks

The GRI (2000) study did not address emissions from fugitive equipment leaks in the gas distribution sector presented in the CGA (1997) study. Following consultations with representatives from CEPEI, ECCC determined the equipment leak estimates in the CGA (1997) study were not representative of the sector in Canada, since the study used EFs and other information from the U.S. gas distribution sector. Notably, cast-iron is known to leak at higher rates on average than other pipeline materials (ORTECH, 2015–), and the U.S. gas distribution network included a larger proportion of cast-iron pipeline than was present in Canada in 1990 and 1995. In the more recent CEPEI data (EC, 2014; CEPEI, 2013−), Canadian gas distribution companies were encouraged to use company-specific information when reporting emissions to CEPEI via ORTECH, or alternatively CEPEI provided reporters with generic equipment leak EFs developed based on Canadian data (CEPEI, 2016). To provide a consistent, representative time series for provinces where the gas distribution sector existed in 1990, equipment leak emissions were backcasted for 1990–2004 using the 2005 estimates from EC (2014) as the basis and pipeline length as the activity factor (Equation A3.2–5).

Similar to the gas transmission sector, estimates for 2012–2014 were interpolated by wedging (Equation A3.2–6). Interpolation was used in this case to address a discontinuity in the CEPEI reported data in 2015, when a significant share of reporters adopted updated EFs for residential meter sets and pipeline leaks and prior estimates were not revised.

Cast-iron gas distribution mains were entirely phased out of service in Canada by 2013 (CGA, 2022; Enbridge, 2019). To account for the removal of cast-iron pipelines, national cast-iron pipeline lengths were estimated using public information on the various materials used in Canada (CGA, 2022; Enbridge, 2019). Leaks from cast-iron distribution mains were then estimated by multiplying the annual pipeline length estimate by the generalized CEPEI CH_4 EF of 2.886 tonnes/km/year (CEPEI, 2022), before estimating CO_2 emissions using representative Canadian natural gas compositions (EC, 2014). The resulting totals were divided by province proportionate to gas distribution pipeline lengths from Statistics Canada (2024) and added to the equipment leak estimates. This adjustment does not apply to New Brunswick, Nova Scotia, or Northwest Territories, as no new cast-iron pipeline was installed at the time gas distribution networks were established in these regions (CEPEI, 2022).

Activity Data

The required activity data is the length of natural gas distribution pipeline per province, which was historically published in StatCan's *Natural Gas Transportation and Distribution* report. StatCan discontinued this publication in 2003 but still collects the data and releases it to ECCC (StatCan, 2024). However, pipeline length data was only available up to and including 2022; pipeline lengths for 2023–2024 were therefore estimated for all provinces based on the change in length between 2021 and 2022. Natural gas distribution pipeline lengths are not required to estimate emissions beyond 2014, but more recent years' estimates are compiled for analysis purposes and reported as activity data at the national level for category 1.B.2.b.v in the CRT.

For New Brunswick and Nova Scotia, pipeline lengths for 2000–2006 were provided by Enbridge Gas New Brunswick[4] and Heritage Gas,[5] respectively. In the Northwest Territories, the Ikhil Pipeline began providing Inuvik with natural gas in 1999. Distribution lengths for 1999–2006 were backcast based on the change in distribution length between 2007 and 2008.

The 2007 pipeline length for British Columbia provided by StatCan was twice the 2006 value. StatCan confirmed that the data for 2006 and previous years was incorrect but was unable to provide corrected distribution lengths. It was assumed that the 1999 value was correct, and a linear trend was used to fill in the 2000–2006 data.

A3.2.2.5. Oil Sands and Heavy Oil Upgrading Industry

The oil sands and heavy oil upgrading (OS/HOU) industry produces synthetic crude oil and other products from bitumen. Bitumen is a naturally occurring viscous mixture consisting of hydrocarbons heavier than pentane and other contaminants (e.g., sulphur compounds); in its natural state, it will not flow under reservoir conditions or on the surface. Bitumen occupies the lower end of the range of heavy crude oils and is sometimes referred to as ultra-heavy crude oil. "Oil sands" is a term applied by the Government of Alberta to a particular geographical area of the province of Alberta that contains concentrations of bituminous sands as well as deposits of other heavy crude oil. Bituminous sands are an unconsolidated mixture of sand, clay, water, and bitumen.

In this area, bitumen is extracted from open-pit mined oil sands or from in-situ bitumen operations using thermal extraction techniques. The emissions from in-situ bitumen extraction are included in the UOG study (CAPP, 2005a). Fugitive emissions from the mining, processing and upgrading of bitumen and heavy oil are taken from two separate reports: *An Inventory of GHGs, CACs, and H_2S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP, 2006), prepared by Clearstone Engineering Ltd. for CAPP (referred to hereafter as the bitumen study), and an update to the study that was completed in 2017 by Clearstone for ECCC titled *An Inventory of GHGs, CACs, and Other Priority Emissions by the Canadian Oil Sands Industry: 2003 to 2015* (ECCC, 2017) (referred to hereafter as the oil sands study).

In general, the bitumen study (CAPP, 2006) is the basis for the 1990–2003 fugitive emissions estimates, and the oil sands study (ECCC, 2017) is the basis for the 2004–2023 fugitive emission estimates for the OS/HOU industry. The major emission sources in the OS/HOU industry includes:

- process emissions from the steam reforming of natural gas to produce hydrogen for upgraders;
- CH_4 present in the oil sands deposits that is released during mining, mine dewatering and ore handling activities;
- volatilization of hydrocarbons from the exposed oil sands and during transport and handling of the oil sands;
- biogenic gas formation (primarily CH_4) in tailings ponds;
- volatilization and decomposition of residual bitumen and diluent, which carry through to the tailings ponds;
- fugitive equipment leaks, venting, flaring and storage losses at ore preparation, extraction and upgrader plants and their associated utility and cogeneration plants;
- spills and accidental releases;
- secondary sources, such as sewage treatment facilities, landfills, onsite construction and fabrication activities, motor vehicle fleets, corporate aircraft, and boats and dredges used on the tailings ponds.

Bitumen Study: 1990–2003 Emission Estimates

The bitumen study (CAPP, 2006) is a compilation of the individual Tier 3 inventories of facilities involved in the OS/HOU industry from 1990 to 2003. Table A3.2–31 lists the OS/HOU facilities included in the study.

The facility boundaries were determined to ensure that all target emissions, including those from cogeneration facilities, were included.

4 Enbridge Gas New Brunswick. 2010. Personal communication (email from Nicholson L, Communications Coordinator, Enbridge Gas New Brunswick, to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated December 7, 2010).

5 Heritage Gas. 2010. Personal communication (email from Bracken J, President, Heritage Gas to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated December 7, 2010).

Table A3.2–31 List of Oil Sands and Heavy Oil Upgrading Facilities in the Bitumen Study (CAPP, 2006)	
Operator	Facility Name
Husky Energy Inc.	Lloydminster Upgrader
Consumer's Co-operative Refineries Ltd.	Regina Upgrader
Suncor Energy Inc.	Tar Island
Syncrude Canada Ltd.	Mildred Lake and Aurora

The bitumen study (CAPP, 2006) used emissions from individual facility reports, where available. These emissions were verified against inventories and data reported to Alberta Environment. When this was not possible, emissions were estimated based on available activity data and EF data. There were two methods for estimating emissions. The first method—the EF method—uses specific activity data and standard EFs. If no activity data were available, the EF ratio technique was applied. Refer directly to the bitumen study (CAPP, 2006) for a discussion of the specific methodologies.

The following sources were used to estimate emissions:

- facility operator information
- energy statistics published by the Alberta Energy Regulator (AER)
- source emission monitoring results reported to Alberta Environment
- data from company submissions to the Voluntary Challenge Registry
- environmental impact assessment files as part of recent energy development applications in the OS/HOU industry
- open literature

Consult the bitumen study (CAPP, 2006) for more details.

Oil Sands Study: 2003–2024 Emission Estimates

The oil sands study (ECCC, 2017) is a facility-based Tier 3 emissions inventory for the OS/HOU industry completed for the 2015 reference year. It was used as the basis for extrapolating emissions both forwards and backwards in time. Where facility emission reports were available from operators, extrapolation was not required, and actual emissions were used. These emission records were verified by Clearstone Engineering Ltd. Table A3.2–32 is a list of the OS/HOU facilities included in the study.

The Regina Upgrader operated by Consumers' Co-operative Refineries Limited was excluded from the oil sands study because it is defined strictly as a refinery even though it does upgrade some heavy crude oil. The refinery began operation in 1935 and added upgrading capabilities in 1988. It was included in the bitumen study (CAPP, 2006) due to its capabilities to upgrade heavy crude oil. Fugitive emissions for this facility are estimated using the refinery model (see section A3.2.2.3).

In 2016, the Horizon liquid extraction plant operated by Inter Pipeline Offgas Ltd. came online. Emissions from this facility were estimated using emissions data from the Suncor liquid extraction plant (ECCC, 2017) and facility-level activity data (AER, 1990–) for the two facilities. This method is justified due to the similar operations at the two facilities. In late 2017, the Fort Hills mine started operations. Emission estimates for this facility were developed using emissions data reported to the GHG Reporting Program (GHGRP) (ECCC, n.d.).

Depending on when each facility commenced operation, emissions were estimated using data from either the bitumen study (CAPP, 2006), the oil sands study (ECCC, 2017), or both. Table A3.2–33 shows the study used to estimate emissions for each year of the time series for each facility.

Table A3.2–32 List of Oil Sands and Heavy Oil Upgrading Facilities in the ECCC Bitumen Study (ECCC, 2017)		
Operator	Facility Name	Oil Sands Operations
Suncor Energy Inc.	Millennium & Steepbank Mines and Upgrader	Integrated Mining and Upgrading
Syncrude Canada Ltd.	Mildred Lake & Aurora Mines and Upgrader	
Canadian Natural Resources Ltd.	Horizon Mine and Upgrader	
Husky Energy Inc.	Lloydminster Upgrader	Upgrading
Shell Canada Energy	Scotford Upgrader	
Nexen Energy ULC	Long Lake Upgrader	
Imperial Oil Resources	Kearl Mine	Mining and Ore Processing
Canadian Natural Upgrading Ltd.	Muskeg River and Jackpine Mines	
Aux Sable Canada Ltd.	Heartland Offgas Plant	Hydrocarbon Liquids Extraction
Inter Pipeline Offgas Ltd.	Suncor Liquids Extraction Plant	

Table A3.2–33 **Basis of Emission Estimates for Each Facility in the Oil Sands and Heavy Oil Upgrading Industry**

Operator	Facility Name	Bitumen Study	Oil Sands Study
Suncor Energy Inc.	Millennium & Steepbank Mines and Upgrader	1990–2003	2004–2024
Syncrude Canada Ltd.	Mildred Lake & Aurora Mines and Upgrader	1990–2003	2004–2024
Husky Energy Inc.	Lloydminster Upgrader	1992–2003	2004–2024
Canadian Natural Upgrading Ltd.	Muskeg River and Jackpine Mines	-	2002–2024
Shell Canada Energy	Scotford Upgrader	-	2003–2024
Inter Pipeline Offgas Ltd.	Suncor Liquid Extraction Plant	-	2003–2024
Canadian Natural Resources Ltd.	Horizon Mine and Upgrader	-	2008–2024
Nexen Energy ULC	Long Lake Upgrader	-	2009–2024
Aux Sable Canada Ltd.	Heartland Offgas Plant	-	2011–2024
Imperial Oil Resources	Kearl Mine	-	2013–2024
Inter Pipeline Offgas Ltd.	Horizon Liquid Extraction Plant	Emission estimates for 2016–2024 were developed using emissions data for the Suncor Liquid Extraction Plant (ECCC, 2017) and facility level activity data (AER, 1990–).	
Fort Hills Energy Corporation	Fort Hills Mine	Emission estimates for 2017–2024 were developed from data reported to the Greenhouse Gas Reporting Program (ECCC, n.d.).	

Methodology for Extrapolating Emission Estimates

The oil sands model provides emission estimates for the OS/HOU industry for 2003–2024 by multiplying base year emissions data (i.e., 2015) by the ratio of the activity data for the non-inventoried year to that of the base year, as shown in Equation A3.2–19. The base year emissions data were taken from the oil sands study (ECCC, 2017).

Equation A3.2–19

$$ER_{i,j}^{k} = ER_{i,j}^{baseYr} \times \left(\frac{AF_{j}^{k}}{AF_{j}^{baseYr}} \right)$$

$ER_{i,j}^{k}$ = emission rate of compound i, source j, and year k, t/year

$ER_{i,j}^{baseYr}$ = base year (e.g., 2015) emission rate for compound i and source j, t/year

AF_{j}^{k} = activity values for source j and year k

AF_{j}^{baseYr} = base year (e.g., 2015) activity factor for source j

Activity Data

Table A3.2–34 lists the activity data used to estimate fugitive emissions for each oil sands operation and emission subcategory.

A3.2.2.6. Abandoned Oil and Gas Wells

When an oil or gas well reaches the end of its productive life, the well operator is required to properly abandon the well by removing all the equipment and plugging the well. This is done to prevent gas leakage from the well and to prevent the migration of oil and gas to the surrounding strata. However, CH_4 can be emitted into the atmosphere even when well abandonment best practices are followed. Additionally, abandoned wells that were not properly decommissioned exist. There are several reasons for this, including abandonment prior to the enactment of regulations and bankruptcy of the well owner.

There are two main categories of abandoned wells: plugged and unplugged wells. Unplugged wells are wells without recent production (i.e., inactive, temporarily abandoned/suspended or dormant) or without an operator (i.e., orphaned wells). Plugged wells are wells that have been plugged with cement or any mechanical plug to prevent migration of fluid. Emissions result from both plugged and unplugged wells, but emissions from unplugged wells are significantly higher than emissions from plugged wells. Emissions also vary depending on the type of production, which the approach described here reflects by differentiating production types using available historical well information.

Table A3.2–34 **Activity Data Required for the Oil Sands Model**

Oil Sands Operation	Source Category	Subcategory	Activity Data for Extrapolation
Hydrocarbon Liquids Extraction	Flaring and Incineration	All	Process Gas Receipts (AER, 1990–)
	Fugitive	Equipment Leaks	
	Venting	All	
Mining and Ore Processing	Flaring and Incineration	All	Crude Bitumen Production (AER, 1990–)
	Fugitive	Equipment Leaks	
		Exposed Mine Face	
		Other	
		Storage Losses	
		Tailings Ponds	
	Process Emissions	Sulphur Recovery	
	Venting	All	
Upgrading	Flaring and Incineration	All	Synthetic Crude Oil Production (AER, 1990– ; Husky Energy Inc., 1998–2019; Cenovus Energy, 2021–)
	Fugitive	Equipment Leaks	
		Other	
		Spills and Pipeline Ruptures	
		Storage Losses	
	Venting	All	
	Process Emissions	Sulphur Recovery	
		H_2 Production	

Methodology

A Tier 1 approach was used to estimate emissions from abandoned oil and gas wells using Equation A3.2–20.

Equation A3.2–20

$$ER_{i,j}^{k} = \sum_{j=1}^{n} EF_{i,l} \times WellCount_{j,l}^{k}$$

$ER_{i,j}^{k}$ = emission rate of compound i, province j and year k, tonnes/year

$EF_{i,l}$ = emission rate per abandoned well for compound i and well type l, tonnes/year

$WellCount_{j,l}^{k}$ = well count for province j, well type l and year k

Emission Factors

A combination of region-specific CH_4 EFs are used in this approach. The EFs were developed from the results of several field studies conducted across Canada and the United States, all of which involved direct measurements of emissions from abandoned wells. The collective geographic coverage of these studies allowed them to provide both national-level and specific provincial-level EFs for abandoned wells in Canada. The national-level EFs for Canada were developed by Williams et al. (2020) using results from well measurements conducted in British Columbia and New Brunswick, in addition to several U.S. jurisdictions. The inclusion of available measurement data from the U.S. provides a larger, more representative sample of abandoned well emissions in North America. The Williams study also provided EFs for the province of British Columbia specifically. Subsequent measurement campaigns in Ontario (El Hachem & Kang, 2022) and Alberta (Bowman et al., 2022) have also provided EFs for abandoned wells in those provinces. This approach uses the provincial-level EFs to estimate emissions from applicable well types in British Columbia, Alberta, and Ontario, and applies the national-level EFs from Williams et al. to all remaining abandoned wells in Canada.

Table A3.2–35 shows the EFs used for estimating emissions for abandoned oil and gas wells, including both production wells and non-producing wells used for injection, disposal, or other ancillary purposes. The EFs are presented in terms of plugging status (i.e., plugged or unplugged) and location (i.e., onshore or offshore). For provinces where limited data is available on the well-plugging status, the EF for unknown plugging status is used.

Table A3.2–35 **Emission Factors for Abandoned Oil and Gas Wells**

Province / Territory	Well Type	Plugging Status	Location	Value (kg CH_4/well/yr)	Uncertainty
AB	Crude oil	Plugged	Onshore	2.61	-75% to 89%
		Unplugged		13.8	-89% to 129%
	Natural gas	Plugged		1.49	-132% to 232%
		Unplugged		277	-99% to 186%
	Other	Plugged		46.9	-100% to 181%
		Unplugged		5.92	-101% to 201%
BC	Crude oil	Plugged	Onshore	0.001	-100% to 200%
		Unplugged		0.849	-100% to 195%
	Natural gas	Plugged		6.07	-85% to 151%
		Unplugged		38.8	-100% to 196%
	Other	Plugged		46.9	-100% to 181%
		Unplugged		2.24	-98% to 165%
MB	Crude oil	Plugged	Onshore	2	-74% to 100%
		Unplugged		37.6	-53% to 64%
NB	Crude oil	Plugged	Onshore	2	-74% to 100%
		Unplugged		37.6	-53% to 64%
	Natural gas	Plugged		6.07	-85% to 151%
		Unplugged		170	-81% to 141%
NL	Crude oil	Plugged	Offshore	0.04	-74% to 100%
		Unplugged		0.752	-53% to 64%
	Natural gas	Plugged		0.1214	-85% to 151%
NS	Crude oil	Plugged	Offshore	0.04	-74% to 100%
	Natural gas	Plugged		0.1214	-85% to 151%
NT	Crude oil	Unknown	Onshore	2	-74% to 100%
	Natural gas	Unknown		123	-100% to 200%
ON	Crude oil	Plugged	Onshore	2	-74% to 100%
		Unplugged		0.0674	-98% to 172%
	Natural gas	Plugged		8.15	-88% to 157%
		Unplugged		94.1	-68% to 84%
	Crude oil	Plugged	Offshore	0.04	-74% to 100%
	Natural gas	Plugged		0.163	-88% to 157%
		Unplugged		1.882	-68% to 84%
QC	Other	Plugged	Onshore	46.9	-100% to 181%
SK	Crude oil	Plugged	Onshore	0.11	-95% to 143%
		Unplugged		64.2	-56% to 68%
	Natural gas	Plugged		6.07	-85% to 151%
		Unplugged		109	-88% to 144%
	Other	Plugged		46.9	-100% to 181%
		Unplugged		0.116	-88% to 132%
YT	Natural gas	Plugged	Onshore	6.07	-85% to 151%
		Unplugged		170	-81% to 141%

Notes:
Unless otherwise indicated, emission factors were adopted directly from Klotz et al. (2025).
Other = service, injection, disposal, or other ancillary wells not attributed to crude oil or natural gas production.
Crude oil emission factors are applied to abandoned wells attributed to all types of crude oil production.
Offshore emission factors were developed by multiplying corresponding onshore emission factors by a factor of 0.02, which assumes 98% of methane emitted from offshore wells is dissolved in marine water (IPCC, 2019).

Activity Data

Annual counts of abandoned wells by province were developed using the data sources shown in Table A3.2–36.

The count of abandoned wells for each year of the time series was further subcategorized into well type (natural gas, crude oil, or other), well status (plugged, unplugged or unknown) and location (onshore or offshore). Several assumptions were made to assign the plugging status of a well.

- An unplugged well is a well with a well status of suspended or inactive.
- A plugged well is a well with a well status of abandoned, downhole abandoned, or junked and abandoned.
- Any offshore well that is abandoned or not producing for an extended period is considered plugged.
- Where the plugging status could not be determined, it was considered unknown, and the corresponding EF was used to estimate emissions.

For the Northwest Territories and Nova Scotia, this level of disaggregation of activity data was not possible. For the Northwest Territories, there is no publicly available data on abandoned wells for oil and gas operations, and it was therefore difficult to evaluate the number of abandoned wells. For this reason, data from CAPP (CAPP, n.d. [a]; [b]) was used to estimate the abandoned well count. It was assumed that the abandoned well count is the difference between the total number of wells drilled in the province and the number of oil and gas wells completed in the province. Additionally, it is assumed that the average lifespan of completed wells is 20 years. For Nova Scotia, monthly production data by well was used to determine the abandonment date of the well. It was assumed that wells were abandoned six months after last production.

For the remaining provinces (i.e., Alberta, British Columbia, Saskatchewan, Yukon, Manitoba, New Brunswick, Newfoundland and Ontario), sufficient information was available in the provincial datasets to determine the number of abandoned wells by well type, well status and location.

Occasionally, the well type was not known. In this case, the emissions from these wells are allocated to oil or gas based on the known ratio of abandoned oil to gas wells in the same year. Similarly, emissions from non-production (i.e., other) wells are also allocated to oil or gas based on the ratio of oil to gas production wells in the same year with the same well status (plugged, unplugged, or unknown).

As of 2024, the estimated total number of abandoned oil and gas wells in Canada was approximately 426 000, of which 22% were considered unplugged.

Table A3.2–36 **Activity Data Required for Abandoned Oil and Gas Wells**

Province / Territory	Source	Publication
AB	Alberta Energy Regulator	ST37: List of Wells in Alberta (AER, n.d. [f])
BC	British Columbia Energy Regulator	Well Surface Hole Locations (BCER, n.d. [i])
SK	Saskatchewan Ministry of Energy and Resources	Abandoned well counts were provided upon request[a]
MB	Manitoba Economic Development, Investment, Trade and Natural Resources	Petroleum Statistics, Unique Well Identifier Key List Report (MB EDITNR, n.d. [d])
ON	Ontario Oil, Gas & Salt Resource Library	Petroleum Well Data (OGSRL, n.d.)
NL	Canada–Newfoundland & Labrador Offshore Energy Regulator	Schedule of Wells Summary (C-NLOER, n.d. [c])
NS	Canada–Nova Scotia Offshore Energy Regulator	Cohasset Panuke production report (C-NSOER, 2019) Sable Offshore production report (C-NSOER, 2019) Deep Panuke production report (C-NSOER, 2019)
YT	Yukon Government: Energy Mines and Resources	Yukon Well Listing (YK, 2020)
NT	CAPP Statistical Handbook	Land, Exploration, Drilling Categories (CAPP, n.d. [b]) • Oil wells completed • Gas wells completed • Wells drilled
QC	Québec Ministère de l'Énergie et des Ressources Naturelles	Rapport sur l'état des puits d'hydrocarbures inactifs au Québec (2021)
NB	New Brunswick Natural Resources and Energy Development	New Brunswick Well Listing (NB NRED, 2020)

Note:
a. Saskatchewan Ministry of Energy and Resources. 2025. Personal communication (email from Lamontagne, S., to Barrigar O., Pollutant Inventories and Reporting Division, Environment and Climate Change Canada, dated October 1, 2025).

A3.2.2.7. Post-meter Fugitives

As described in section A3.2.2.4, the natural gas distribution sector includes emissions occurring up to and including the residential, commercial or industrial meter. Post-meter fugitives are emissions that occur beyond the gas meter including leaks from natural gas appliances in the residential and commercial sectors, leaks from natural gas vehicles, and leakage at power plants and industrial facilities that consume natural gas.

Methodology

A Tier 1 approach was used to estimate post-meter fugitive emissions using Equation A3.2–21.

Equation A3.2–21

$$ER_{i,j,k} = \sum_{j=1}^{n} EF_veh_{i,j} \cdot AD_veh_{j,k} + EF_app_{i,j,k} \cdot AD_app_{j,k} + EF_ind_{i,j,k} \cdot AD_ind_{j,k}$$

$ER_{i,j,k}$	=	emission rate of compound i, province j and year k, tonnes/year
$EF_veh_{i,j}$	=	natural gas-fueled vehicle emission factor for compound i and province j, tonnes/year
$AD_veh_{j,k}$	=	number of natural gas-fueled vehicles in province j and year k
$EF_app_{i,j,k}$	=	residential and commercial natural gas appliance emission factor for compound i, province j and year k, tonnes/year
$AD_app_{j,k}$	=	number of residential and commercial natural gas appliances in province j and year k
$EF_ind_{i,j,k}$	=	emission factor for leaks at industrial plants and power stations for compound i, province j and year k, tonnes/10^6 m^3 natural gas consumption
$AD_ind_{j,k}$	=	volume of natural gas consumed at industrial plants and power stations in province j and year k, 10^6 m^3

Emission Factors

Tier 1 EFs are provided in the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2019) based on an average density of 0.72 kg/m^3, energy content of 35 MJ/m^3, a CO_2 content of 0.9% and a non-methane volatile organic compound (NMVOC) content of 2.8%. These EFs were adapted to Canadian specific circumstances using annual average gas compositions, densities, and energy contents for each province/territory to align with the marketable natural gas properties used to estimate natural gas combustion emissions. See Annex 6, section A6.1.1 for more details on the data used for marketable natural gas combustion. Note that the IPCC default EF of 0.3 kg CH_4 per vehicle for natural gas-fueled vehicles was not modified. Post-meter fugitive CH_4 EFs for residential and commercial natural gas appliances are presented in Table A3.2–37, while Table A3.2–38 provides post-meter fugitive CH_4 EFs for leaks at industrial plants and power stations.

Note that post-meter fugitive CO_2 emissions are not estimated since an oxidation factor of 1 is used when calculating natural gas combustion emissions (Annex 3.1).

Activity Data

Table A3.2–39 presents the activity data and sources used to estimate emissions from post-meter fugitives.

The number of natural gas-fueled vehicles is taken from ECCC internal vehicle fleet statistics for each province and year.

The number of natural gas furnaces, hot water heaters, clothes dryers and ranges in the residential sector were taken from data published by NRCan (2024) for the years 2000–2022 by province/territory. Note that after review, appliance count data for Prince Edward Island and Newfoundland and Labrador were not used since neither province has a natural gas distribution system and natural gas is not transported to either island for residential consumption. Similarly, there is no natural gas consumption in Yukon or Nunavut. Appliance count data for New Brunswick, Nova Scotia and Northwest Territories were not used as the average number of appliances per residential customer ranged from 5 to 22 and was considered unrealistic considering the average of all other provinces was 2.64. Appliance counts for all other provinces were used as reported in the NRCan (2024) data. Appliance counts for 1990–1999 and 2023–2024 were extrapolated based on the annual change in the number of natural gas customers by province. Similarly, appliance counts for New Brunswick, Nova Scotia and Northwest Territories were estimated using the national average number of appliances per residential customer (i.e., 2.64) and the annual number of residential natural gas customers from StatCan data (StatCan, n.d. [i], n.d. [j]).

Table A3.2–37 **Residential and Commercial Natural Gas Appliance Post-Meter Fugitive Emission Factors by Year and Province/Territory**

Year	CH_4 Emission Factor (kg/appliance)							
	NS & NB	QC	ON	MB	SK	AB	BC	NT
1990–1998	3.42	3.39	3.39	3.38	3.36	3.51	3.44	4.00
1999	3.39	3.37	3.37	3.36	3.34	3.46	3.41	4.00
2000	3.37	3.35	3.35	3.34	3.33	3.42	3.38	4.00
2001	3.34	3.33	3.33	3.33	3.31	3.37	3.35	4.00
2002	3.32	3.31	3.31	3.31	3.30	3.33	3.32	4.00
2003	3.30	3.29	3.29	3.29	3.28	3.28	3.30	4.00
2004	3.27	3.27	3.27	3.27	3.26	3.24	3.27	4.00
2005	3.25	3.25	3.25	3.25	3.25	3.19	3.24	4.00
2006	3.26	3.26	3.26	3.26	3.26	3.18	3.25	4.00
2007	3.26	3.26	3.26	3.27	3.27	3.19	3.24	4.00
2008	3.26	3.26	3.26	3.26	3.26	3.19	3.24	4.00
2009	3.27	3.27	3.27	3.27	3.27	3.19	3.25	4.00
2010	3.28	3.28	3.27	3.28	3.28	3.20	3.26	4.00
2011	3.28	3.28	3.28	3.28	3.27	3.20	3.27	4.00
2012	3.27	3.27	3.26	3.28	3.04	3.19	3.26	4.00
2013	3.27	3.27	3.26	3.28	3.04	3.19	3.25	4.00
2014	3.26	3.27	3.25	3.28	3.02	3.19	3.23	4.00
2015	3.24	3.24	3.24	3.25	3.02	3.18	3.20	4.00
2016	3.25	3.25	3.24	3.26	3.18	3.17	3.19	4.00
2017	3.24	3.22	3.24	3.24	3.13	3.16	3.17	4.00
2018–2024	3.23	3.21	3.23	3.23	3.14	3.16	3.16	4.00

Table A3.2–38 **Post-Meter Fugitive Emission Factors for Leaks at Industrial Plants and Power Stations by Year and Province/Territory**

Year	CH_4 Emission Factor (kg/10^6 m^3 natural gas consumption)							
	NS & NB	QC	ON	MB	SK	AB	BC	NT
1990–1998	366	388	388	389	384	394	404	400
1999	370	389	389	389	385	392	403	400
2000	373	389	389	390	386	391	401	400
2001	377	389	390	390	387	390	400	400
2002	380	390	390	390	388	388	399	400
2003	384	390	390	391	389	387	397	400
2004	388	391	391	391	390	386	396	400
2005	391	391	391	391	391	384	394	400
2006	394	393	394	394	394	379	395	400
2007	395	394	394	395	395	382	395	400
2008	395	394	394	395	395	384	395	400
2009	397	396	396	397	397	385	397	400
2010	398	398	398	399	399	386	399	400
2011	399	399	399	399	398	385	401	400
2012	399	399	398	400	350	386	399	400
2013	401	400	400	402	350	386	397	400
2014	399	400	397	401	348	388	395	400
2015	397	396	398	397	347	385	392	400
2016	400	398	401	400	380	384	390	400
2017	398	395	401	398	372	384	387	400
2018–2024	397	394	400	395	373	383	385	400

Table A3.2–39 **Summary of Post-Meter Fugitive Activity Data and Sources**

Post-Meter Segment	Publisher	Publication	Activity Data
Natural gas-fueled vehicles	Environment and Climate Change Canada	Unpublished data	Number of natural gas vehicles
Residential and commercial appliances	Natural Resources Canada (NRCan)	Comprehensive Energy Use Database – Residential Sector (NRCan, n.d.)	Heating system stock by building type and heating system type Water heater stock by building type and energy source Appliance stock by appliance type and energy source – Clothes Dryer Appliance stock by appliance type and energy source – Range
	Statistics Canada	Table 25-10-0033-01 – Natural Gas, monthly sales (Statistics Canada, n.d. [i])	Number of residential and commercial customers
		Table 25-10-0059-01 – Canadian monthly natural gas distribution (Statistics Canada, n.d. [j])	Number of residential and commercial customers
		Table 17-10-0005-01 – Population estimates on July 1st, by age and sex (Statistics Canada, n.d. [k])	Northwest Territories population
	Northwest Territories Bureau of Statistics (StatsNWT)	Population estimates by community – Norman Wells (StatsNWT, 2022)	Norman Wells population
	Northwest Territories Department of Infrastructure (NWT DOI)	Unpublished data (NWT DOI, n.d.)	Annual fossil fuel and synthetic natural gas consumption
Industrial plants and power stations	Statistics Canada	Report on Energy Supply and Demand in Canada (Statistics Canada, n.d. [b])	Natural gas consumption for the following sectors: Agriculture Aluminum and non-ferrous metal manufacturing Cement manufacturing Chemicals and fertilizers manufacturing Construction Electricity by utilities Electricity by industry[a] Iron and steel manufacturing Other manufacturing Public administration Pulp and paper manufacturing Total mining and oil and gas extraction[a]

Note:
a. Excluding natural gas consumed at oil and gas facilities or oil and gas industry owned cogeneration plants.

The number of residential and commercial natural gas customers were missing for the years 1990–2011 in Nova Scotia, 1990–2006 in New Brunswick, and 1990–2015 in the Northwest Territories. The number of customers in Nova Scotia and New Brunswick were therefore extrapolated based on the natural gas distribution pipeline length (StatCan, 2024). The circumstance in the Northwest Territories is more complex. Only the two small communities of Norman Wells and Inuvik have used natural gas in the residential and commercial sectors. The gas distribution system in Norman Wells stopped providing service to customers in 2014. In Inuvik, natural gas is produced locally from the Ikhil field, which began production in 1999 (StatsNWT, n.d.). However, in 2014, the distribution system stopped providing pure natural gas in its system due to declining production. “Synthetic natural gas”, which is a mixture of propane and air, is used to supplement the natural gas produced locally. The fraction of fossil natural gas ranges from approximately 24% to 40% depending on the year. Therefore, the number of natural gas customers from 1990 to 1998 is estimated based on the annual population change in Norman Wells (StatsNWT, 2022; StatCan, n.d. [k]). Distribution pipeline length data (StatCan, 2024) is available from 1999 to 2022 and is used to estimate the number of customers from 1999 to 2015. Finally, the number of customers from 2014 onwards is adjusted to reflect the fraction of fossil natural gas distributed to customers (NWT DOI, n.d.).

The number of commercial natural gas appliances is estimated using the annual number of commercial natural gas customers by province/territory and the national average number of residential appliances per customer of 2.64.

Lastly, natural gas consumption data is taken from the RESD for the sectors shown in Table A3.2–33. Since fugitive emissions at oil and gas facilities are already estimated using the methods discussed previously, any natural gas consumption occurring at oil and gas facilities is excluded from the post-meter fugitive emissions calculations.

A3.2.2.8. Flaring and Venting Special Case – Avoiding Double Counting

As defined in the RESD, producer consumption "is the consumption by the producing industry of its own produced fuel—for example refined petroleum products consumed by the refined petroleum product industry, or natural gas used in the field, flared and waste, field uses, gathering uses, plant uses and metering adjustments." StatCan determines natural gas producer consumption volumes using administrative data provided by provinces and territories.

Combustion emissions from the consumption of producer-consumed fuels are estimated using the fuel volumes reported in the RESD (see Annex 3.1). Since flaring and venting emissions are estimated separately using the various fugitive models and reported as fugitives, it is necessary to subtract the volume of flared and vented gas, and the associated emissions, from the combustion estimates to avoid double counting, as described in section A3.1.4.1.2.

The provinces that have producer consumption of natural gas values in the RESD accounted for 99% of total crude oil production in Canada in 2024 and 99.9% of gross natural gas production. The volumes of gas reported as flared and vented are subtracted from producer consumption. In situations where flaring or venting emissions are estimated for a particular province that has no producer consumption reported in the RESD, the flaring emissions and associated natural gas volumes are not subtracted to ensure there is no underestimation of emissions.

Estimates for flaring emissions from petroleum refining are calculated as described in section A3.2.2.3. The volume of fuel flared is subtracted from producer consumption as required.

A3.3. Methodology for the Industrial Processes and Product Use Sector

The Industrial Processes and Product Use (IPPU) sector covers greenhouse gas (GHG) emissions arising from non-energy-related industrial activities. Categories included in this sector are Mineral Industry, Chemical Industry, Metal Industry, Non-energy Products from Fuels and Solvent Use, Electronics Industry, Product Uses as Substitutes for Ozone Depleting Substances (ODS), and Other Product Manufacture and Use. Chapter 4 presents methodological issues for each of these categories. This section of Annex 3 provides additional details on the methodologies used to estimate emissions in the following IPPU categories:

- Metal Industry – Carbon dioxide (CO_2) emissions from Iron and Steel Production
- CO_2 emissions from Non-Energy Products from Fuels and Solvent Use
- Hydrofluorocarbon (HFC) emissions from Product Uses as Substitutes for ODS
- Other Product Manufacture and Use – Sulfur Hexafluoride (SF_6) emissions from Electrical Equipment

A3.3.1. CO_2 Emissions from Iron and Steel Production (CRT Category 2.C.1)

Canadian Iron and Steel Manufacturing Facilities

The Canadian steel sector consists of 14 facilities, namely four integrated mills and 10 non-integrated mills (nine mini-mills and one ilmenite mill). Of the 14 facilities, eight are located in Ontario (including four integrated mills), three in Quebec and one in each of Alberta, Saskatchewan, and Manitoba. In 2013, U.S. Steel Canada – Hamilton Works closed its iron and steel producing facilities; however, it still operates its coke oven battery process. Table A3.3–1 provides a list of these facilities along with the type of manufacturing processes used.

Table A3.3–1 **Iron, Steel and Ilmenite Smelting Facilities**

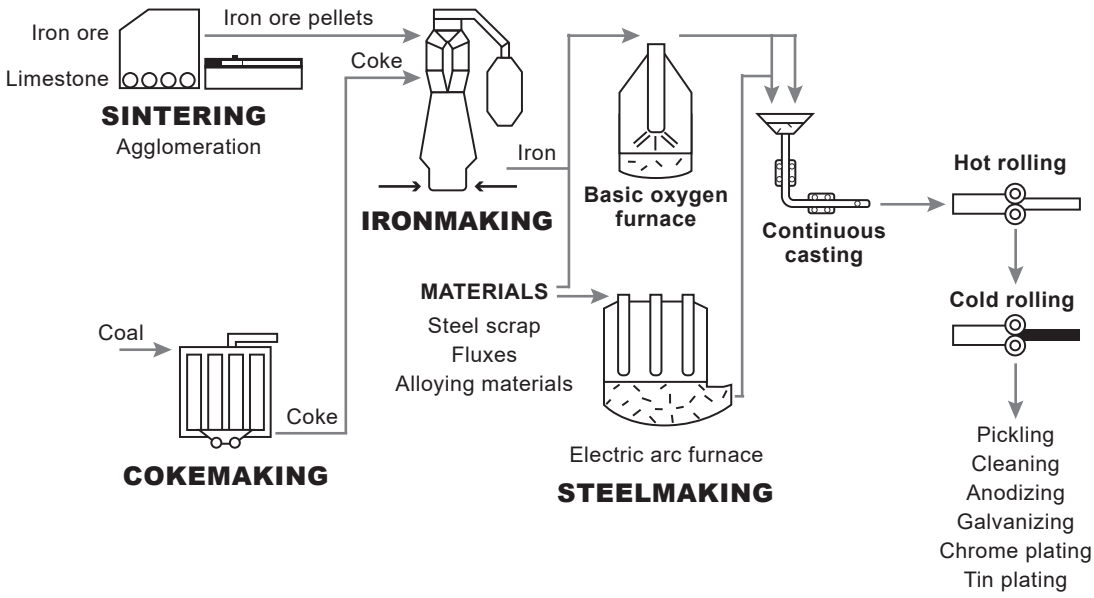
Integrated Mills	
ArcelorMittal Dofasco	Hamilton, ON
Essar Steel Algoma	Sault Ste. Marie, ON
U.S. Steel Canada – Hamilton Works	Hamilton, ON
U.S. Steel Canada – Lake Erie Works	Nanticoke, ON
Mini-Mills[a, b]	
AltaSteel Ltd.	Edmonton, AB
ArcelorMittal Contrecoeur	Contrecoeur, QC
ArcelorMittal Contrecoeur – Ouest	Contrecoeur, QC
Valbruna ASW Steel	Welland, ON
EVRAZ North America	Regina, SK
Gerdau Ameristeel – Cambridge	Cambridge, ON
Gerdau Ameristeel Manitoba	Selkirk, MB
Gerdau Ameristeel – Whitby	Whitby, ON
Ivaco Inc.	L'Orignal, ON
Ilmenite Smelting Facility	
Rio Tinto – Fer et Titane Inc.	Sorel-Tracy, QC

Notes:
Information adapted from ECCC (2017).
a. Removed Mini-mill: Hamilton Specialty Bar Corp., Hamilton, ON, which closed permanently in 2018.
b. Added ASW Steel, Welland, ON, which is a small mini-mill that was excluded from the *Canada Gazette* notice.

Canadian Iron and Steel Process Technologies

Steel is produced in Canada by two main steelmaking processes (see Figure A3.3–1): basic oxygen furnaces and electric arc furnaces. The basic oxygen furnace is used in integrated mills in conjunction with coke making, sintering, and blast furnace iron-making operations. Integrated mills, which smelt iron ore and melt scraps, produce the greatest diversity of products, including bars, rods, structural shapes, plates, sheets, pipes and tubes, and wire rods. Although electric arc furnace technology is gaining importance, it is usually used in non-integrated mills (mini-mills or specialty steel mills) fed by scrap or direct reduced iron to produce a wide product range of carbon and alloy steels. ArcelorMittal Dofasco Inc. operates the only integrated steel plant in Canada that produces part of its steel by the electric arc furnace process. ArcelorMittal Contrecoeur operates the only Canadian steel mill that produces and uses direct reduced iron as part of its raw material feed. Ancillary or secondary steelmaking processes that are common to both integrated and non-integrated steelmaking include ladle metallurgy, continuous casting, hot forming, cold forming and finishing.

Figure A3.3–1 **Canadian Steelmaking Processes**



A3.3.2. CO_2 Emissions from Non-Energy Products from Fuels and Solvent Use (CRT category 2.D.3)

Industrial activities in Canada that use fuel for non-energy purposes (e.g., feedstock material) include ammonia production, petrochemical production, non-ferrous mining and processing, iron and steel production, and other chemical industries.

CO_2 emissions from non-energy use of hydrocarbons—which are not reported elsewhere in the inventory—are reported under the category of Non-energy Products from Fuels and Solvent Use. The emission estimates are based on non-energy fossil fuel use data collected by Statistics Canada (*Report on Energy Supply and Demand in Canada* [RESD]) (Statistics Canada, n.d.) and aggregated by fuel type (e.g., natural gas, coke, butane, ethane, etc.) at the provincial/territorial level. Statistics Canada does not disaggregate this fuel data by industry or industrial activity, which means that without other supporting information, it is not possible to allocate this fuel data to a specific industry.

In some cases, Canada has obtained supporting information (e.g., through studies, surveys, other data sources, etc.) such that all or part of the non-energy fuel use data can be disaggregated and allocated to the appropriate source category. Allocation of non-energy fuel use data to specific source categories is possible for the following industrial activities:

- natural gas used to produce hydrogen for ammonia production
- various fuels used as feedstock in the production of petrochemicals (methanol and ethylene)
- carbon anodes used to electrically reduce alumina to aluminium in the aluminium production process
- coke used in iron and steel production
- lubricating oils combusted in off-road two-stroke engines

For these industrial activities, known or estimated non-energy fuel types and quantities are used in estimating emissions. The known or estimated fuel quantities are then subtracted from the RESD non-energy fuel use data, and the remaining (residual) fuel quantities represent the non-energy fuel used by other industries. This avoids double counting of emissions and improves transparency in the inventory.

To estimate emissions, average national level CO_2 emission factors are available for each fuel type and are applied to the total non-energy fuel quantities (or residual quantities, if applicable) at the provincial/territorial level. Provincial/territorial estimates are then aggregated to provide a national total for CRT source category 2.D, Non-energy Products from Fuels and Solvent Use.

The following describes the methods used to estimate emissions for each category of non-energy use of fossil fuels (gaseous, solid and liquid fuels) and explains how emissions are disaggregated and allocated to specific source categories (previously mentioned) in order to avoid double counting of emissions.

Gaseous Fuels

The only gaseous fuel considered in this category is natural gas. Natural gas can be used for methanol and thermal carbon black production; however, a large portion is used in the SMR process to manufacture ammonia.

CO_2 emissions from ammonia production and methanol production are estimated and reported in CRT source categories 2.B.1 and 2.B.8.a, respectively. The quantities of natural gas used as feedstock in ammonia and methanol manufacturing are subtracted from the RESD's overall non-energy natural gas to determine the remaining (residual) quantity of non-energy natural gas.

Based on a study conducted in 2005 (Cheminfo Services, 2005a), a CO_2 emission factor for the residual non-energy use of natural gas was developed (38 g CO_2/m^3) and applied to the residual non-energy natural gas quantity to estimate emissions from this source.

Note that emissions arising from non-energy use of natural gas to produce hydrogen in the oil refining and bitumen industries are allocated to the Energy sector of the inventory.

Solid Fuels

Solid fuels considered in the Non-energy Products from Fuels and Solvent Use category are:

- Canadian bituminous coal
- sub-bituminous coal
- foreign bituminous coal
- lignite
- anthracite
- metallurgical coke
- petroleum coke

CO_2 emissions from the non-energy use of these solid fuels are determined by applying the fuel-, province- and/or year-specific emission factors presented in tables A6.1–7, A6.1–10 and A6.1–11 of Annex 6 for petroleum coke, coal and metallurgical coke (coke from coal), respectively, to the RESD data.

The emission factors used for estimating releases of CO_2 from the non-energy use of coal are the same as those for combustion; it is assumed that 100% of the carbon in these products will eventually be oxidized and emitted as CO_2.

CO_2 emissions resulting from the consumption of electrodes in the aluminium industry are reported in CRT source category 2.C.3, Aluminium Production. A key fuel used to make electrodes for the aluminium industry is petroleum coke. Non-energy coke is also used to make electrodes used in electric arc furnaces in the iron and steel industry (CRT source category 2.C.1, Iron and Steel Production). The quantities of petroleum coke used in the aluminium industry and iron and steel industry are subtracted from the RESD's overall non-energy use of petroleum coke. The CO_2 emissions from the residual non-energy petroleum coke use are calculated by applying the emission factors provided in Table A6.1–7 of Annex 6.

Liquid Fuels

In addition to the emissions from gaseous and solid fuels, CO_2 emissions from the non-energy use of liquid fuels (natural gas liquids (NGLs), oil refinery petrochemical feedstocks and lubricants) are also reported in CRT category 2.D, Non-energy Products from Fuels and Solvent Use.

CO_2 emissions resulting from the use of liquid fuels (feedstock use) in the production of ethylene are estimated and reported in CRT source category 2.B.8.b. The quantities of liquid fuels (specifically propane, butane, ethane, petrochemical feedstocks) used as feedstock in the production of ethylene are subtracted from the RESD's overall non-energy liquid fuels. The remaining quantities of non-energy liquid fuels are multiplied by the corresponding emission factors, as shown in Table A6.2–11 in Annex 6 to estimate CO_2 emissions from this source.

It should also be noted that, owing to the way in which energy statistics are currently collected in Canada, a portion of non-energy use of liquid fuels has been reported under energy use, which is accounted for in the Energy sector.

In the case of the residual non-energy use of NGLs—i.e., residual of petrochemical production use—the emission factors provided in the McCann (2000) study assumes that all the carbon is oxidized and are presented in Table A6.2–11 in Annex 6.

The residual and non-residual non-energy use of petroleum products coming out of the oil refineries (i.e., petrochemical feedstocks, naphthas, lubricants, greases and other petroleum products) also results in CO_2 emissions and is accounted for in the Non-energy Products from Fuels and Solvent Use category. Derivations of the non-energy use emission factors are shown in Table A6.2–11 in Annex 6. To estimate emissions at national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

A3.3.3. HFC Emissions from Product Uses as Substitutes for Ozone Depleting Substances (CRT Category 2.F)

A3.3.3.1. Activity Data

Table A3.3–2 shows the years where there are activity data for bulk HFC imports and exports or sales, the years when the activity data were collected, and the source of the data. Table A3.3–3 shows the years where there are activity data for imported and exported manufactured items containing HFCs, the years when the activity data were collected, and the source of the data.

Table A3.3–2 **Years of Activity Data for Bulk HFC Imports and Exports or Sales, Years of Collection, and Data Source**

Data Year(s)	Data Collection Year	Data Source	Reference
1995	1996	Mandatory survey collected through subsection 16 of Canadian Environmental Protection Act (CEPA) 1988.	EC, 1996
1996–1997	1998	Mandatory survey collected through subsection 16 of CEPA 1988.	EC, 1998
1998	1999	Mandatory survey collected through subsection 16 of CEPA 1988.	EC, 1999
1999–2000	2001	Mandatory survey collected through section 71 of CEPA 1999.	EC, 2001
2001–2003	2005	Voluntary survey collected by Cheminfo Services.	Cheminfo Services, 2005b
2004	2005	Mandatory survey collected through section 71 of CEPA 1999.	EC, 2005
2005–2007	NA & 2006–2008	Mostly interpolated from the 2004 and 2008 activity data. Voluntary surveys were collected by the inventory team for data years 2005–2007 in 2006–2008, respectively and data was integrated for certain distributors.	EC, 2011
2008–2012	2009–2011 & 2014	Annual voluntary surveys were collected by the inventory team for the data years 2008–2010 in years 2009–2011, respectively. A mandatory survey collected through section 71 of CEPA 1999 in 2014 also collected more complete data. When distributor reporting was available in both datasets, the mandatory survey data was used.	EC, 2011; ECCC, 2015a
2013–2015	2016	Mandatory surveys collected through section 71 of CEPA 1999.	ECCC, 2016a, 2016b
2016	NA	Extrapolated from 2015 activity data using proxy variables provided by ECCC's Analysis and Modelling Division.	ECCC, 2025b
2017 onwards	2018 onwards	Mandatory surveys collected through the Ozone-depleting Substances and Halocarbon Alternatives Regulations (ODSHAR) of CEPA 1999.	ECCC, 2023, 2024, 2025a

Note:
NA = Not applicable, since data collection did not occur for the data year(s).

Table A3.3–3 **Years of Activity Data for Imported and Exported Manufactured Items Containing HFCs, Years of Collection, and Data Source**

Data Year	Data Collection Year	Data Source	Reference
1995	NA	Data was extrapolated backwards using the 1996–1998 trend.	NA
1996–1997	1998	Mandatory survey collected through subsection 16 of CEPA 1988.	EC, 1998
1998	1999	Mandatory survey collected through subsection 16 of CEPA 1988.	EC, 1999
1999–2003	NA & 2001	Interpolated using the 1998 and 2004 activity data, with the exception of 1999 and 2000 data on vehicle air-conditioners mandatorily collected through section 71 of CEPA 1999.	EC, 2001
2004	2005	Mandatory survey collected through section 71 of CEPA 1999.	EC, 2005
2005–2007	2006–2008	Annual voluntary surveys collected by the inventory team.	EC, 2011
2008–2010	2009–2011 & 2014	Annual voluntary surveys collected by the inventory team and voluntary additional data collected during the mandatory bulk data survey through section 71 of CEPA 1999.	EC, 2011; ECCC, 2015a
2011–2012	2014	Voluntary additional data collected during the mandatory bulk data survey through section 71 of CEPA 1999 and extrapolations from 2010 activity data using proxy variables provided by ECCC's Analysis and Modelling Division.	ECCC, 2015a
2013–2015	2016	Voluntary additional data collected during the mandatory bulk data survey through section 71 of CEPA 1999 and extrapolations from 2010–2012 activity data using proxy variables provided by ECCC's Analysis and Modelling Division.	ECCC, 2016a, 2016b
2016 onwards	NA	Extrapolations from 2010–2015 activity data using proxy variables provided by ECCC's Analysis and Modelling Division.	ECCC, 2025b

Note:
NA = Not applicable, since data collection did not occur for the data year(s).

A3.3.3.2. Methodology

Canada uses a detailed sector breakdown of HFC sub-applications (Table A3.3–4), requiring that the HFC use data be broken down at this level annually. To meet this requirement, missing data had to be filled in, and data collected at an application level had to be broken down to sub-application levels.

A variety of techniques were used to fill in the data gaps from reporters between voluntary surveys. For instance, when a company did not report in subsequent years, the data were held constant. Another technique employed for years in which no surveys were performed (e.g., imports/exports of manufactured items from 1999 to 2003) or limited survey responses were received (e.g., bulk sales from 2005 to 2007) was the use of linear interpolation to estimate the missing data. Forward and backward extrapolation using data trends or proxy variables were also used to complete the time series. Data is not available on imported and exported manufactured items for years 2011 onwards. Extrapolation using proxy variables provided by the ECCC's Analysis and Modelling Division (ECCC, 2025b) were applied to fill in this data gap. Table A3.3–4 lists the various proxy variables selected on a sub-application basis for the extrapolation process. To meet the requirements of a Tier 2 methodology, ECCC used two approaches to break down the 1995 to 2004 data reported at the application-level to the sub-application level. In a given year, the HFCs reported at an application level were broken down based on the proportions of the corresponding sub-application levels if a large amount of HFCs were reported in those corresponding sub-application levels in the same year. If sufficient breakdown was not available for the year and application level, the breakdown from the closest historical year for the same HFC and application level was used.

For the 2008 to 2012 mandatory survey data, any HFCs reported at an application level were broken down based on the most recent (2004) breakdown. For the 2013 to 2015 data from the mandatory surveys, the HFCs reported at an application level were broken down to sub-application levels based on the 2012 company and/or gas-level breakdowns and, when sufficient information was not available, on the 2004 breakdown. For some of the 2008–2015 data, when bulk importers had initially only reported HFCs (by HFC type) without specifying the associated applications or sub-applications, the surveyed bulk importers were asked to provide, to the best of their knowledge, a list of sub-application levels for the reported HFCs. This list of sub-applications was then used by ECCC to evenly distribute the reported HFC quantities.

For the 2017 to 2024 bulk import and export data collected under the Ozone-depleting Substances and Halocarbon Alternatives Regulations (ODSHAR), all the reported data needed to be broken down to sub-application levels. The most recent available company and/or gas-level breakdowns are used.

When new HFC species were imported or exported in bulk or when new distributors submitted ODSHAR reports, research was conducted to determine the most likely sub-application breakdown. For existing reporters, if the usage of the new HFC species was believed to align with previously imported HFCs for which a breakdown was available (generally HFC-134a), then the existing breakdown was used for the newly reported HFC. Otherwise, HFC use quantities were evenly distributed to a list of the most likely sub-applications based on research.

The Technical Expert Review associated with Canada's 2024 NIR, recommended that the inventory team collect data to achieve more accurate estimates of HFCs within imported and exported manufactured items for 2011 onwards. The inventory team has reached out to the Heating, Refrigeration, and Air-Conditioning Institute (HRAI) to inquire on manufactured item data. Efforts on data sourcing, analysis, and inventory incorporation will continue.

A3.3.3.3. Emission Factors and Lifetimes

In 2013, EC conducted a survey of the air-conditioning and refrigeration manufacturers, industry associations, and service providers to obtain information for developing or selecting emission factors and equipment lifetimes. One of the most successful elements of the study was the preliminary development of country-specific in-service emission factors using data from service providers in Equation A3.3–1.

Equation A3.3–1

$$EF_{IS} = \frac{\textit{Amount of refrigerant purchased, or the average amount added at service calls} \times \textit{number of service calls}}{\textit{Total refrigerant capacity of equipment responsible for servicing}}$$

EF_{IS} = in-service emission factor for air conditioners or refrigerators, fraction

Table A3.3–4 **Canadian HFC Applications and Sub-Applications and Proxy Variables used for Extrapolation**

Application/Sub-Application Description	Proxy Variable Description
Aerosols	
Personal care products	Population
Pharmaceutical products	Population
Medical products	Deflated economic gross output data: Health & Social Assistance (NAICS 62)
Household products	Population
Mining application products	Deflated economic gross output data: Mining (NAICS 212)
Commercial/industrial products	Commercial floor space
Blowing Agent in Foams	
Cushioning – automobiles (seats, roof, etc.)	Deflated economic gross output data: Transportation Equipment (NAICS 336)
Cushioning – other (furniture, mattresses, etc.)	Deflated economic gross output data: Furniture & Related Products (NAICS 337)
Thermal insulation – homes and buildings	Commercial and residential floor space
Thermal insulation – pipes	Commercial and residential floor space
Thermal insulation – refrigerators and freezers	Commercial and residential floor space
Thermal insulation – other (specify)	Commercial and residential floor space
Packaging – food (specify)	Deflated economic gross output data: Food (NAICS 311)
Packaging – non-food (specify)	Deflated economic gross output data: Other Manufacturing (NAICS 339)
Other foam uses (specify)	Deflated economic gross output data: Other Manufacturing (NAICS 339)
Air Conditioning (Original Equipment Manufacture)	
Air conditioner units in motor vehicles	Deflated economic gross output data: Transportation equipment (NAICS 336)
Chillers (specify centrifugal or reciprocating)	Commercial floor space
Residential (air conditioners, dehumidifiers, etc.)	Number of households
Air Conditioning (Service/Maintenance)	
Air conditioner units in motor vehicles	Deflated economic gross output data: Transportation equipment (NAICS 336)
Chillers (specify centrifugal or reciprocating)	Commercial floor space
Residential (air conditioners, dehumidifiers, etc.)	Number of households
Refrigeration (Original Equipment Manufacture)	
Commercial transport	Commercial floor space
Commercial and institutional (retail foods, vending machines, etc.)	Commercial floor space
Industrial (warehouses, process equipment, etc.)	Commercial floor space
Residential (freezers, refrigerators)	Number of households
Other equipment (specify)	Commercial and residential floor space
Refrigeration (Service/Maintenance)	
Commercial transport	Commercial floor space
Commercial and institutional (retail foods, vending machines, etc.)	Commercial floor space
Industrial (warehouses, processes, etc.)	Commercial floor space
Residential (refrigerators, freezers, etc.)	Number of households
Other equipment (specify)	Commercial and residential floor space
Solvent	
Electronic industry	Deflated economic gross output data: Computer & Electronics (NAICS 334)
Metal cleaning/drying	Deflated economic gross output data: Fabricated Metal Products (NAICS 332)
Dry cleaning	Deflated economic gross output data: Other Services (NAICS 81)
Laboratory solvent	Deflated economic gross output data: Professional & Scientific Services (NAICS 54)
General cleaning (specify)	Deflated economic gross output data: Other Services (NAICS 81)
Fire Suppression/Extinguishing Systems (Original Equipment Manufacture)	
Portable (mobile) systems	Commercial and residential floor space
Total flooding (fixed) systems	Commercial and residential floor space
Fire Suppression/Extinguishing Systems (Service/Maintenance)	
Portable (mobile) systems	Commercial and residential floor space
Total flooding (fixed) systems	Commercial and residential floor space
Miscellaneous	
Hospital/institutional sterilizing	Deflated economic gross output data: Health & Social Assistance (NAICS 62)
Leak testing	Deflated economic gross output data: Other Services (NAICS 81)
Other (Specify)	Deflated economic gross output data: Gross domestic product

The information was reviewed (EHS, 2013; ECCC, 2015b), in accordance with the quality control measures set out in Volume 1, Chapter 6, Section 6.7.1.2 of IPCC 2006 Guidelines (IPCC, 2006). The emission factors developed using the collected information were also compared to default emission factors published in Table 7.9 of Volume 3, Chapter 7 of IPCC 2006 Guidelines and most were found to be within the same range. Some emission factors (e.g., end-of-life decommissioning) did not meet the quality control checks from Volume 1, Chapter 6, Section 6.7.1.2 of IPCC 2006 Guidelines for expert elicitation; values were therefore chosen within the range of emission factors published in Table 7.9 of Volume 3, Chapter 7 of IPCC 2006 Guidelines, guided by other information such as the regulatory environment in Canada. These emission factors have been applied to the whole time series from 1995 onwards.

The emission factors for the sub-application of "Other equipment" under Refrigeration—a mix of specialty applications—were derived through a weighted average of the emission factors from the other specific refrigeration sub-applications.

For the air conditioning and refrigeration applications, the expected lifetimes applied in the emission estimations were chosen based on the survey results and the information published in Table 7.9 of Volume 3, Chapter 7 of IPCC 2006 Guidelines.

For the remaining HFC applications, emission factors and lifetimes were chosen from Volume 3, Chapter 7 of IPCC 2006 Guidelines. Table A6.2–13 in Annex 6 presents the emission factors used to estimate the HFC emissions.

The Technical Expert Review associated with Canada's 2024 NIR recommended that the inventory team perform research to verify or update country-specific emission factors, with a focus on end-of-life emission factors for the applications with the largest emissions (refrigeration, air-conditioning, and foam blowing). The inventory team has reached out to the HRAI to inquire on domestic recovery, recycling, reclamation and destruction data. The inventory team also has access to data from 2017 onwards on exports of used HFCs reported to ODSHAR (ECCC, 2023, 2024, 2025a). Efforts on data sourcing, analysis, and inventory incorporation will continue.

A3.3.3.4. Emission Estimations

The net consumption of an HFC in a specific sub-application is calculated using Equation A3.3–2. This equation is a modified version of Equation 7.1 from Volume 3, Chapter 7 of IPCC 2006 Guidelines that has been adapted to the Canadian context. The total quantity of each HFC that remains in products after assembly, in-service and end-of-life losses, also known as an HFC bank, is also calculated.

Equation A3.3–2

$$C_{net,i} = IM_{bulk,i} - EX_{bulk,i} + IM_{manufacture,i} - EX_{manufacture,i}$$

$C_{net,i}$	=	net consumption of HFC i, kg
$IM_{bulk,i}$	=	imports or sales of bulk HFC i, kg
$EX_{bulk,i}$	=	exports of unused bulk HFC i, kg—this is set to zero during years when sales data is collected instead of import and export data
$IM_{manufacture,i}$	=	imports of manufactured items containing HFC i, kg
$EX_{manufacture,i}$	=	exports of manufactured items containing HFC i, kg

Annual emissions for each applicable lifecycle stage are estimated for each sub-application by multiplying the HFC quantity in that stage by its corresponding emission factor. It is assumed that once an item is manufactured, the technology and its inherent in-service emission rate will remain constant throughout its lifetime. The in-service emission estimate takes into consideration the quantity of HFC that has already been emitted during the assembly stage. Likewise, the emission estimate from the end-of-life of the product is based on the quantity of HFC available after the assembly and in-service emissions have taken place and on the corresponding emission factor for the sub-application. The end-of-life emission factor used also considers regulations in place at the time of decommissioning.

The following sections explain the HFC emission estimation equations applied for each unique application/sub-application in more detail.

A3.3.3.4.1. HFC Emissions from Aerosols

HFC emissions from aerosols application are estimated using Equation A3.3–3, which is Equation 7.6 from Volume 3, Chapter 7 of IPCC 2006 Guidelines.

Equation A3.3–3

$$EA_t = (A_t \times EF_A) + (A_{t-1} \times (1 - EF_A))$$

EA_t	=	emissions from aerosols in year t, tonnes
A_t	=	quantity of HFC contained in aerosol products sold in year t, tonnes
A_{t-1}	=	quantity of HFC contained in aerosol products sold in year t-1, tonnes
EF_A	=	in-service emission factor for aerosols, fraction

A3.3.3.4.2. HFC Emissions from Blowing Agent in Open-cell Foams

HFC emissions from open-cell foam blowing are estimated using Equation A3.3–4, which is Equation 7.8 from Volume 3, Chapter 7 of IPCC 2006 Guidelines.

Equation A3.3–4

$$EOCF_t = M_t$$

$EOCF_t$	=	emissions from blowing agent in open-cell foams in year t, tonnes
M_t	=	quantity of HFC used in manufacturing new open-cell foams in year t, tonnes

A3.3.3.4.3. HFC Emissions from Blowing Agent in Closed-cell Foams

HFC emissions from closed-cell foam blowing are estimated using Equation A3.3–5, which is a modified version of Equation 7.7 from Volume 3, Chapter 7 of IPCC 2006 Guidelines. The reason for the modification is that no information on recovery and destruction of HFCs in closed-cell foams and their blowing agents is available.

Equation A3.3–5

$$ECCF_t = (CCF_t \times EF_A) + (CCFBank_{t\text{-}n+1\rightarrow t} \times EF_{IS}) + (CCFEOL_{t\text{-}n+1} \times EF_{EOL})$$

$ECCF_t$	=	emissions from blowing agent in closed-cell foams in year t, tonnes
CCF_t	=	quantity of HFC used in manufacturing new closed-cell foams in year t, tonnes
EF_A	=	assembly emission factor for closed-cell foams, fraction
$CCFBank_{t\text{-}n+1\rightarrow t}$	=	quantity of HFC charged into closed-cell foam manufacturing or imported in products/equipment between year t-n+1 and year t (inclusive) that is remaining in in-service products/equipment in Canada in year t, tonnes
EF_{IS}	=	in-service emission factor for closed-cell foams, fraction
$CCFEOL_{t\text{-}n+1}$	=	quantity of HFC charged into closed-cell foam manufacturing or imported in products/equipment in year t-n+1 that is remaining in decommissioned products/equipment in Canada in year t, tonnes
EF_{EOL}	=	end-of-life emission factor for closed-cell foams, fraction
n	=	product lifetime of closed-cell foam
t	=	current year

A3.3.3.4.4. HFC Emissions from Air Conditioners and Refrigerators Manufactured in Canada

HFC emissions from air conditioning and refrigeration equipment manufactured in Canada are estimated using Equation A3.3–6, which is a modified version of Equation 7.10 from Volume 3, Chapter 7 of IPCC 2006 Guidelines.

Equation A3.3–6

$$EACROEM_t = (ACROEM_t \times EF_A) + (ACROEMBank_{t\text{-}n+1\rightarrow t} \times EF_{IS}) + (ACROEMEOL_{t\text{-}n+1} \times EF_{EOL})$$

$EACROEM_t$	=	emissions from air conditioners or refrigerators manufactured in Canada in year t, tonnes
$ACROEM_t$	=	quantity of HFC used in manufacturing new air conditioners or new refrigerators in year t, tonnes
EF_A	=	assembly emission factor for new air conditioners or new refrigerators, fraction
$ACROEMBank_{t\text{-}n+1\rightarrow t}$	=	quantity of HFC charged into new air conditioners or refrigerators between year t-n+1 and year t (inclusive), that is remaining in in-service equipment in Canada in year t, tonnes
EF_{IS}	=	in-service emission factor for air conditioners or refrigerators, fraction
$ACROEMEOL_{t\text{-}n+1}$	=	quantity of HFC charged into new air conditioners or refrigerators in year t-n+1 that is remaining in decommissioned equipment in Canada in year t, tonnes
EF_{EOL}	=	end-of-life emission factor for air conditioners or refrigerators, fraction
n	=	product lifetime of air conditioner or refrigerator
t	=	current year

A3.3.3.4.5. HFC Emissions from Air Conditioners and Refrigerators Manufactured Elsewhere

Equation A3.3–6 is applied for estimating HFC emissions from air conditioners and refrigerators manufactured elsewhere, except that the assembly emission factor in this case is zero.

A3.3.3.4.6. HFC Emissions from Solvents

HFC emissions from solvents are estimated using Equation A3.3–7, which is a modified version of Equation 7.5 from Volume 3, Chapter 7 of IPCC 2006 Guidelines. The reason for the modification is that no information on the destruction of HFCs used as solvents is available.

Equation A3.3–7

$$ES_t = (S_t \times EF_S) + (S_{t-1} \times (1 - EF_S))$$

ES_t	=	emissions from solvents in year t, tonnes
S_t	=	quantity of HFC contained in solvents sold in year t, tonnes
S_{t-1}	=	quantity of HFC contained in solvents sold in year t-1, tonnes
EF_S	=	in-service emission factor for aerosols, fraction

A3.3.3.4.7. HFC Emissions from Fire Suppression and Extinguishing Systems

HFC emissions from fire suppression/extinguishing systems are estimated using Equation A3.3–8, which is a modified version of Equation 7.17 from Volume 3, Chapter 7 of IPCC 2006 Guidelines. The reason for the modification is that no information on the destruction of HFCs used in fire suppression and extinguishing systems is available.

Equation A3.3–8

$$EFSES_t = (FSESBank_{t-n+1 \to t} \times EF_{IS}) + (FSESEOL_{t-n+1} \times EF_{EOL})$$

$EFSESM_t$	=	emissions from fire suppression and extinguishing systems in year t, tonnes
$FSESBank_{t-n+1 \to t}$	=	quantity of HFC charged into fire suppression and extinguishing systems or imported in systems between year t-n+1 and year t (inclusive) that is remaining in in-service systems in Canada in year t, tonnes
EF_{IS}	=	in-service emission factor for fire suppression and extinguishing systems, fraction
$FSESEOL_{t-n+1}$	=	quantity of HFC charged into fire suppression and extinguishing systems or imported in systems in year t-n+1 that is remaining in decommissioned systems in Canada in year t, tonnes
EF_{EOL}	=	end-of-life emission factor for fire suppression and extinguishing systems, fraction
n	=	product lifetime of fire suppression and extinguishing system
t	=	current year

A3.3.3.4.8. HFC Emissions from Miscellaneous and Other Applications

HFC emissions from miscellaneous and other application are estimated using Equation A3.3–9, which is Equation 7.18 from Volume 3, Chapter 7 of IPCC 2006 Guidelines.

Equation A3.3–9

$$EMOA_t = (MOA_t \times EF_{MOA}) + (MOA_{t-1} \times (1 - EF_{MOA}))$$

$EMOA_t$	=	emissions from miscellaneous and other applications in year t, tonnes
MOA_t	=	quantity of HFC contained in miscellaneous and other products sold in year t, tonnes
MOA_{t-1}	=	quantity of HFC contained in miscellaneous and other products sold in year t-1, tonnes
EF_{MOA}	=	in-service emission factor for miscellaneous and other products, fraction

A3.3.3.4.9. Total Annual HFC Emission Estimations

The total annual emission estimates for each HFC are derived by summing the emissions from all applicable applications. Once the total annual emission estimates at the national level are obtained, they are distributed by province/territory based on proxy variables, such as commercial floor space for commercial refrigeration, and number of households for residential refrigeration. Proxy variable data for this purpose was received from ECCC's Analysis and Modelling Division and from the Transport section of the Pollutant Inventories and Reporting Division (ECCC, 2025b, 2025c).

A3.3.4. SF_6 Emissions from Electrical Equipment (CRT category 2.G.1)

A3.3.4.1. Methodology – Derivation of the Country-Specific Quantification Method

To quantify SF_6 emissions, the Canadian electricity industry uses a method derived from the basic Tier 3 IPCC 2006 Guidelines life-cycle Equation 8.10 (Volume 3), as explained in the following sections.

A3.3.4.1.1. Equipment Manufacturing Emissions

According to some utilities, electrical equipment purchased by the Canadian electricity sector is manufactured in the United States, Europe or Asia and hence emissions associated with manufacturing would have occurred mainly outside of Canada.

A3.3.4.1.2. Equipment Installation Emissions

SF_6 equipment is delivered to utilities pre-charged with some SF_6 and charged to full capacity at the time of installation. In the Canadian electricity industry, the potential for SF_6 emissions during equipment installation is considered to be extremely low. A vacuum hold check is typically performed prior to the installation of new equipment to ensure that the equipment is gas tight.

A3.3.4.1.3. Equipment Use Emissions

The primary source of SF_6 releases is associated with the cumulative minute releases that occur during normal equipment operation. Gas releases could potentially occur during gas handling and transfer operations, although such releases would be significantly smaller in magnitude than emissions that occur during normal operations.

Due to the SF_6 leakage that occurs during the above circumstances, utilities are required to "top-up" their equipment to keep it properly charged and operational. By topping up equipment with SF_6 gas, utilities are able to replace the amount of gas that has escaped.

A3.3.4.1.4. Equipment Decommissioning and Failure Emissions

During the decommissioning of retired equipment, SF_6 gas must be recovered from the retired equipment prior to disposal. As SF_6 gas releases may occur as a result of the way in which the gas is transferred out of the equipment during gas recovery, decommissioning of retired equipment becomes a potential source of SF_6 releases.

When catastrophic failures of equipment occur, a significant amount of SF_6 leaks out of the equipment. Equipment damage is therefore a potential source of emissions.

Retired equipment and damaged equipment that cannot be repaired are sent off-site for disposal.

A3.3.4.1.5. Emissions from SF_6 Recycling

When SF_6 gas is recovered from equipment, it is filtered through a gas cart or other filtering equipment to remove moisture and impurities before it is reused. When SF_6 gas has been contaminated with air and impurities and has a purity of less than a certain level (the acceptable level can vary between 95% and 99%, depending on utility practices), it cannot be reused and is sent for off-site purification in the United States. There are no facilities in Canada that perform SF_6 gas purification. One of the methods utilized to purify SF_6 gas is the use of a cryogenic process to separate and remove the air/nitrogen from the SF_6 gas. The purification of SF_6 gas does not produce SF_6 emissions. Hence, emissions from SF_6 recycling are eliminated from the calculation of total emissions.

Given the reasoning above, the Canadian electricity industry uses a modified, country-specific Tier 3 IPCC approach to estimate SF_6 releases. Only emissions from equipment use and equipment decommissioning and failure are calculated, as shown in Equation A3.3–10.

Equation A3.3–10

$$\textit{Total utility } SF_6 \textit{ emissions} = \sum \textit{Equipment use emissions} + \sum \textit{Equipment decommissioning and failure emissions}$$

A3.3.4.2. Methodology – Quantifying Equipment Use Emissions

Emissions that occur during equipment use are a result of leakages during gas transfer and handling operations and during normal operation of the equipment. To keep equipment properly charged and operational, utilities must fill their equipment to replace the amount that has escaped. This amount is referred to as a "top-up."

Leakages of SF_6 are also seen during maintenance/repair activities. When equipment needs to be repaired or sent for maintenance, the SF_6 gas is recovered from it and, once the equipment is repaired, it is refilled with the SF_6 gas that was recovered. There will be an additional amount needed to refill the equipment, since some gas may have escaped due to normal operations and during the transfer of the recovered gas from the equipment to gas carts (or storage cylinders) and back to the equipment. It is this additional/incremental amount of SF_6 gas that is referred to as the "top-up." Hence, an accurate estimate of the amount of SF_6 released is the amount used by utilities to top up their equipment during the equipment use stage.

A3.3.4.2.1. Options for Tracking SF_6 Consumed for Top-ups

The following is a list of options for Canadian electric utilities to track the amount of SF_6 that is used for top-up purposes to quantify emissions of SF_6 from the equipment use phase. These options are listed in order of most accurate to least accurate. The most accurate method involves directly measuring the amount of gas transferred during top-ups, and the less accurate methods involve utilities relying on inventory records or purchase receipts to obtain an estimate. Each utility will have discretion over which method to use. Canadian electric utilities may track the amount of SF_6 that is used annually for top-up purposes (i.e., the amount that has been emitted) by using mass flow meters or a mass balance, or by counting the number of cylinders consumed.

For all these tracking options, it is assumed that the quantities of SF_6 tracked do not include the gas used to pressurize the new switchgear to its full capacity at the time of installation. Quantities of gas used for pressurization are typically provided by the switchgear vendor at time of installation and hence do not come out of the utility inventory (see also A3.3.4.1.2).

Option 1: Mass Flow Meters

Mass flow meters provide the most accurate method for measuring the quantity of SF_6 consumed during each equipment top-up operation. The sum of all measured quantities during top-up operations will be used to determine the equipment use emissions.

Option 2: Mass Balance

Utilities may choose to weigh their SF_6 cylinders to determine the quantity of SF_6 consumed for top-up operations. The difference in mass of the cylinders can be determined whether every time there is an equipment top-up operation or on an inventory basis. Utilities must also account for any purchases or additions to the inventory, the weight of SF_6 cylinders returned to suppliers, and the quantity of SF_6 sent off-site for recycling or destruction during the year. When using a mass balance, utilities should ensure that the accuracy of the weight scale is compatible with the weight of the cylinders to be weighed. For example, utilities should use a scale accurate to ±1 kg, rather than ± 5 kg, to weigh a 50 kg cylinder.

Option 3: Cylinder Count

In the absence of mass flow meters or weigh scales, utilities may choose to rely on information from supplier or inventory records and from purchase receipts to obtain the number and weight of SF_6 cylinders purchased for top-up purposes. The mass of SF_6 consumed can be assumed to be equal to the amount of SF_6 purchased in a year or equal to the change in maintenance inventory.

The weight of SF_6 found in different types of cylinders should be known. Therefore, utilities can simply obtain the weight of SF_6 consumed for top-up purposes by performing a cylinder count. If more than one type of cylinder is used, utilities must ensure that the number of cylinders of each type is multiplied by the cylinder weight for that type. The products obtained for all cylinder types are then summed together to give the total SF_6 use.

A3.3.4.3. Methodology – Quantifying Equipment Disposal and Failure Emissions

Equipment disposal and failure emissions include emissions from decommissioning of retired equipment and emissions that result from the rare event of catastrophic equipment failures.

In the decommissioning of retired equipment, SF_6 losses occur as gas is being recovered from the retired equipment. Emissions can be estimated by taking the difference between the nameplate capacity of the equipment and the recovered amount of SF_6, as shown in Equation A3.3–11.

Equation A3.3–11

$$\textit{Equipment decommissioning emissions} = \textit{Nameplate capacity of retired equipment} - \textit{SF}_6 \textit{ amount recovered from retired equipment}$$

The value of nameplate capacity (in mass units) can be obtained from equipment specifications provided by the equipment manufacturer or from sound engineering estimates. The amount of recovered SF_6 gas is weighed.

When equipment failure or damage occurs to the point where it cannot be repaired, it is assumed that the nameplate capacity of the equipment is representative of the emissions that have taken place as a result of equipment failures.

The information provided in this section (A3.3.4) is extracted from the *SF_6 Emission Estimation and Reporting Protocol for Electric Utilities* (EC and Canadian Electricity Association 2008), available at http://www.publications.gc.ca/site/eng/454401/publication.html. For further details on data uncertainty, data quality control, data verification by third parties, transfer of information and data to ECCC, documentation and archiving, new information or data updates, and protocol reviews and amendments, please refer to the Protocol.

A3.4. Methodology for the Agriculture Sector

Overview of Agricultural Emission Methodologies

This section of Annex 3 describes the estimation methodologies, equations, activity data, emission factors and parameters that are used to derive the greenhouse gas (GHG) estimates in the Agriculture sector, namely:

- methane (CH_4) emissions from enteric fermentation
- CH_4 and nitrous oxide (N_2O) emissions from manure management and field burning of agricultural residues
- N_2O emissions from agricultural soils (direct emissions, indirect emissions and animal manure emissions on pasture, range and paddock)
- carbon dioxide (CO_2) emissions from agricultural use of lime and urea

The sources of animal population data required to calculate agricultural emissions of CH_4 and N_2O are presented in section A3.4.1. The methods used to calculate agricultural GHG emissions are described in sections A3.4.2 to A3.4.8. Note that agricultural soils also emit and sequester CO_2, but these sources/sinks are reported in the Land-Use, Land-Use Change and Forestry (LULUCF) sector (see Annex 3.5).

Livestock and crop production are integrated systems that interact in the production of GHG emissions. The GHG estimation methodology described in Annex 3.4 begins with an estimation of emissions related to livestock production, followed by emissions related to crop production (Figure A3.4–1). All approaches prescribed by the Intergovernmental Panel on Climate Change (IPCC, 2006) for calculating emissions follow the basic formula of multiplying the "activity data" by the "emission factor". In the case of agricultural emissions, "activity data" may refer to the number of animals, an amount of nitrogen (N) applied to soils, or some other measure of agricultural activity. "Emission factor" is an average emission rate for a specific GHG from a given source, relative to a unit of activity data. The calculation of agricultural emissions is often sequential, as many processes are interrelated. For example, changes in livestock populations and characteristics may alter the quantity of manure nitrogen that is transferred from the livestock system to the cropping production system.

Livestock emissions are primarily driven by animal populations, but emission factors are dependent on other drivers. The quality and quantity of animal feed influence how quickly animals grow and how productive they are (e.g., dairy cow milk production), but changes in animal feed characteristics will affect the amounts of CH_4 and manure produced by each animal, and therefore the amount of carbon (C) and N it excretes in the environment. As a result, feed quality and animal productivity are potential drivers of change in livestock emission factors over time. Other drivers include changes in manure management infrastructure (for manure storage and spreading) or farming practices—such as the amount of time animals spend on pasture— which may further alter the quantity or profile of emissions. Therefore, emission factors can also vary from year to year, in addition to activity data.

Livestock estimation methodologies used in the National Inventory Report (NIR) can generally be grouped into four categories: (1) dairy; (2) beef (i.e., non-dairy); (3) swine; and (4) other livestock (Figure A3.4–1). For the beef category, the estimated emissions from enteric fermentation and manure management processes are based on IPCC Tier 2 methodologies populated with country-specific parameters obtained from expert consultations (Boadi et al., 2004a; Marinier et al., 2004) and animal production data in the form of carcass weight increases (AAFC, n.d. [a]). For the dairy category, the expert consultation was improved by the introduction of better feed and production data, as well as information derived from Statistics Canada's farm environmental survey data. For the swine and other livestock categories, the default IPCC Tier 1 methodology is used to estimate emissions from enteric fermentation. Emissions from swine manure management are estimated using a Tier 2 methodology based on expert consultation data (Marinier et al., 2004), animal production data in the form of carcass weight increases, and information derived from the Statistics Canada farm environmental surveys. For most other livestock, emissions from manure management are calculated based on expert consultations or IPCC Tier 1 methods. Emissions from animals other than cattle, swine, sheep, poultry, horses and bison represent less than 0.5% of total agricultural emissions and less than 0.05% of total national anthropogenic emissions.

N_2O emissions from crop production on agricultural soils are primarily driven by N fertilizer sales, annual crop area, the type of N applied and the cropping system to which N is applied. To a lesser extent, emissions within a province are influenced by the availability of manure and biosolids relative to crop N requirements. A combination of activity data (animal populations) and drivers such as feed quality and quantity, animal productivity and manure management infrastructure influence the total quantity of N that is transferred from the livestock system to agricultural soils and the amount of N lost to the environment during these transfers.

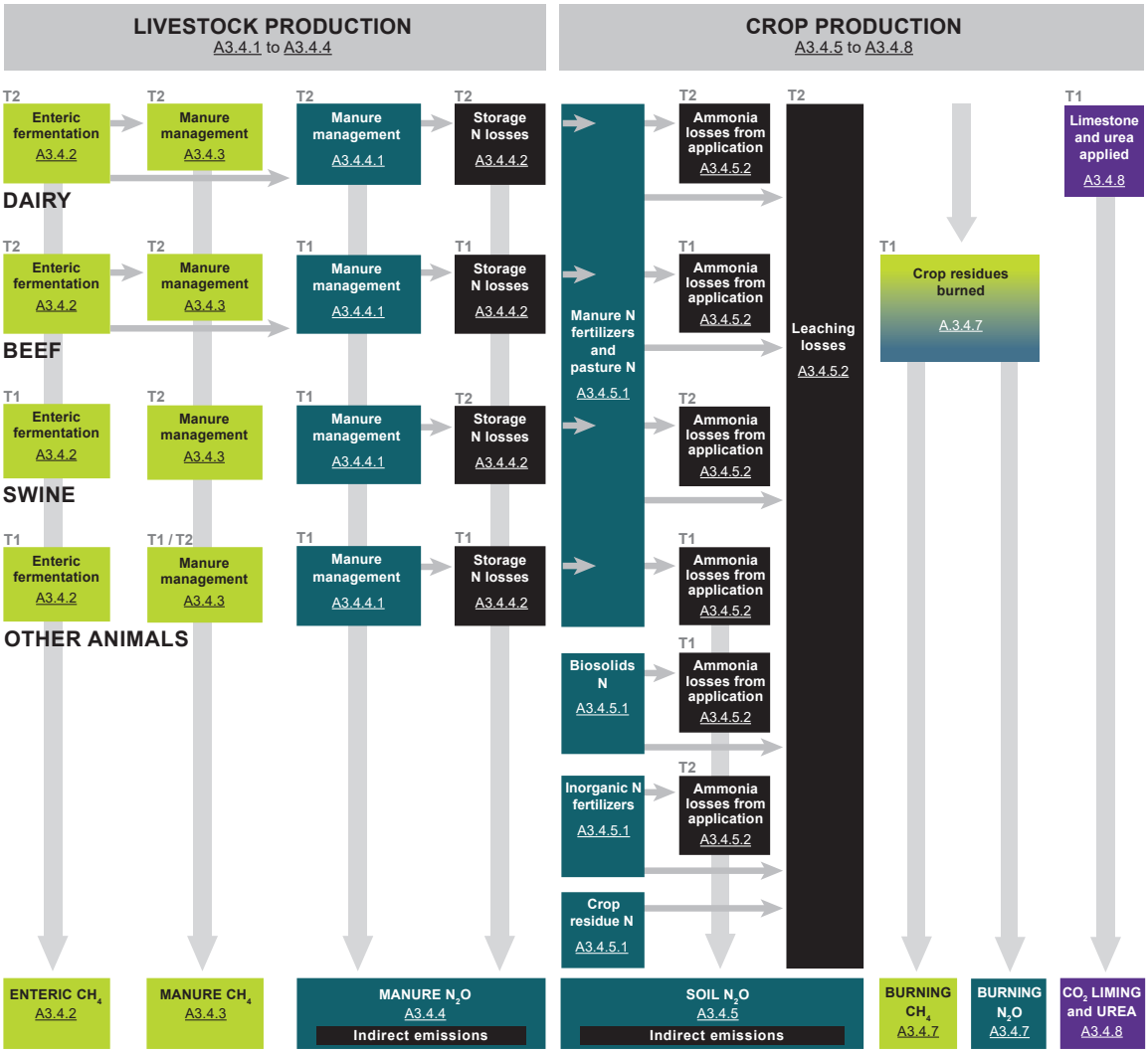
Spatially, N is distributed to agricultural ecodistricts, which represent one level within Canada's National Ecological Framework. The country is divided into 1027 ecodistricts, each characterized by a distinctive assemblage of relief types, landforms, geology, soils, vegetation, water bodies and fauna. Application rates are calculated as a function of the total organic N in the ecodistrict and crop requirements, and are then adjusted to provincial fertilizer shipments as outlined in section A3.4.5. A country-specific emission factor for agricultural soils is calculated for each ecodistrict (section A3.4.5.1) that is adjusted based on the source of N, cropping system, topography, soils and climate of the ecodistrict, as well as

management practices such as tillage and irrigation. Emissions are then calculated based on the amount of N applied to the soil, multiplied by the unique emission factor for the ecodistrict. The quantity of emissions that results from a given unit of N added to soils therefore varies by ecodistrict. Sources of N include organic and inorganic fertilizers, and crop residues (N contained in plant matter remaining in fields after harvest).

Nitrogen losses from the application of N to agricultural soils are calculated using a Tier 2 approach for inorganic N fertilizers, dairy and swine manure, and a Tier 1 approach for all other livestock. Indirect emissions of N_2O from N that is lost from the agriculture system are estimated using 2006 IPCC Tier 1 emission factors (see section A3.4.5.2).

Minor emission sources, such as CO_2 emissions from the agricultural use of lime and urea and CH_4 and N_2O emissions from the field burning of agricultural residues are estimated using 2006 IPCC Tier 1 emission factors, and are described in sections A3.4.8 and A3.4.7, respectively.

Figure A3.4–1 **Overview of the Key Methodologies and IPCC Tier Levels Used in Estimating Emissions from Livestock and Crop Production**



A3.4.1. Animal Population Data Sources

Annual livestock population data at a provincial level were used to develop emission estimates. Livestock and poultry populations, by animal subcategory and by province, were obtained from Statistics Canada and other sources, as described in Table A3.4–1.

Annual cattle, sheep and swine populations are presented as the simple mean of semi-annual or quarterly surveys. These smaller surveys are corrected by Statistics Canada to the *Census of Agriculture* (COA) population estimates, which are collected every five years, to assure the accuracy of the estimates.

Table A3.4–1 **Animal Categories and Sources of Population Data**

Category	Sources/Notes
Cattle	Statistics Canada. No date (d). Table: 32-10-0130-01—Number of cattle, by class and farm type, annual (head) [accessed 2025 August 13]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210013001.
– Dairy cattle	All cattle used in the production of milk and milk products
– Non-dairy cattle	All other cattle
Bison, goats, horses, llamas and alpacas, deer and elk	Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue No. 23-502-X) Statistics Canada. No date (e). Table 32-10-0427-01 Other livestock inventories on farms, *Census of Agriculture*, 2011 and 2016, inactive. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042701. Statistics Canada. 2022. 2021 *Census of Agriculture*: Selected livestock and poultry, *Census of Agriculture* historical data. Table 32-10-0155-01. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210015501. - Linear interpolation between census years; remains constant after last census
Wild boars	Census year 2021: Statistics Canada. 2022. Selected livestock and poultry, *Census of Agriculture* historical data. Table 32-10-0155-01. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210015501. Census year 2016[a]: Taylor, Patrick (Statistics Canada). Personal communication received September 21, 2018. Census years 2001 to 2011: Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue No. 23-502-X) 2011 Census: Statistics Canada. Table 95-640-XWE—2011 Farm and farm operator data (database). Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042701. - Linear interpolation between census years; remains constant after last census Census years[a] 1991, 1996: Laborde, Leon (Statistics Canada). Personal communication received October 26, 2016. - Linear interpolation between census years; assumed to remain constant in 1990 at the 1991 level.
Mink and foxes	Statistics Canada. No date. Table 32-10-0116-01 (formerly CANSIM Table 003-0015)—Supply and disposition of mink and fox on fur farms, annual (Number) [accessed 2021 October 28]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210011601.
Mules and asses[a]	Census year 2021: Statistics Canada. No date. Other livestock inventories on farms, *Census of Agriculture*, 2021. Table 32-10-0155-01. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210015501. Census year 2016: Laborde L (Statistics Canada). Personal communication received May 16, 2018. Census years 2001 to 2011: Laborde L (Statistics Canada). Personal communication received September 2, 2015. - Population held constant prior to 2001 census, and after the last census
Rabbits	Agriculture and Agri-Food Canada, Red Meat Market Information, Alternative Livestock. Available online at: https://agriculture.canada.ca/en/agriculture-and-agri-food-canada/canadas-agriculture-sectors/animal-industry/red-meat-and-livestock-market-information/rabbit-industry-glance - Linear interpolation between census years, remains constant after last census - Correction factor applied to isolate the breeding population based on expert opinion from Brian Tapscott, Alternative Livestock Specialist, OMAFRA
Sheep and lambs	Statistics Canada. No date (c). Table 32-10-0129-01—Number of sheep and lambs on farms, annual (head) [accessed 2025 August 13]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210012901.
Swine	Statistics Canada. No date (f). Table 32-10-0290-01—Number of hogs on farms at end of quarter, quarterly (head), CANSIM (database). Years 1990–2006. Statistics Canada. No date (b). Table 32-10-0126-01. Hogs, sheep and lambs, farm and meat production [accessed 2023 August 29]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210012601.
Poultry	Farm data and farm operator data tables (section 6.5 of publication #95-629) (Statistics Canada [2007a])
	Selected historical data from the *Census of Agriculture*, Canada and provinces: census years 1976 to 2006 (Table 2.16 and section 4.6 of Statistics Canada Catalogue No. 95-632). (Statistics Canada [2007b]) 2011 and 2016 Census: Statistics Canada. Table: 32-10-0428-01 (formerly CANSIM 004-0225). Poultry inventory on census day [accessed 2018 October 22]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042801.
	2021 Census: Statistics Canada. Poultry inventories on farms, *Census of Agriculture*, 2021 [accessed October 6, 2022]. Table: 32-10-0374-01. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210037401. - Linear interpolation between census years; remains constant after latest census

Note:
a. These data may be affected by errors due to coverage.

The population estimates for horses, goats, bison,[1] llamas and alpacas, deer and elk, wild boars, rabbits and poultry are taken from the COA exclusively, and annual populations are developed by linear interpolation to avoid large changes between census years. Populations of deer and elk, considered new to Canadian livestock production and only reported in the COA for census years beginning in the reporting period, were extrapolated back to zero for the census year before their first appearance in the COA. Mule and ass populations for the years 2001, 2006, 2011, 2016, and 2021 were received via personal communication[2] and originate from compiled responses to the COA, while populations for the year 2024 were extrapolated. Mule and ass populations were not compiled prior to the 2001 census year and were assumed to be constant at the 2001 level from 1990 to 2000. Wild boar populations for census years 1991, 1996 and 2016 were received via personal communication[3,4] and were compiled from responses to the COA. Wild boar and buffalo populations were not collected in 1986; thus, the populations were set constant for 1990 at the 1991 level.

The estimates for breeding mink and fox populations are taken from an annual Statistics Canada survey titled *Supply and Disposition of Mink and Fox on Fur Farms*, which provides the number of foxes and mink on farms for January 1 of the survey year. Statistics Canada recently cancelled the Fur Farm survey on which the fox and mink populations are based and are in the process of investigating alternative data sources. In the interim, 2024 populations have been held constant from 2020. Rabbit populations were taken from responses to the COA as provided on the Agriculture and Agri-Food Canada (AAFC) Red Meat Market website (AAFC, n.d. [b]), but were modified based on expert opinion[5] using a correction factor to estimate the number of does, as opposed to total rabbits.

To populate an IPCC Tier 2 enteric fermentation approach for the Beef and Dairy sectors, the subcategories of provincial cattle populations collected by Statistics Canada were further disaggregated into sub-annual production stages (i.e., "production subcategory") to isolate and quantify the effect of specific production practices on gross energy (GE) intake and, as a consequence, CH_4 emissions. Data to describe the production environment and associated performance of classes of animals were collected from a combination of sources, including: (1) production and management practices published in scientific journals; (2) a survey of dairy and beef production practices administered to regional and provincial beef and dairy livestock specialists across the country; (3) consultation with scientists at universities and federal research institutions; and (4) provincial/national associations and provincial/regional performance-recording organizations (Boadi et al., 2004a).

These data were used to create an annual cattle production approach that considers regional and seasonal variations in production practices. For example, some beef cattle may be pastured for different periods in different provinces. Accordingly, the eight cattle subcategories were broken down into 38 distinct cattle production stages—29 for the Beef sector and 9 for the Dairy sector—observed throughout the different provinces of Canada (Table A3.4–2). The approach characterizes cattle by physiological status, diet, age, sex, weight, growth rate, activity level and production environment. Further work on the Dairy sector was implemented in the 2018 inventory analysis to refine estimates of certain Tier 2 parameters. This improvement created a time series that better captures changes in production practices in the Dairy sector and introduced an analysis of changes in dairy nutrition considering more recent Canadian and North American research (Ellis et al., 2007; Ellis et al., 2010; Sheppard et al., 2011a, 2011b; Vanderzaag et al., 2013; Appuhamy et al., 2016; Chai et al., 2016; Jayasundara et al., 2016).

The feeding practices for Beef and Dairy sector livestock are detailed in the next section.

1 In the Common Reporting Tables (CRTs), the IPCC category "Buffalo" is used to report values for North American bison (*Bison bison*) raised for meat.

2 Laborde L. 2015. Personal communication (email from Laborde L to Section Head, Agriculture, Forestry and Other Land Uses, dated September 2, 2015). Pollutant Inventories and Reporting Division, ECCC.

3 Laborde L. 2016. Personal communication (email from Laborde L to Flemming C, Agriculture, Forestry and Other Land Uses, dated October 26, 2016). Pollutant Inventories and Reporting Division, ECCC.

4 Taylor, P. 2016. Personal communication (email from Taylor P to Flemming C, Agriculture, Forestry and Other Land Uses, dated September 21, 2018).

5 Tapscott B. 2015. Personal communication (email from Tapscott B, OMAFRA, to Section Head, Agriculture, Forestry and Other Land Uses, dated September 16, 2015). Pollutant Inventories and Reporting Division, ECCC.

Table A3.4–2 **Cattle Production Stage Approach**

Subcategory	Production Environment	Period of Year[a]	Province
Beef cows	Pregnant, confined	Jan–Apr/Oct–Dec	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef cows	Lactating, pasture	May–Oct	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef cows	Pregnant, confined	Feb–Mar	MB
Beef cows	Lactating, pasture	Jan/Mar–Dec	MB
Breeding bulls	Mature, confined	Jan–Apr/Nov–Dec	PE/NS/QC/ON/MB/SK/AB/BC
Breeding bulls	Mature, pasture	May–Oct	PE/NS/QC/ON/MB/SK/AB/BC
Breeding bulls	Young, confined	Mar–Apr	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Breeding bulls	Young, pasture	May–Oct	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Breeding bulls	Young, confined	Nov–Dec/Jan–Feb	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Birth to pasture	Mar	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Pasture	Apr–Sep	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Heifer replacement	Oct–Dec/Jan–Mar	PE/NS/QC/ON/MB/SK/AB/BC
Beef calves	Background heifers	Oct–Dec/Jan–Mar	PE/NS/QC/ON/MB/SK/AB/BC
Beef calves	Background steers	Oct–Dec/Jan–Mar	NL/PE/NS/NB/ON/MB/SK/AB/BC
Beef calves	Finisher heifers	Oct–Dec/Jan–Mar	NL/PE/NS/NB/ON/MB/SK/AB/BC
Beef calves	Finisher steers	Oct–Dec/Jan–Mar	PE/NS/NB/ON/MB/SK/AB/BC
Heifer replacements	Young, not pregnant	Apr–May	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Heifer replacements	Early gestation	Jun–Sep	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Heifer replacements	Late gestation	Oct–Dec/Jan–Mar	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Finisher heifers	Feedlot, short-keeps	Apr–Jun	PE/NS/NB/ON/MB/SK/AB/BC
Finisher steers	Feedlot, short-keeps	Apr–Jun	PE/NS/NB/ON/MB/SK/AB/BC
Finisher heifers	Feedlot, short-keep, long-finish	Apr–Jul	NS/ON/MB
Finisher steers	Feedlot, short-keep, long-finish	Apr–Jul	NS/ON/MB
Background heifers	Confined	Mar–May	NL/NS/ON/MB/SK/AB/BC
Background steers	Confined	Mar–May	NL/NS/ON/MB/SK/AB/BC
Background heifers	Pasture	Jun–Sep	NL/NS/ON/MB/AB/BC
Background steers	Pasture	Jun–Sep	NL/NS/ON/MB/AB/BC
Finisher heifers	Feedlot, long-keeps	Oct–Dec	PE/NS/NB/QC/ON/MB/SK/AB/BC
Finisher steers	Feedlot, long-keeps	Oct–Dec	PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy cows	Lactating, confined	var[b]	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy cows	Lactating, pasture	var	NL/PE/NB
Dairy cows	Lactating, confined (after pasture)	var	PE
Dairy cows	Dry, low-quality feed	var	NL/PE/NS/NB/QC/ON/MB/SK/BC
Dairy cows	Dry, high-quality feed	var	MB/SK/AB/BC
Dairy cows	Dry, pasture	var	NL/ON
Dairy heifers	Confined (243 days per year)	Jan–Apr/Oct–Dec	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy heifers	Pasture	May–Oct	NL/PE/NB/ON/SK
Dairy heifers	Confined (365 days per year)	Jan–Dec	NB/ON/SK

Notes:
a. The actual period of the year could vary slightly from province to province.
b. Variable dependent on farm, province and animal cycles.

Dairy Sector Production and Performance

Dairy production practices vary across the country because of differences in land prices, climate, forage availability and market access. They have also changed significantly between 1990 and the present. The predominant management practices for each province are reflected in the province-specific parameters entered into the IPCC Tier 2 equations for both enteric fermentation and manure management emissions.

Table A3.4–3 provides an example of production performance data collected for the Canadian Dairy sector, originally used for quality assurance verification of the data incorporated in the Tier 2 method at the inception of the Boadi et al. (2004a) study. While the basic subcategory classes developed by Boadi et al. (2004a) were accurate for the mid-2000s when the Tier 2 model was populated, it was recognized that certain production parameters should not be static over time and that these parameters could impact all aspects of emissions from the sector. Since 1990, with the increase in milk production in the dairy herd, there has also been a shift in the diet of an average dairy cow, both in the quantity and quality of feed consumed.

There are no complete and consistent national data sources on dairy feed quality and its linkage to dairy production and performance. However, certain regional and partial resources exist, specifically the feed quality database from Lactanet[6] for parts of Eastern Canada and Cost of Production[7] (COP) surveys for Quebec and Ontario. Nonetheless, consistent milk production statistics do exist for the entire country. Production statistics identifying the relative proportions of the national dairy herd that fall into high, medium and low productivity classes and are linked to herd characteristics such as farm size are collected, managed and prepared for the inventory by Lactanet.

To develop parameters that link productivity with production practice, the feed quality database developed by Lactanet, consisting of feed data collected and analyzed for more than 2000 dairy herds in Quebec and Atlantic Canada, was used as a model to develop a matrix of animal diets that could be related to specific farm sizes and productivity classes. Feed composition, digestibility, crude protein content and some herd characteristics, such as lactation lengths and cattle weights, were grouped according to five categories of farm size and three categories of productivity class. The feed composition statistics required for Tier 2 calculations were attributed to provinces based on the proportions of their animal populations that fell into different farm size and productivity classes. As the data used in this analysis from Lactanet were collected between 2000 and 2010, further COP survey data were used as a proxy to project changes in certain feed components, specifically the proportion of silage in diets relative to the proportion of hay for the period of 1990 to 1999.

A time series consisting of the annual weighted provincial averages for feed digestibility, lactation lengths and crude protein content in feed was transferred into the existing structure for the Boadi et al. (2004a) approach. Furthermore, provincial cattle weights for dairy animals were modified based on average measurements included in the Lactanet database for each farm size and productivity class. The percentage change in cattle weight was used as an indicator of changes in body weight, mature weight and weight gain from the 2001 benchmark values established by Boadi et al. (2004a). The resulting dairy animal weight time series is also incorporated into the Tier 2 methodology.

Table A3.4–3 **Typical Characteristics of Canadian Dairy Production in 2001**

Animal Category / Parameters	Production Characteristics[b]	Data Sources[c]
Dairy cows[a]		
Average weight, kg	634 (51)	Okine and Mathison (1991); Kononoff et al. (2000); Petit et al. (2001)
Mature weight, kg	646 (55)	
Conception rate, %	59.2 (7.3)	
Calves		
Birth weight, kg	41 (3.3)	
Average weight, kg	186 (18.5)	
Mature weight, kg	330.5 (37.6)	
Daily weight gain, kg day^{-1}	0.7 (0.3)	
Calf crop,[d] %	93 (6)	
Replacement heifers		
Average weight, kg	461.6 (24.7)	
Beginning weight (1 year), kg	327.8 (31.0)	
Mature weight at calving, kg	602.1 (45.9)	
Mature weight, kg	646.1 (54.9)	
Daily weight gain, kg day^{-1}	0.77 (0.14)	
Replacement rate, %	32.3 (3.2)	Western Canadian Dairy Herd Improvement Services (2002)

Notes:
a. Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian dairy production, as reported in the CRTs.
b. The numbers in parentheses represent the standard deviation.
c. Values with no references were obtained from expert consultations (see Boadi et al., 2004b).
d. "Calf crop" is the percentage of the overwintering cows that produced a live calf.

6 https://lactanet.ca/en/library/

7 https://www.cdc-ccl.ca/en/node/643

Milk Yield and Fat Data

Milk productivity has increased in all Canadian provinces (Table A3.4–4), as documented by Lactanet, which collected a sample of milk production representing approximately two-thirds of the Canadian dairy cow population for the 1999–2024 period and compiles and prepares the data for use in the inventory. These data are the best estimate of actual milk production per cow per province in Canada and are a representative sample of overall milk production in Canada as the recorded milk statistics capturing all farm sizes and levels of milk productivity. However, from 1990 to 1998, this data set does not exist for all of Canada. The only data that are available from 1990 to 1998 for all of Canada are publishable data that were reported by AAFC. The publishable data are collected for the most productive animals and the quantity of milk that is produced in the first 305 days of their lactation period. The time series of milk production for the entire Canadian herd from 1990 to 1998 was calculated based on the average ratio between the publishable data and the management data from 1999 to 2007. The trend of increased milk production is reflected in the emission factor for dairy cows.

Length of Time in a Production Environment

It was assumed that cows that were dry (not lactating) during the summer months were on pasture; cows that were dry during the remainder of the year were in confinement. Replacement heifers were assumed to calve at 24 months. Lactation cycles were on average 320 days; however, cycles vary regionally and are based on herd productivity.

Percentage of Cows Pregnant

An estimate of the percentage of cows pregnant in the herd at any given time was calculated in Boadi et al. (2004a) by dividing average gestation length by the regional average calving interval and subtracting the number of cows that are culled annually due to reproductive failure.

Table A3.4–4 **Average Milk Production from 1990 to 2024 by Province**

Year	Average Milk Production (kg head^{-1} day^{-1})									
	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC
1990	21.0	20.9	21.0	20.8	20.3	21.7	22.1	22.2	23.2	24.3
2005	27.0	27.1	26.9	26.4	25.9	26.7	27.4	29.3	29.3	30.4
2018	31.8	31.6	31.1	29.8	30.3	31.3	32.0	37.0	35.5	33.9
2019	34.9	33.1	32.0	30.2	31.2	32.5	33.2	36.4	35.7	34.3
2020	33.7	32.8	31.6	30.4	31.5	33.2	34.1	36.2	34.7	35.1
2021	34.5	34.0	32.9	31.2	31.9	34.6	34.0	36.5	35.7	35.4
2022	33.5	33.6	32.7	30.5	32.0	34.2	35.5	37.8	36.6	35.4
2023	37.3	32.2	32.2	30.3	31.7	34.5	33.4	37.1	36.0	34.4
2024	34.5	33.9	32.7	30.0	32.1	34.2	34.6	38.2	37.8	36.3

Note:
Data source: Lactanet (2024)

Ration Digestibility (DE%)

Digestibility of rations (DE%) was derived from feed data in the Lactanet database and COP surveys. The values used in the Tier 2 calculations are weighted averages based on measured digestibility in the different diets associated with a specific farm size and productivity class from the data collected by Lactanet. For individual provinces not represented directly by Lactanet's data, DE% values were obtained by multiplying the DE% by the proportion of animals in each farm size and productivity class for each province. The provincial DE% time series was then inserted into the existing Tier 2 approach, replacing the fixed values from Boadi et al. (2004a).

Since 1990, the proportion of hay in feed has decreased, while the proportion of silages has increased. Silages typically have a higher feed value as the digestible portion of the feed is better preserved and, as a result, more of the feed is available for digestion by the animal. Furthermore, there has been a small overall increase in the quantity of concentrates and supplements used in diets. Overall, DE% ranges from 69% to 72% for lactating cows, and 63% to 65% for dry cows, while heifers were assumed to have a diet similar to dry cows.

A3.4.1.1. Non-Dairy Cattle

Production Practices and Performance

Production practices for livestock reported under Non-Dairy Cattle also vary across the country due to climate, land prices and differences in traditional farming practices. The study conducted by Boadi et al. (2004a) characterized the predominant practices in 2001 for each province according to animal type, physiological status, age, gender, growth rate, activity level and production environment. The values presented in Table A3.4–5 provide examples of production performance data collected for Canadian beef cattle, originally used as a QA verification of the data incorporated in the Tier 2 method.

Trends in carcass weights are used as an indicator of changes in mature weight relative to the 2001 benchmark values established by Boadi et al. (2004a) for the specific animal subcategories presented in Table A3.4–6. Carcass weight data are collected by the Canadian Beef Grading Agency (CBGA) and published by AAFC (AAFC, n.d. [a]). Carcass weights increased from 1990 to 2003 for beef cows, heifers for slaughter, steers and bulls (Figure A3.4–2). Since 2003, beef cow carcass weights have remained relatively stable, but slaughter animal weights have continued to increase until recently when weights stabilized.

Table A3.4–5 **Typical Characteristics of Beef Production in Canada in 2001 from Various Sources**

Animal Category / Parameters	Production Characteristics[a]	Data Sources[b]
Beef cows		
Average weight, kg	603 (36)	Kopp et al. (2004)
Mature weight, kg	619 (52)	AAFRD (2001)
Milk, kg day^{-1}	7.3 (1.2)	Kopp et al. (2004)
Milk fat, %	3.6 (0.6)	Kopp et al. (2004)
Conception rate, %	93.7 (1.3)	Manitoba Agriculture and Food (2000); AAFRD (2001)
Replacement heifers		
Average weight, kg	478 (34)	
Mature weight, kg	620 (51)	
Daily weight gain, kg day^{-1}	0.64 (0.14)	
Replacement rate, %	14.4 (3.1)	Manitoba Agriculture and Food (2000)
Bulls		
Yearling weight, kg	541 (18)	
Average weight, kg	940 (98)	
Mature weight, kg	951 (112)	
Daily weight gain, kg day^{-1}	1.0 (0.17)	
Calves (including dairy calves)		
Birth weight, kg	40 (3)	AAFRD (2001)
Wean weight, kg	258.4 (19.1)	Small and McCaughey (1999)
Age at weaning, days	215 (15)	
Daily weight gain, kg day^{-1}		
- Replacement heifers	0.67 (0.13)	Kopp et al. (2004)
- Backgrounders	0.98 (0.17)	
- Finishers	1.37 (0.12)	
Calf crop, %	95 (2.3)	
Heifer and steer stockers		
Average weight, kg	411 (47)	Kopp et al. (2004)
Mature weight, kg	620 (51)	
Daily weight gain, kg day^{-1}	0.98 (0.16)	
Proportion to feedlot, %	65 (30)	
Feedlot animals		
Average weight, kg		
- Direct finish	540 (25)	
- Background finish	562 (64)	
Mature weight, kg	630 (46)	
Finish weight, kg	609 (28)	
Daily weight gain, kg day^{-1}	1.37 (0.12)	

Notes:
Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian beef production, as reported in the CRTs.
a. The numbers in parentheses represent the standard deviations.
b. Values with no references were obtained from expert consultations compiled in Boadi et al. (2004b).

In 2003, the Canadian beef cattle industry was affected by bovine spongiform encephalopathy disease, which shut down beef exports to the United States. After 2003, the slaughtered carcass weights of bulls had evidently increased due to the culling of older bulls. To provide an estimate more representative of the on-farm herd, the average live weights of bulls were retained at their 2002 value. From 2009 to 2018, the slaughter weights of bulls were used in the time series again. Bull weights were observed to decrease considerably in 2013. This observation was verified; in general, bull weights are prone to higher variability due to the low numbers being slaughtered on an annual basis.

Figure A3.4–2 **Non-Dairy Cattle Carcass Weight, Based on Data Collected by CBGA and Published by Agriculture and Agri-Food Canada**

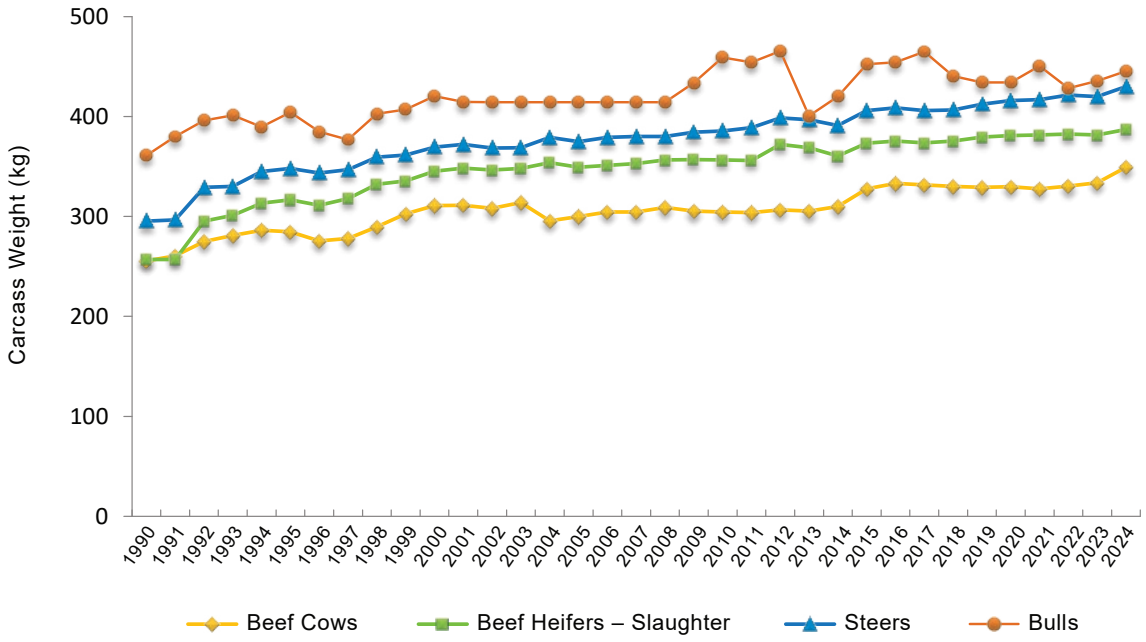


Table A3.4–6 **Indicators of Live Body Weight Change Over Time for Cattle Subcategories**

Cattle Subcategory	Trend in Live Weight Applied
Beef cows	Trends in beef cow carcass weight used as an indicator of live weight.
Heifers for slaughter	Trends in heifer carcass weight used as an indicator of live weight.
Beef heifers	Trends in beef cow carcass weight used as an indicator of live weight.
Steers	Trends in steer carcass weight used as an indicator of live weight.
Bulls	Trends in bull carcass weight used as an indicator of live weight from 1990 to 2002; 2003 to 2008 live weights are set constant to the 2002 live weight; for 2009–present, carcass weight trends used again.
Calves	No change
Dairy cows	Provincial trends in dairy cow productivity are used along with average body weight by productivity class as an indicator of live weight.
Dairy heifers	Trends in dairy cow live weight used as an indicator of dairy heifer live weight.

Length of Time in a Production Environment

Replacement heifers over 15 months of age are assumed to be bred or pregnant. All replacement stock (breeding bulls, young and replacement heifers over 12 months of age) is assumed to enter the breeding herd (mature breeding bulls and beef cows) at 24 months of age. Slaughter heifers and steers at 12 months of age are either in feedlots or backgrounded. Animals scheduled for slaughter may be identified as either short-keeps or long-keeps. Short-keeps go directly to the feedlot to be slaughtered after 3 to 4 months, whereas long-keeps are typically backgrounded for 6 months before being sent to feedlots, where they are finished after 2 to 4 months.

Ration Digestibility (DE%)

DE% values determined by Christensen et al. (1977) for forages grown on the Prairies were used to estimate DE% for Saskatchewan and Manitoba. Values from Alberta Agriculture, Food and Rural Development and the University of Alberta (2003) were used for Alberta, whereas values from the U.S. National Research Council (2001) were used to estimate DE% for British Columbia and the Eastern provinces. Overall, DE% ranged from 60% to 84%, depending on rations and feeding regimes.

Calves were assumed to have a non-functional rumen or to consume very small amounts of dry feed from birth until 2 to 3 months of age. Therefore, enteric CH_4 emissions in these first few months are assumed to be zero.

Examples of Regional Variability and Disaggregation of Parameters

The country-specific methodologies used by Canada to estimate emissions from cattle are implemented at various spatial scales and for different categories and are weighted to the national and Common Reporting Tables (CRTs) category levels for reporting in the NIR and in the CRTs.

Owing to the variability in parameters across the country, as a result of different farming practices, livestock populations, climate types, cropping systems, soil characteristics and other factors, Canada's national estimates, presented in the CRTs, represent weighted averages. Many of the calculations are carried out at a highly disaggregated level. Data are processed through a series of relational databases, and with tables that may contain more than 10 million records. This section aims to present some examples of cattle parameters for select year(s), region(s) and livestock categories, to improve the transparency of the country-specific approaches for cattle. An example of the provincial livestock activity data obtained from Statistics Canada is provided in Table A3.4–7, for major livestock types and for the most recent inventory year.

To calculate enteric fermentation emissions from cattle, populations are collected and maintained at the provincial spatial scale. However, the eight cattle subcategories are disaggregated into 38 production subcategories listed in Table A3.4–2, following the approach in section A3.4.2. GE is calculated as described in Equation A3.4–2 for each production subcategory (Table A3.4–8). The value of GE for each production subcategory is then weighted by the amount of time spent in each stage of production, to arrive at a weighted value per livestock subcategory, which is then converted to dry matter intake (DMI) (see Table A3.4–10) in the emission factor calculations in Equation A3.4–4. The provincial emission factors, GE values, milk production figures (Table A3.4–4), cattle weights (Table A3.4–9) and other parameters are weighted by the fraction represented by the provincial population of the subcategory in relation to the national population and then totalled to obtain the national values reported in the CRTs in the Dairy Cattle and Non-Dairy Cattle categories.

Table A3.4–7 **Provincial Livestock Populations by Subcategory for Select Livestock in 2024**

Category	Subcategory	Population (x1000 head)									
		AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
Cattle	Dairy cows	83	81	44	16	5.1	21	322	12	354	28
	Beef cows	1 545	180	373	11	0.7	15	219	7.5	119	982
	Bulls	94	13	21	0.6	0.1	1.1	16	0.6	7.5	54
	Dairy heifers	41	36	19	6.5	2.0	8.9	146	5.6	130	11
	Beef heifers	246	39	57	1.5	0.2	2.5	35	1.3	15	155
	Heifers for slaughter	512	18	38	2.0	0.2	2.0	121	4.4	19	77
	Steers	829	25	60	2.8	0.2	2.5	307	7.4	51	153
	Calves	1 598	168	312	15	2.5	17	416	17	290	813
Sheep & lambs	Sheep	103	24	41	3.7	1.7	9.5	169	4.6	113	50
	Lambs	95	20	40	3.1	1.4	7.5	121	5.6	76	40
Swine	Sows	111	6.0	356	5.8	0.1	2.9	319	3.5	296	116
	Boars	0.7	0.0	0.0	0.0	0.0	0.0	0.3	0.0	2.5	0.7
	Pigs (<20 kg)	573	31	1 443	17	0.3	7.5	1 406	16	1 345	408
	Pigs (20-60 kg)	328	18	680	2.2	0.1	1.2	827	7.1	969	156
	Pigs (>60 kg)	514	25	954	3.9	0.1	1.6	1 106	11	1 643	260
Poultry	Turkeys	541	734	656	61	4.2	189	2 453	2.6	1 351	93
	Hens	2 286	3 378	2 194	488	345	780	10 120	151	3 814	1 223
	Pullets	948	1 377	940	237	174	366	5 241	51	1 934	451
	Broilers	10 565	16 899	3 662	2 053	1 643	3 112	35 858	276	29 275	4 604
Other	Goats	34	17	7.4	0.5	0.1	1.8	148	0.3	32	12
	Buffalo	65	15	12	0.0	0.0	0.0	3.0	0.0	1.7	53
	Horses	68	19	15	0.7	0.0	1.2	42	0.5	14	23
	Llamas and alpacas	2.8	1.7	0.4	0.1	0.0	0.1	4.2	0.1	1.8	1.3

Note:
Source: See Table A3.4–1

Table A3.4–8 **Example of Gross Energy Equation Parameters by Production System, for Two Provinces in 2024**

Year	Province	Subcategory	Production Subcategory	NE_m	NE_a	NE_g	NE_L	NE_p	REM	REG	DE	GE
2024	QC	Dairy cows	Lactating, confined	48	0	2.0	102	2.9	0.53	0.34	71	415
			Lactating, pasture	0	0	0	102	0	0	0	0	0
			Lactating, confined (after pasture)	0	0	0	102	0	0	0	0	0
			Dry, low-quality feed	40	0	2.0	0	2.4	0.51	0.30	64	139
			Dry, high-quality feed	0	0	0	0	0	0	0	0	0
			Dry, pasture	0	0	0	0	0	0	0	0	0
		Beef cows	Pregnant, confined	54	0	11	0	5.0	0.48	0.26	58	284
			Lactating, pasture	55	9.3	11	29	5.1	0.51	0.31	65	347
			Pregnant, confined	0	0	0	0	0	0	0	0	0
			Lactating, pasture	0	0	0	29	0	0	0	0	0
		Bulls	Mature, confined	74	0	0	0	0	0.48	0.26	58	267
			Mature, pasture	65	11	0	0	0	0.51	0.31	65	226
			Young, confined	50	0	14	0	0	0.48	0.26	58	270
			Young, pasture	51	9	15	0	0	0.51	0.31	65	256
			Young, confined	69	0	18	0	0	0.48	0.26	58	368
		Dairy heifers	Confined (243 days/year)	32	0	14	0	1.9	0.51	0.30	64	177
			Pasture	0	0	0	0	0	0	0	0	0
			Confined (365 days/year)	0	0	0	0	0	0	0	0	0
		Beef heifers	Young, not pregnant	37	0	15	0	0	0.48	0.26	58	233
			Early gestation	38	6	17	0	3.5	0.51	0.31	65	227
			Late gestation	52	0	20	0	4.8	0.48	0.26	58	335
		Heifers for slaughter	Feedlot, short-keeps	0	0	0	0	0	0	0	0	0
			Feedlot, short-keep, long-finish	0	0	0	0	0	0	0	0	0
			Confined	0	0	0	0	0	0	0	0	0
			Pasture	0	0	0	0	0	0	0	0	0
			Feedlot, long-keeps	40	0	27	0	0	0.56	0.38	84	170
		Steers	Feedlot, short-keeps	0	0	0	0	0	0	0	0	0
			Feedlot, short-keep, long-finish	0	0	0	0	0	0	0	0	0
			Confined	0	0	0	0	0	0	0	0	0
			Pasture	0	0	0	0	0	0	0	0	0
			Feedlot, long-keeps	37	0	23	0	0	0.56	0.38	84	152
		Calves	Birth to pasture	8.2	0	3.9	0	0	0	0	0	0
			Pasture	16	2.7	8.5	0	0	0.51	0.31	65	97
			Replacement heifers	30	0	13	0	0	0.48	0.26	58	193
			Background heifers	0	0	0	0	0	0	0	0	0
			Background steers	0	0	0	0	0	0	0	0	0
			Finisher heifers	31	0	21	0	0	0.50	0.28	61	228
			Finisher steers	31	0	18	0	0	0.50	0.28	61	209
	SK	Dairy cows	Lactating, confined	51	0	8.8	121	3.0	0.53	0.34	71	498
			Lactating, pasture	0	0	0	121	0	0	0	0	0
			Lactating, confined (after pasture)	0	0	0	121	0	0	0	0	0
			Dry, low-quality feed	43	0	8.8	0	2.5	0.51	0.30	63	190
			Dry, high-quality feed	43	0	8.8	0	2.5	0.52	0.32	67	173
			Dry, pasture	0	0	0	0	0	0	0	0	0
		Beef cows	Pregnant, confined	60	0	3.2	0	5.6	0.49	0.27	59	243
			Lactating, pasture	51	8.7	3.2	19	4.8	0.51	0.31	65	266
			Pregnant, confined	0	0	0	0	0	0	0	0	0
			Lactating, pasture	0	0	0	19	0	0	0	0	0
		Bulls	Mature, confined	94	0	0	0	0	0.49	0.27	58	329
			Mature, pasture	69	12	0	0	0	0.51	0.31	65	243
			Young, confined	61	0	13	0	0	0.49	0.27	58	297
			Young, pasture	55	9.4	15	0	0	0.51	0.31	65	269
			Young, confined	87	0	17	0	0	0.49	0.27	58	417
		Dairy heifers	Confined (243 days/year)	31	0	13	0	1.8	0.50	0.29	62	180
			Pasture	31	5.3	13	0	1.8	0.53	0.34	71	157
			Confined (365 days/year)	31	0	13	0	1.8	0.50	0.29	62	180
		Beef heifers	Young, not pregnant	34	0	7.0	0	0	0.49	0.27	59	160
			Early gestation	31	5.2	7.8	0	2.9	0.51	0.31	65	154
			Late gestation	50	0	8.9	0	4.7	0.49	0.27	59	242
		Heifers for slaughter	Feedlot, short-keeps	42	0	35	0	0	0.55	0.36	79	220
			Feedlot short-keep, long-finish	0	0	0	0	0	0	0	0	0
			Confined	36	0	20	0	0	0.53	0.33	69	189
			Pasture	0	0	0	0	0	0	0	0	0
			Feedlot, long-keeps	41	0	34	0	0	0.55	0.36	79	215
		Steers	Feedlot, short-keeps	40	0	30	0	0	0.55	0.36	79	196
			Feedlot, short-keep, long-finish	0	0	0	0	0	0	0	0	0
			Confined	34	0	17	0	0	0.53	0.33	69	170
			Pasture	0	0	0	0	0	0	0	0	0
			Feedlot, long-keeps	39	0	29	0	0	0.55	0.36	79	192
		Calves	Birth to pasture	10	0	4.3	0	0	0	0	0	0
			Pasture	16	2.6	9.1	0	0	0.51	0.31	65	100
			Replacement heifers	33	0	6.4	0	0	0.49	0.27	59	152
			Background heifers	36	0	17	0	0	0.53	0.33	69	176
			Background steers	36	0	14	0	0	0.53	0.33	69	164
			Finisher heifers	39	0	26	0	0	0.55	0.36	79	182
			Finisher steers	39	0	22	0	0	0.55	0.36	79	168

Note: Detailed descriptions of each parameter shown in this table (NE_m, NE_a, NE_g, NE_L, NE_p, REM, REG, DE, GE) can be found in Volume 4, Chapter 10, section 10.2.2 of the 2006 IPCC Guidelines, and are used to populate Equation 10.16.

Table A3.4–9 **Example of Cattle Weight Time Series by Production System, for Two Provinces in Select Years**

Province	Subcategory	Production Stage	Body Weight (kg)			Mature Weight (kg)		
			1990	2005	2024	1990	2005	2024
QC	Dairy cows	Lactating, confined	613	616	615	635	638	637
		Lactating, pasture	0	0	0	0	0	0
		Lactating, confined (after pasture)	0	0	0	0	0	0
		Dry, low-quality feed	613	616	615	635	638	637
		Dry, high-quality feed	0	0	0	0	0	0
		Dry, pasture	0	0	0	0	0	0
	Beef cows	Pregnant, confined	540	634	738	540	634	738
		Lactating, pasture	540	634	738	540	634	738
		Pregnant, confined	0	0	0	0	0	0
		Lactating, pasture	0	0	0	0	0	0
	Bulls	Mature, confined	790	906	974	790	906	974
		Mature, pasture	790	906	974	790	906	974
		Young, confined	481	552	594	790	906	974
		Young, pasture	576	661	711	790	906	974
		Young, confined	711	816	878	790	906	974
	Dairy heifers	Confined (243 days/year)	456	458	458	635	638	637
		Pasture	0	0	0	0	0	0
		Confined (365 days/year)	0	0	0	0	0	0
	Beef heifers	Young, not pregnant	349	410	477	540	634	738
		Early gestation	420	492	573	540	634	738
		Late gestation	520	610	710	540	634	738
	Heifers for slaughter	Feedlot, short-keeps	0	0	0	0	0	0
		Feedlot, short-keep, long-finish	0	0	0	0	0	0
		Confined	0	0	0	0	0	0
		Pasture	0	0	0	0	0	0
		Feedlot, long-keeps	363	493	611	485	659	816
	Steers	Feedlot, short-keeps	0	0	0	0	0	0
		Feedlot, short-keep, long-finish	0	0	0	0	0	0
		Confined	0	0	0	0	0	0
		Pasture	0	0	0	0	0	0
		Feedlot, long-keeps	391	496	569	522	662	760
	Calves	Birth to pasture	63	63	63	658	658	658
		Pasture	178	178	178	658	658	658
		Replacement heifers	331	331	331	658	658	658
		Background heifers	0	0	0	0	0	0
		Background steers	0	0	0	0	0	0
		Finisher heifers	360	360	360	658	658	658
		Finisher steers	360	360	360	658	658	658
SK	Dairy cows	Lactating, confined	666	678	678	738	751	751
		Lactating, pasture	0	0	0	0	0	0
		Lactating, confined (after pasture)	0	0	0	0	0	0
		Dry, low-quality feed	666	678	678	738	751	751
		Dry, high-quality feed	666	678	678	738	751	751
		Dry, pasture	0	0	0	0	0	0
	Beef cows	Pregnant, confined	494	579	675	494	579	675
		Lactating, pasture	494	579	675	494	579	675
		Pregnant, confined	0	0	0	0	0	0
		Lactating, pasture	0	0	0	0	0	0
	Bulls	Mature, confined	869	997	1072	869	997	1072
		Mature, pasture	869	997	1072	869	997	1072
		Young, confined	514	589	634	869	997	1072
		Young, pasture	640	734	789	869	997	1072
		Young, confined	759	871	937	869	997	1072
	Dairy heifers	Confined (243 days/year)	441	448	448	738	751	751
		Pasture	441	448	448	738	751	751
		Confined (365 days/year)	441	448	448	738	751	751
	Beef heifers	Young, not pregnant	277	325	379	494	579	675
		Early gestation	317	372	433	494	579	675
		Late gestation	379	444	518	494	579	675
	Heifers for slaughter	Feedlot, short-keeps	397	540	668	443	603	746
		Feedlot, short-keep, long-finish	0	0	0	0	0	0
		Confined	318	433	536	443	603	746
		Pasture	0	0	0	0	0	0
		Feedlot, long-keeps	385	524	648	443	603	746
	Steers	Feedlot, short-keeps	427	542	622	477	605	695
		Feedlot, short-keep, long-finish	0	0	0	0	0	0
		Confined	343	435	499	477	605	695
		Pasture	0	0	0	0	0	0
		Feedlot, long-keeps	415	526	604	477	605	695
	Calves	Birth to pasture	65	65	65	601	601	601
		Pasture	176	176	176	601	601	601
		Replacement heifers	296	296	296	601	601	601
		Background heifers	339	339	339	601	601	601
		Background steers	339	339	339	601	601	601
		Finisher heifers	371	371	371	601	601	601
		Finisher steers	371	371	371	601	601	601

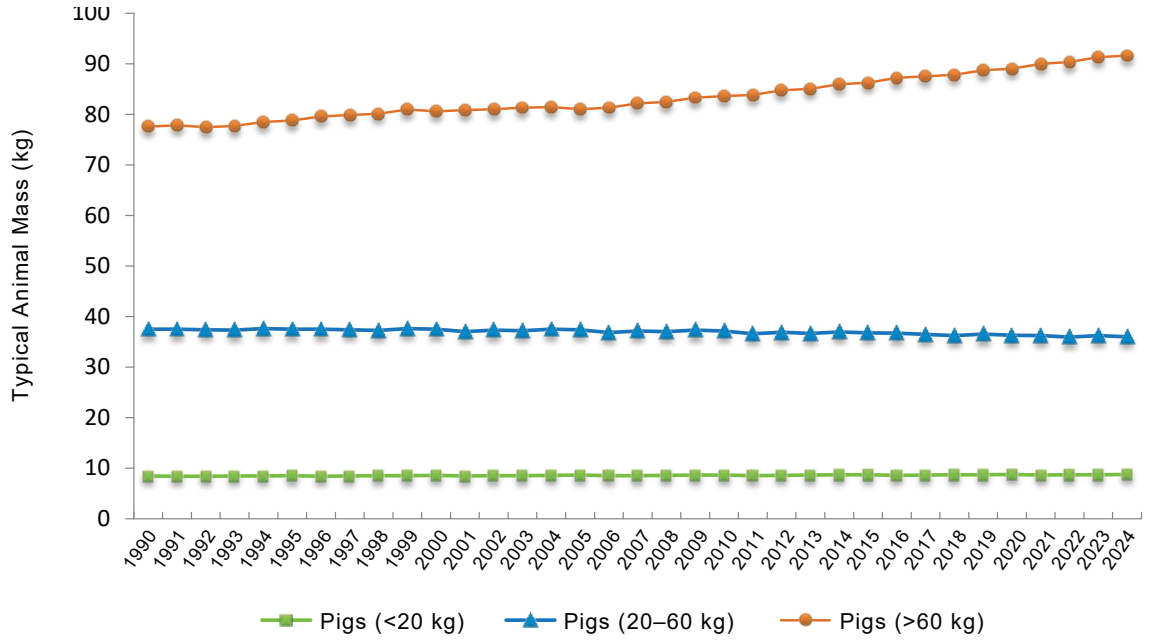
For the calculation of N_2O emissions from cattle manure, the eight cattle subcategories in Table A3.4–7 are retained. However, the spatial scale of the activity data is expanded from 10 provinces to 405 individual ecodistricts, which are further divided into 22 manure management types per animal category to estimate the N_2O emissions from manure management. The N from manure storage is applied across 32 crop types, in coordination with other N sources, and associated with eight soil N_2O emission factors per ecodistrict to estimate the direct N_2O emissions from the land application of manure.

A3.4.1.2. Swine

Production Performance

Trends in carcass weights are used as an indicator of changes in mature weight. Carcass weight data are collected and published by Statistics Canada as part of the quarterly Farm Cash Receipts survey (Statistics Canada, n.d.[b]). Average cold-trimmed carcass weights are converted to live weights using a corresponding conversion factor (AAFC, 2018). Since 1990, hog carcass weights have increased steadily from 77 kg to 104 kg (+36%), as a result of a change in production practices and genetics. Relationships between live weight and average daily weight gain, as well as changes in average daily weight gain over time by animal weight class, were developed based on data from the Prairie Swine Research Centre and combined with the time series of mature weights to develop a time series of typical animal mass for market swine. The typical animal mass for market swine varies by weight class (Figure A3.4–3) based on increased rates of growth and, in the case of the upper weight class, an increase in carcass weights since 1990. Animal mass for breeding animals was held constant using the default IPCC value.

Figure A3.4–3 **Typical Animal Mass of Swine, by Weight Class**



A3.4.2. CH_4 Emissions from Enteric Fermentation

The release of CH_4 from the enteric fermentation process is calculated using Equation A3.4–1 for all categories of livestock in Canada. CH_4 emissions reported under Enteric Fermentation for cattle are estimated using country-specific emission factors derived from IPCC (2006) Tier 2 equations (Table A3.4–11). For the other animal categories, the IPCC Tier 1 methodology and default emission factors are applied (see Annex 6).

Equation A3.4–1

$$CH_{4EF} = \sum_{T} \left(N_T \times EF_{(EF)T} \right)$$

CH_{4EF} = CH_4 emissions from the enteric fermentation process for all animal categories, kg
N_T = population of the Tth animal category or subcategory in each province
$EF_{(EF)T}$ = emission factor for the Tth animal category or subcategory, kg head^{-1} (Table A3.4–11 for cattle; for other animal categories, see Annex 6)

A3.4.2.1. Enteric CH_4 Emission Factors for Cattle

Emission factors were derived at the provincial level using IPCC (2006) Tier 2 equations for different subcategories of cattle (dairy cows, dairy heifers, beef cows, beef heifers, bulls, calves, replacement heifers, heifers > 1 year and steers > 1 year) based on stages of production. Tier 2 enteric fermentation estimates require an approximation of GE consumed calculated according to Equation A3.4–2.

Equation A3.4–2

$$GE = \left[\left[\frac{\left(NE_m + NE_a + NE_l + NE_p \right)}{(REM)} \right] + \left[\frac{NE_g}{(REG)} \right] \right] / \left[\frac{DE\%}{100} \right]$$

GE = gross energy, MJ day^{-1}
NE_m = net energy required for maintenance, MJ day^{-1}
NE_a = net energy required for activity, MJ day^{-1}
NE_l = net energy required for lactation, MJ day^{-1}
NE_p = net energy required for pregnancy, MJ day^{-1}
REM = ratio of net energy available in a diet for maintenance to digestible energy consumed
NE_g = net energy required for growth, MJ day^{-1}
REG = ratio of net energy available in a diet for growth to digestible energy consumed
$DE\%$ = digestibility of the ration, %

All net energy estimates are applied according to equations in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). Due to the Canadian climate, Equation 10.2 from the Guidelines (Equation A3.4–3) was implemented for Non-Dairy Cattle.

Equation A3.4–3

$$Cf_i \text{ (in cold)} = Cf_i + 0.0048 \times (20 - T°C)$$

Cf_i = coefficient that varies for each animal category relating weight to energy requirements for body maintenance, MJ day^{-1} kg^{-1}
$T°C$ = mean daily temperature during the winter season in °C

The cold-adjusted Cf_i was derived by using the average temperature for the period October to April for each Canadian province, weighted based on the geographic location of non-dairy types of cattle (distributed at the ecodistrict scale) in the province. It was then corrected based on the percentage of animals kept in barns for different provinces, taken from Sheppard and Bittman (2012) and was applied to all production stages that occur during the winter months. Production stages that occur in both winter and summer, specifically finishing stages for steers and slaughter heifers, were averages of the default and the cold-adjusted Cf_i. As a result of this implementation, considering the different production stages of the animal, average annual Cf_i values varied between 0.43 for non-dairy cows in Manitoba, the coldest province, and 0.37 for non-dairy cows in Ontario and some of the Maritime provinces. Based on a weighting of production stages, the Cf_i would typically be 0.35, not considering the temperature effect. The lower Cf_i in Eastern Canada is due mainly to milder temperatures, but also to the practice of keeping animals in barns over winter, whereas in Western Canada, cattle are mainly kept outdoors. As a result, the impact of cold on the net energy of maintenance is largely observed in Western Canada.

Different stages of production require different consumption patterns to supply the necessary energy for specific animal products and environmental conditions and therefore have different GE values. For example, emissions reported under Dairy Cattle were estimated for two production categories: dry cows and lactating cows. Lactating cattle require high consumption rates (GE) for milk production. Dry cattle may also be confined or on pasture, which also modifies their required energy intake.

The total duration of time an animal spends in a production stage can also be variable, and a weighted average emission factor was therefore calculated. Criteria used in the weighting included duration of time spent in each production stage and relative percentage of the population in each stage of production. Furthermore, some net energy calculations may be modified based on a factor that considers the time at which energy is supplied within a production stage.

For each province, an emission factor ($EF_{(EF)T}$) is calculated according to Equation A3.4–4. Provincial emission factors were weighted on the basis of the proportion of the provincial animal population relative to the national population to calculate a national emission factor for each subcategory, for each year in the time series (Table A3.4–11). For emission factors reported under Non-Dairy Cattle, the IPCC default methane conversion rate (Y_m) of 6.5% was used to calculate non-feedlot cattle emission factors and 3% was used for animals in feedlots.

The dairy Y_m factor was derived directly from production data and empirical CH_4 prediction equations developed from North American research. Briefly, the farm size by productivity matrix used to derive ration digestibility was also used to provide more detailed feed characteristics such as neutral detergent fibre, fat content and non-fibre carbohydrate content. These feed, herd and production characteristics separated by farm size and productivity class were inserted into 12 predictive methane equations, compiled from three scientific publications (Ellis et al., 2007, 2010; Appuhamy et al., 2016). Gross energy for each production and farm size class was calculated according to Equation A3.4–2 based on the herd-specific characteristics. Finally, the methane conversion rates (Y_m) were back calculated from predicted methane emissions and calculated GE intake.

An average Y_m per productivity and farm size class was calculated based on the results of the 12 predictive equations. This value was then weighted for each province based on the proportional breakdown of the population of animals in each productivity and farm size class in the same way as a provincial digestibility value was derived. The Y_m that was derived varied between 5.9% for the lowest productivity classes and 5.4% for the highest productivity class. Weighted provincial Y_m values varied between 5.5% and 5.7%.

Dry matter intake (DMI) is based on the cattle production approach and calculated at the provincial level based on regional trends and seasonal stages of production. Weighted national DMI (Table A3.4–10) for dairy cows has increased by 28% since 1990 in response to increased milk production per cow (Table A3.4–4), while DMI for dairy heifers decreased by 3% over this period due to increased feed digestibility resulting from changes in ration composition. For beef cattle, DMI is driven by trends in carcass weights (Figure A3.4–2).

Equation A3.4–4

$$EF_{(EF)T} = \sum_{T} \left[\frac{GE_P \times Y_{mP} \times 365}{55.65} \times TP_P \right]$$

$EF_{(EF)T}$ = annual emission factor for defined animal population T, kg head^{-1} yr^{-1}
GE_P = gross energy for a given stage of cattle production P, MJ day^{-1}
Y_{mP} = methane conversion rate, or the rate at which the fraction of GE is converted to methane by an animal in defined population T, m^3 kg^{-1}
55.65 = energy content of methane, MJ kg^{-1} CH_4
TP_P = time within a stage of production P, days yr^{-1}

Table A3.4–10 **Dry Matter Intake by Cattle Subcategory, for Selected Years from 1990 to 2024, Estimated from Gross Energy Intake**

Year	DMI (kg DM head^{-1} day^{-1})							
	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[a]	Steers[a]	Calves
1990	17	10	14	13	10	10	9	6
2005	18	10	15	15	11	11	10	7
2018	20	10	16	15	12	12	11	7
2019	21	10	16	15	12	12	11	7
2020	21	10	16	15	12	12	11	7
2021	21	10	16	15	12	12	11	7
2022	21	10	16	15	12	12	11	7
2023	21	10	16	15	12	12	11	7
2024	21	10	16	16	12	12	11	7

Note:
a. Reported as kg head^{-1} day^{-1}; however, emissions are calculated based on time to slaughter.

Table A3.4–11 **CH_4 Emission Factors for Enteric Fermentation in Cattle, for Selected Years from 1990 to 2024**

Year	$EF_{(EF)T}$ (kg CH_4 $head^{-1}$ yr^{-1})[a]							
	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	115.4	79.4	108.0	105.9	82.5	44.7	41.4	43.8
2005	125.0	77.2	119.9	114.4	87.0	52.8	46.0	43.6
2018	139.6	76.7	125.5	120.6	91.4	54.0	48.7	43.9
2019	142.1	76.7	124.2	120.4	91.2	54.2	49.3	43.8
2020	142.9	76.7	124.2	120.5	91.3	54.2	49.6	43.9
2021	145.3	76.7	127.6	120.0	90.9	54.2	49.7	43.9
2022	145.8	76.7	123.2	120.7	91.4	54.6	49.9	43.9
2023	145.6	76.7	124.6	121.5	91.8	54.4	49.6	44.0
2024	147.4	76.7	126.6	124.7	93.9	57.1	50.1	44.0

Notes:
a. Enteric emission factors are derived from Boadi et al. (2004b), modified to take account of trends in milk production in dairy cows and carcass weights for several beef cattle categories.
b. Reported as kg $head^{-1}$ yr^{-1}; however, emissions are calculated based on time to slaughter.

A3.4.2.2. Verification of Parameter Selection Against Canadian Research

In 2011, an internal Tier 2 quality assurance/quality control (QA/QC) was carried out on the Enteric Fermentation source category (MacDonald and Liang, 2011). In this analysis, a review and compilation of Canadian literature related to methane production from the process of enteric fermentation were carried out. The results were then evaluated in light of the implementation of the 2006 IPCC Guidelines.

The 2011 analysis research measuring enteric fermentation processes in Canada indicates that the average measured methane conversion rates (Y_m) are 6.6% (±2.4) of GE for non-dairy cattle animals outside of feedlots, 3.2% (±1.9) of GE for non-dairy types of cattle on feedlots and 5.7% (±0.9) for dairy livestock (McCaughey et al., 1997, 1999; Boadi and Wittenberg, 2002; Boadi et al., 2002, 2004b; McGinn et al., 2004, 2008, 2009; Beauchemin and McGinn, 2005, 2006; Chaves et al., 2006; Kebreab et al., 2006; Ominski et al., 2006; Odongo et al., 2007; Eugène et al., 2008; Van Haarlem et al., 2008; Beauchemin et al., 2009; Ellis et al., 2010; Jayasundara et al., 2016). For the Non-Dairy Cattle category, these values agree broadly with the values published in the 2006 IPCC Guidelines. A study by Escobar-Bahamondes et al. (2017) suggests that further differentiation of Y_m factors by production subcategory is possible, which could aid in improving the accuracy of emission estimates. From the same compilation of research, the emission factor for the Non-Dairy Cattle category is observed to be 57 (±22) kg CH_4 $head^{-1}$ yr^{-1} outside of feedlots and 56 (±24) kg CH_4 $head^{-1}$ yr^{-1} in feedlots, and the average measured emission factor for the Dairy Cattle category is 130 (±34) kg CH_4 $head^{-1}$ yr^{-1}.

Caution must be used in interpreting these values because this data set did not include animals in cold conditions and because most studies focus on yearling heifers and steers. Also, the average value does not consider the relative importance of different cattle subcategories to the average emission factor. Nonetheless, the emission factor values do agree, in general, with the emission factors used by Canada for the Non-Dairy Cattle category (i.e., 60 to 70 kg CH_4 $head^{-1}$ yr^{-1}) and Dairy Cattle category (i.e., 115 to 146 kg CH_4 $head^{-1}$ yr^{-1}). Publication by Jayasundara et al. (2016) compiled literature data from 11 studies and found that Y_m for Canadian dairy livestock were on average 5.7% (±0.9). In the current Canadian cattle approach, Y_m for dairy cows is varied over time and by province, averaging 5.5%–5.7% of GE, while a fixed Y_m of 6.5% is used for dry dairy cows and dairy heifers.

As it currently stands, no evident bias could be identified from the review of Canadian literature results. It appears that a bias that is introduced through the use of the Y_m values from the 2006 IPCC Guidelines is compensated for by the estimate of GE for specific animal subcategories.

Researchers from Canada have participated in some extensive reviews and validations of the IPCC Tier 2 enteric fermentation method comparing measured and observed emissions using Canadian data. In general, their analysis indicates that the IPCC Tier 2 method tends to underestimate high-emitting animals and overestimate low-emitting animals (Ellis et al., 2007, 2009, 2010).

Improvements to the dairy methodology first implemented in the 2018 National Inventory Report, in particular the Y_m derived directly from empirical relationships from North American studies, assure that emission rates are consistent with recent measurements of CH_4 emissions, greatly improving the accuracy of emission estimates. Similar approaches would significantly improve estimates for the Non-Dairy Cattle category, but data are still being compiled to carry out these studies. In general, it is difficult to improve Canadian estimates through updates of single parameters. Improving on the current approach requires a comprehensive approach effectively linking regional animal production characteristics to animal productivity, as has been done for the Dairy Cattle category.

A3.4.2.3. Enteric CH_4 Emission Factors for Non-Cattle

For non-cattle animal categories, IPCC Tier 1 emission factors are used to calculate emissions (see Annex 6). When default emission factors are not available for the minor livestock categories, logical proxies are used to estimate emissions; swine emission factors are used for wild boars, and sheep emission factors are used for llamas and alpacas. These proxies are based on species similarities as well as similarities in production practices. Emissions from llamas and alpacas are combined because population totals are not available separately and there is no indication of the ratio of these animals in Canadian statistics.

A3.4.2.4. Uncertainty

An uncertainty analysis was carried out for all methodologies used to calculate methane emissions from livestock in 2010, building on a study by Karimi-Zindashty et al. (2012). A comprehensive uncertainty analysis was carried out on all methodologies used in the calculation of methane from livestock for 2010. Uncertainty ranges (percentages) of means were rerun for the 2014 NIR submission and have not been rerun since that submission. In the analysis, a stochastic representation of the livestock CH_4 emission quantification approach was built in Mathematica© and a Monte Carlo simulation (MCS) was run according to the methodology proposed in the IPCC good practice guidance (IPCC, 2000). This analysis built on the study of Karimi-Zindashty et al. (2012). However, the Environment Canada stochastic model (ECSM) built in Mathematica© (1) applied the exact parameters and equations used in the Canadian inventory methodology based on the Good Practice Guidance (IPCC, 2000); (2) included uncertainty associated with populations and duration of production stages, which impacts subcategory emission factors (Table A3.4–12); and (3) used the provincial distribution of manure management systems with improved estimates of probability distributions (Table A3.4–12). The ECSM was run for the years 1990, 2005, 2010 and 2012. A trend analysis was carried out to establish the uncertainty in the estimate of the differences in emissions from 1990 to 2012. The relative uncertainties from the previous analysis were applied to the current year's values. Uncertainty analysis on the revised dairy methodology, however, has not yet been carried out and reported uncertainty estimates are based on the Boadi et al. (2004a) methodology.

Currently, the data required to create probability distributions of the coefficients used in the agricultural IPCC Tier 2 method simply do not exist. Some of the default coefficients in Tier 2 equations are provided with an uncertainty range, often estimated by expert opinion; for other coefficients, ranges are taken from a few studies, often using methodologies that are not easily comparable. In general, the analysis of Rypdal and Winiwarter (2001) applies to the agricultural emission estimation approach as a whole, and it can be understood that large probability distributions are associated with default Tier 2 coefficients due to a lack of appropriate measurements and subsequent generalizations, uncertainties in measurements and an inadequate understanding of emission processes. This initial uncertainty analysis has applied a precautionary principle, and for coefficients with very little information, uncertainty bounds were conservative.

Uncertainties in populations of major animal categories, i.e., cattle, swine and sheep, were supplied directly by Statistics Canada based on biannual and quarterly survey statistics. For small provinces with few animals in certain categories, sample variance is large, as indicated by uncertain values of > ±50%. However, because the data were collected based on a sampling design proportional to population distributions, the overall uncertainty for major animal categories at the national level was low. National populations for non-dairy cattle types have the lowest uncertainty (±1.8% of the mean), with slightly higher uncertainty for swine (±2.6% of the mean), dairy cattle (±5.4% of the mean) and sheep (±6.0% of the mean).

All other animal population estimates are renewed only through the COA. To account for the increase in uncertainty due to the time that has elapsed since the census, a procedure was developed that estimated the increase in uncertainty as a function of time from the census. A linear regression was run through census year population estimates from 1991, 1996, 2001, 2006 and 2011. The uncertainties for populations in 2012 were estimated as the agricultural census uncertainty at the provincial level plus the 95% confidence interval for the linear regression multiplied by the number of years since the last census (one year). Due to the recent COA, the other animals tended to have lower population uncertainties in the 2012 analysis than the 2010–2011 uncertainties, similar to those animals for which population estimates are taken from biannual and quarterly surveys, though this had little impact on total uncertainty. The national population uncertainties for other animal categories ranged from ±2% of the mean for poultry to ±4% of the mean for bison; however, these animal categories contribute little to total emissions.

The parameters used in the calculation of Tier 2 emission factors for cattle can be divided into two categories: (1) those associated with cattle production and performance (see section A3.4.2 for detailed descriptions of parameters); and (2) those that are specific to the IPCC Tier 2 equations (see section A3.4.2 for details). For the most part, the uncertainty assigned to parameters associated with cattle production and performance is relatively low, as these estimates are collected on a provincial basis, from provincial experts, and are values that are generally known within the industry. The largest source of uncertainty in production practices is the duration and fraction of animal populations in specific production stages. This source of uncertainty is associated with the number of animals that are backgrounded and the duration of that backgrounding period. These are parameters that are highly dependent on prices and import/export markets, and therefore confidence in the values that are currently being used is low. A high level of uncertainty (30%) was applied to the number of animals backgrounded, and a non-symmetrical triangular distribution was applied to the duration of

backgrounding as a precautionary approach to account for high levels of potential variability in these production practices. The uncertainty in production population fraction and the duration of production stages was not accounted for directly in Karimi-Zindashty et al. (2012).

The uncertainties for parameters used in IPCC Tier 2 equations were taken, for the most part, directly from Karimi-Zindashty et al. (2012), who used the probability distributions either from Monni et al. (2007) or from the 2006 IPCC Guidelines. Two differences are notable: (1) digestible energy probability distributions became available from data supplied by Lactanet after the Karimi-Zindashty et al. (2012) study was completed, allowing the calculation of typical distributions of different types of feed; and (2) Karimi-Zindashty et al. (2012) used the 2006 IPCC methodology and therefore did not include the effects of weight loss on GE. A uniform distribution was therefore used in the ECSM analysis to account for the impact of incorporating an estimate of net energy mobilized through weight loss during lactation (NEmob) that varied according to duration of weight loss between 0% and 20% of the lactation period. As this parameter has been removed from the 2006 IPCC Guidelines, this approach was an effective way to evaluate the overall impact of this parameter.

A trend analysis was carried out using the ECSM in which the uncertainty in the magnitude of the change in emissions over time was calculated. For the long-term trend, emissions for 1990 and 2012 were calculated simultaneously, allowing only time-dependent parameters to vary independently in the estimates. These parameters are the elements of the calculation approach that change over time, and therefore an estimate is available for a value in 1990 and in 2012 (noted by a superscript 7 in Table A3.4–12). The parameters in 1990 and 2012 are considered entirely independent and, as a consequence, for each calculation in the MSC, a value was selected from the probability distribution for 1990 and 2012 independently. In contrast, other parameters used a value selected once from their probability distribution for the calculation of emissions in both 1990 and 2012. The parameters that were allowed to vary independently for the enteric fermentation process analysis were animal populations, milk production and fat content for dairy cows, and body weights for cattle. The relative uncertainty values for the trend analysis were applied to the 2013 results.

The summary results of the uncertainty analysis for emissions from the process of enteric fermentation are reported in Chapter 5, section 5.2.3. Briefly, the fixed range used in calculating uncertainty ranges for emissions from enteric fermentation is 39% (-17% to +22% of the mean) (see Chapter 5). Most uncertainty in the estimate is associated with the Tier 2 emission factors for cattle; they lie within an uncertainty range of -19% to +22% of the mean emission factor for the Non-Dairy Cattle category and -16% and +21% of the mean emission factor for the Dairy Cattle category. In the case of other animals that use Tier 1 IPCC (2006) default emission factors, uncertainty ranges of ±50% were assigned, except for swine, which was ±37% based on Monni et al. (2007). Relative to cattle, the Tier 1 emission factors for other animals have little impact on the total uncertainty because of the small contribution of other animal categories to total enteric fermentation emissions. Mean emissions for both the Dairy Cattle and Non-Dairy Cattle categories estimated using the stochastic model are slightly higher than calculated in the inventory database (roughly 2%). This difference is likely due to the introduction of the non-symmetrical triangular distribution that increased the length of backgrounding for slaughter heifers and steers and to the uniform distribution of the factor that defines energy released from weight loss during lactation in dairy cows.

The overall uncertainty for each estimate of each individual year changes little over time. The uncertainty range for emissions in 1990 and 2012 is 39% to 40%. Based on the trend analysis, over the long term, CH_4 emissions increased between the 1990 base year and 2012 by 9% to 19%, with a most likely value (MLV) of 15% (trend uncertainty 10%). Most of the increase in emissions is associated with the Enteric Fermentation category, which increased by 11% to 22%, with an MLV of 16%. To estimate the trend uncertainty reported in Chapter 5, the relative trend uncertainties from the previous analysis were applied to the current year's mean change in emissions. In general, this uncertainty analysis was consistent with other agricultural estimates of uncertainty. The paper by Monni et al. (2007) is, an example of an analysis detailing agricultural CH_4 emission uncertainty with the use of IPCC Tier 2 methodology. The use of comparable probability distributions for IPCC Tier 2 default parameters provides comparability between the two different national emission estimation methodologies. Monni et al. (2007) estimated the national-scale uncertainty for Enteric Fermentation emissions from Finnish agriculture for different cattle subcategories as ranging from -22% to +29% of the mean to -29% to +39% of the mean. Rypdal and Winiwarter (2001) reported uncertainties for some European countries ranging from ±20% of the mean in the United Kingdom to ±50% of the mean in Austria, but they used mainly Tier 1 estimation methodologies. We did not find comparable publications for trend uncertainty analysis in the field of agriculture.

The results of this uncertainty analysis were, of course, very similar to those produced by Karimi-Zindashty et al. (2012), who also observed an overall uncertainty range for enteric fermentation emissions of 39%, indicating that the uncertainty associated with the production stage duration and population fractions had little impact on the overall uncertainty. The incorporation of the uncertainty associated with weight loss during lactation did not increase overall uncertainty, but tended to skew the uncertainty distribution for Dairy Cattle category estimates towards higher emission estimates. The sensitivity analysis carried out by Karimi-Zindashty et al. (2012) indicated that the major drivers of uncertainty in emission estimates were associated with the default IPCC Tier 2 parameters, in particular the methane conversion rate (Y_m) and the factor associated with the net energy of maintenance (Cf_i), applied at the national scale. Uncertainty in the Tier 2 methodology may be reduced through the development of country-specific parameters at the regional scale for different animal categories. It is suspected that the recent revisions to the dairy methodology will have reduced the overall uncertainty of enteric emission estimates; however, further analysis is required to quantify the impact of improvements on the uncertainty estimates.

A3.4.3. CH_4 Emissions from Manure Management

The IPCC Tier 2 methodology is used to estimate CH_4 emission factors from manure management systems (IPCC, 2006), also referred to as animal waste management systems (AWMS). Equation A3.4–5 is used to calculate CH_4 emissions from the management of manure for all categories of livestock in Canada except for deer and elk, rabbits, mules and asses, and fur-bearing animals, which were calculated using IPCC Tier 1 emission factors. Wild boar emission factors were calculated based on average swine Tier 2 parameters, but assuming only solid manure. Sources of animal population data are the same as those used in the reporting of Enteric Fermentation estimates and are listed in Table A3.4–1.

When default emission factors or country-specific information sources are not available for the minor livestock categories, logical proxies are used to estimate emissions. These proxies are based on similarities between species as well as in production practices. When proxies are used at a provincial level, the weighted national values for the native and proxy livestock categories may not match due to differences in the provincial populations used for weighting.

The following proxies and expert judgments are used for minor animal categories:

- Manure management system parameters for the Non-Dairy Cattle category are used to represent bison, including maximum CH_4 producing potential (B_0) and provincial AWMS distribution.
- Provincial AWMS distributions for horses are used to represent mules and asses.
- Provincial AWMS distributions for the Non-Dairy Cattle category are used to report emissions from deer and elk, except for liquid systems, which are allocated to pasture, range and paddock (PRP) based on the expert judgment that deer and elk manure is unlikely to be handled in liquid manure systems.
- Values for VS in the Swine category are used to represent wild boars at the provincial level. However, this proxy relationship does not include the disaggregation of Swine animal subcategories and the use of animal mass to scale VS (section A3.4.3.6). Lastly, all wild boar manure is allocated to solid AWMSs based on expert judgment.
- Parameters for sheep manure management systems are used to represent llamas and alpacas, including VS and provincial AWMS distributions.

Total emissions from the minor animal categories of Mules and Asses, Deer and Elk, Llamas and Alpacas, Mink, Foxes, Rabbits and Wild Boars represented less than 100 kt CO_2 eq in 2024 (<0.2% of total agricultural emissions), including direct and indirect emissions and emissions resulting from the application of manure on agricultural soils. Changes to these proxies would not have a significant impact on emission estimates from the agricultural sector, and based on the insignificant impact of these animal categories on agricultural emissions, improvements to these animal categories are of the lowest priority in the agricultural inventory.

Equation A3.4–5

$$CH_{4MM} = \sum_{T} \left(N_T \times EF_{(MM)T} \right)$$

CH_{4MM}	=	emissions for all animal categories, kg CH_4 yr^{-1}
N_T	=	animal population for the Tth animal category or subcategory in each province
$EF_{(MM)T}$	=	emission factor for the Tth animal category or subcategory calculated according to Equation A3.4–6, kg CH_4 $head^{-1}$ yr^{-1}

To develop Tier 2 CH_4 emission factors representing manure management systems, country-specific inputs were required that consider climate, livestock rations, and the type of manure storage system included in Equation A3.4–6. The following equation is used to develop an IPCC Tier 2 estimate of CH_4 emission factors from manure management systems:

Equation A3.4–6

$$EF_{(MM)T} = VS_T \times 365 \times B_{0T} \times 0.67 \times \sum_{ij} MCF_{ij} \times AWMS_{Tij}$$

$EF_{(MM)T}$	=	annual emission factor for defined animal population T, kg CH_4 $head^{-1}$ yr^{-1}
VS_T	=	daily volatile solids excreted by an animal in defined population T, kg day^{-1}
B_{0T}	=	maximum CH_4 producing potential for manure produced by an animal within defined population T, m^3 kg^{-1} volatile solids (VS)
MCF_{ij}	=	CH_4 conversion factor (MCF) for each manure management system i in climate region j
$AWMS_{Tij}$	=	system distribution factor, defined as the fraction of animal category T's manure that is handled using manure system i in climate region j, often referred to in IPCC documents as an animal waste management system (AWMS)
0.67	=	conversion factor of m^3 CH_4 to kg CH_4

The following sections outline the sources of input values for VS, DE%, ash content of manure, %(ASH), B_0, MCF and AWMS.

Table A3.4–12 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Enteric Fermentation**

Parameter Category	Parameter	Coefficient / Parameter Source	Distribution Type	Uncertainty Range[a]	Uncertainty Distribution Source and Notes	Spatial / Animal Category Allocation
POPULATION DATA[b]						
Biannual cattle surveys						
	Dairy	Statistics Canada (Table 003-0032)	normal	±6% – ±42%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[c]	Provincial / subcategory
	Non-dairy			±5% – ±73%		
Other survey-based populations						
	Swine	Statistics Canada (Tables 003-0004 and 003-0031)		±8% – ±89%		
	Sheep			±14% – ±80%		
Census of Agriculture						
	Goats	*Census of Agriculture* (Statistics Canada, 2012a)		±9% – ±21%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, and function of time from census	
	Poultry			±5% – ±12%		
	Bison			±18% – ±85%		
	Llamas and alpacas			±16% – ±42%		
	Horses			±5% – ±16%		
CATTLE PRODUCTION PARAMETERS AND PERFORMANCE						
	Milk production[b]	Valacta / Canwest DHI	normal	±8%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial / subcategory
	Fat content[b]					
	Dairy herd efficiency[b]					
	Pregnancy coefficient	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	
	Average daily gain (ADG)					
	Pregnancy period					
	Production stage duration		normal except slaughter animals, triangular, non-symmetric	±5%, Slaughter animals: MLV[f] from Boadi et al. (2004b) LB: 12% of MLV UB: 25% of MLV	Expert opinion, Boadi et al. (2004b) – for feeder heifers and steers, a triangular distribution was assumed based on interpretation of potential market effects (Canfax Research Services, 2009)	Provincial / production stage subcategory, internal correlation[g]
	Production stage population fraction		normal	±5% – ±30%		
Cattle weight estimates[b]						
	Live weight, 2001	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial / production stage subcategory
	Mature weight, 2001					
	Carcass weight	CBGA[d] and published AAF[e] (1990–2010)				National / subcategory
EMISSION FACTORS FOR CATTLE (IPCC TIER 2 EQUATIONS)						
	Methane conversion rate (Y_m)		normal	Feedlot animals – ±30% Other animals – ±15%	Karimi-Zindashty et al. (2012) – IPCC (2006)	National / feedlot vs. non feedlot
Calculation of gross energy for cattle, IPCC Tier 2 Equation A3.4–2						
	Digestible energy (DE)	Boadi et al. (2004b)	normal	Pasture ±9% Confined ±9% Background ±7.5% Prepared feed ±5.5%	Derived from raw data supplied by Valacta Dairy Services	Provincial / production stage subcategory
Net energy for cattle, Tier 2 Equations 4.1 to 4.10, IPCC Good Practice Guidance (2000)						
	Animal activity coefficient (C_a)	IPCC (2000)	normal	±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National / cattle
	Gender coefficient (C)			±30%		
	Maintenance coefficient Cf_i			±30%		
	Lactation coefficient			±30%		
	Weight loss rate			5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial / subcategory
	Weight loss duration		uniform	LB: 0 UB: 20% of lactation period	Interpretation of differences between 2000 and 2006 IPCC Guidelines	
Emission factors for non-cattle categories						
	Swine	IPCC (2000)	normal	±37%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National / category
	Other animals			±50%		

Notes:
a. Where differences in uncertainty exist for different provinces or animal categories, maximum and minimum uncertainties are given.
b. Values that were allowed to vary independently during trend analysis
c. Personal communication. Plourde R, Statistics Canada, Livestock and Food Section, Ottawa, ON. April 4, 2010
d. Canadian Beef Grading Agency
e. Agriculture and Agri-Food Canada
f. MLV = most likely value; LB = lower bound; UB = upper bound
g. Internal correlation indicates values that vary in terms of a fraction of the whole, i.e. a fraction of a total equalling 100%.

A3.4.3.1. Volatile Solids (VS)

Cattle, VS

Volatile solids (VS) are the organic fraction of total solids in manure. The VS of manure was estimated using the digestibility (DE%) of dietary intake, manure ash content and GE consumed by a given animal subcategory, and the urinary energy (UE) fraction of the GE intake, according to the 2006 IPCC Guidelines.

For cattle subcategories, the GE depends on the cattle production system-based approach defined for estimating emissions from the enteric fermentation process (Boadi et al., 2004a), as shown in Equation A3.4–3. Estimates of VS were derived for each cattle subcategory at the provincial level based on regional and seasonal stages of production (Equation A3.4–7). Increases in milk production in dairy cows and carcass weight in beef cattle have increased VS with increased dry matter intake and, as a result, CH_4 emission factors over the time series; however, increases of DE% in dairy feed over time have moderated this effect for dairy cows.

Equation A3.4–7

$$VS = \left[GE \times \left(1 - \frac{DE\%}{100}\right) + (UE \times GE)\right] \times \left(\frac{1 - ASH}{18.45}\right)$$

VS = volatile solids excretion, kg head^{-1} yr^{-1}
GE = gross energy consumed by a given animal, MJ head^{-1} yr^{-1}
$DE\%$ = digestibility of the ration, %
UE = urinary energy (unit less)
ASH = ash content of the manure, %
18.45 = Constant to convert from energy, MJ to mass, kg^{-1}

Swine, VS

Volatile solids reported for the Swine category (Table A3.4–14) were estimated by first calculating provincial VS excretion based on values in Marinier et al. (2004), using the IPCC 2006 Tier 2 approach and taking into account the variability in the values of DMI, DE% and ASH obtained from expert surveys. Typical animal mass was used to convert the temporally fixed VS into units of VS per 1000 kg body weight (kg VS 1000 kg animal mass^{-1} day^{-1}), which was then applied to the complete animal mass time series.

All Other Animals, VS

Volatile solids for animal categories other than Dairy Cattle, Non-Dairy Cattle and Swine were calculated based on values in Marinier et al. (2004), using the IPCC 2006 Tier 2 approach and considering the variability in the values of DMI, DE% and ASH derived from expert surveys. The values for DMI, DE% and ASH taken from that survey were used to calculate VS for non-cattle livestock categories for each individual province (Equation A3.4–8). Confidence intervals were developed using a Monte Carlo simulation performed with Crystal Ball® (Decisioneering, 2000), resulting in a probability distribution based on the variance in expert opinion and scientific literature (Table A3.4–13).

Equation A3.4–8

$$VS = \left[DMI \times 18.45 \times \left(1 - \frac{DE\%}{100}\right) + (UE \times DMI \times 18.45)\right] \times \left(\frac{1 - ASH}{18.45}\right)$$

VS = volatile solids excretion, kg head^{-1} yr^{-1}
DMI = dry matter intake, kg head^{-1} yr^{-1}
$DE\%$ = digestibility of the ration, %
UE = urinary energy (unit less)
ASH = ash content of the manure, %
18.45 = constant to convert from energy, MJ to mass, kg

Table A3.4–13 **Mean Volatile Solids in Manure of Non-Cattle or Swine Animal Categories in 2024 and Associated 95% Confidence Interval, Expressed as a Percentage of the Mean**

Animal Category	Mean VS (kg head^{-1} day^{-1})	95% Confidence Interval (%)
Sheep and lambs[a]	0.60	31
Mature horses	3.5	16
Goats	0.72	41
Bison	3.1	16
Wild boars[b]	0.24	50
Poultry	0.02	20

Notes:
a. Llamas and alpacas were given the same values as sheep at the provincial level, and these values were weighted based on the population of llamas and alpacas in each province. The value denotes the aggregate of sheep and lambs, not one category alone.
b. The value for wild boars was calculated on the basis of the value for swine.

Table A3.4–14 **Mean Volatile Solids in Swine Manure in 2024**

Animal Category	VS (kg 1000 kg body mass^{-1} day^{-1})	Typical Animal Mass (kg)	VS (kg day^{-1})
Sows	1.6	198	0.31
Boars	1.6	198	0.31
Pigs (<20 kg)	11.0	8.7	0.10
Pigs (20–60 kg)	5.2	36	0.19
Pigs (>60 kg)	4.6	92	0.42

The following sections outline the data for estimating VS developed by Marinier et al. (2004).

Digestibility (DE%) and Dry Matter Intake (DMI)

The sources of information used for DE% for both the Dairy Cattle and Non-Dairy Cattle categories are detailed in section A3.4.1.1.

Broad regional differences in ration composition were identified for sheep, horses and swine livestock. Regional differences were not considered for goats or poultry livestock since these data were not available.

Generally, rations for grazing livestock consist of roughage and grains. Diet digestibility will vary, with grains having a higher digestibility than roughage. The distribution of grain-based and roughage-based diets was estimated for sheep and horses in each province. A weighted estimate of DE% was calculated using the known approximate DE% for grains and roughage for each animal type and the distribution of grain and roughage usage by province (Table A3.4–15). This method does not, however, account for additives that may increase or decrease digestibility. The DMI for non-cattle animal categories was determined through consultation with experts and published values (Table A3.4–16).

Table A3.4–15 Approximate Ration Digestibility (DE%) for Selected Livestock Subcategories, and Data Sources

Animal Category	DE (%)	Data Sources
Goats	65	W. Whitmore, Manitoba Agriculture and Food
Laying hens	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Chickens	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkeys	78	S. Leeson, University of Guelph
Swine	87	C.F. deLange, University of Guelph
Feeding on Grain Diet		
Sheep	74	Weston (2002)
Horses	70	L. Warren, Colorado State University
Feeding on Roughage Diet		
Sheep	65	W. Whitmore, Manitoba Agriculture and Food
Horses	60	L. Warren, Colorado State University

Note:
Data source: Expert consultations (Marinier et al., 2004).

Table A3.4–16 Dry Matter Intake for Selected Livestock Categories

Animal Category	DMI (kg head^{-1} day^{-1})	Data Sources
Sheep and lambs		
Ewes	1.2–2.8	NRC (1985)
Rams	2.1–3.0	W. Whitmore, Manitoba Agriculture and Food
Replacement lambs	1.2–1.5	NRC (1985)
Market lambs	1.3–1.6	NRC (1985)
Horses		
Mature idle horses	7.4–11	NRC (1989); L. Warren, Colorado State University
Mature working horses	7.4–13.7	NRC (1989); L. Warren, Colorado State University
Weanlings	3.6–6.3	NRC (1989)
Swine		
Starters (5–20 kg)	0.55–0.72	C. Wagner-Riddle, University of Guelph
Growers (20–60 kg)	1.4–2.1	J. Patience, Prairie Swine Centre
Finishers (60–110 kg)	2.1–3.3[a]	M. Nyachoti, University of Manitoba; C. Pomar, AAFC
Sows	2.28	C. Wagner-Riddle, University of Guelph
Boars	2.0–2.5	M. Nyachoti, University of Manitoba; NRC (1998)
Goats		
Does	1.2–2.8	NRC (1981)
Bucks	1.4–2.3	CRAAQ (1999)
Kids	1.4	CRAAQ (1999)
Poultry		
Laying hens	0.072–0.11	S. Leeson, University of Guelph; D. Korver, University of Alberta
Broilers	0.085–0.088	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkeys	0.023–0.53	Hybrid (2001)

Notes:
Data source: Expert consultations (Marinier et al., 2004).
a. Calculated as 3.5% of body weight.

Manure Ash Content (ASH)

The ash content in the manure is the inorganic portion of the manure. Table A3.4–17 contains the values used in this inventory for ash content in volatile solid calculations and their sources.

Table A3.4–17 **Manure Ash Content for Selected Livestock and Data Sources**

Animal Category	ASH (%)	Data Sources
Cattle	8	IPCC (2000)
Sheep	8	IPCC (2000)
Goats	8	IPCC (2000)
Horses	4	IPCC (2000)
Laying hens	10	Marinier et al. (2004)
Chickens	7	Marinier et al. (2004)
Turkeys	5	Marinier et al. (2004)
Swine	5	Marinier et al. (2004)
Wild boars	5	Swine used as a proxy

A3.4.3.2. Maximum CH_4 Producing Potential (B_0)

The B_0 is defined as the maximum volume of CH_4 that can be produced from 1 kg of VS loaded into a manure management system and is expressed as m^3 kg^{-1} VS loaded. The values published in the 2006 IPCC Guidelines were used for all animals. For bison, the values of the Non-Dairy Cattle category were used.

A3.4.3.3. Animal Waste Management System (AWMS) Distribution Factor

The AWMS factor is the proportional distribution of AWMS of a livestock category within a given area. There is little reliable published information on the distribution of manure management systems in Canada.

Anaerobic treatment lagoons and daily spread are not typically used for manure storage in Canada. Though some examples may exist, they cannot be quantified and, for this reason, are currently considered non-significant and are not estimated. The existence of these types of systems was not identified in the expert consultation carried out by Marinier et al. (2004) or across Farm Environmental Management Surveys, which are the sources of AWMS allocation data for Canada. Therefore, the amount of manure treated by these systems is assumed to be negligible. Earthen storage systems exist in Canada, but in these storage systems, solids are removed regularly when the storage systems are emptied on an annual basis and there is no long-term accumulation and anaerobic treatment of solids in the lagoon, as is the case with “anaerobic treatment lagoons” as defined by the IPCC guidelines.

Dairy

For the Dairy Cattle category, a relationship between farm size and time spent on pasture, in exercise yards and in barns was developed from Sheppard et al. (2011b) for each province. The proportion of manure excreted in each of these locations is assumed to be equal to the time spent in each area. Time spent on pasture was found to decrease with increasing farm size, and the fraction of manure deposited on pasture decreased on average from 19% in 1990 to 16% in 2016 due to a shift towards larger farm operations.

For manure deposited in barns, a manure storage time series was developed from a combination of data from the Farm Inputs Management Survey (1995), the Farm Environmental Management Surveys (2001, 2006, 2011) and the Livestock Farm Practices Survey (2005). The use of liquid systems was estimated based on a relationship to farm size, for Eastern and Western Canada respectively, derived from the survey data. Liquid system use increased from 17% in 1990 to 64% in 2011, while solid manure is assumed to be inversely related to liquid use. Percentage of dairy farm following daily spread and year-round pasture is negligible in Canada. Survey data were used to disaggregate liquid systems into three AWMS sub-systems: earthen basin, tank and slatted floor. A portion of total solid manure is composted, while the remainder is disaggregated into two solid AWMS sub-systems based on survey data: pack and pile. For each liquid subsystem, manure was separated by the presence or absence of crust formation based on data collected from the Livestock Farm Practices Survey compiled in Sheppard et al. (2011a). Lastly, for each liquid and solid subsystem in a given province, manure was further divided based on the use of manure covers during storage.

Swine

For swine, a manure storage time series was developed from a combination of data from the Farm Inputs Management Survey (1995), the Farm Environmental Management Surveys (2001, 2006, 2011) and the Livestock Farm Practices Survey (2005). The use of liquid systems was estimated based on a relationship with farm size and was modelled based on provincial farm sizes from the COA. Liquid system use increased from 80% in 1990 to 97% in 2011, while solid manure was assumed to be inversely related to liquid use. Data from multiple surveys were used to disaggregate liquid systems into three AWMS sub-systems: earthen basin, tank and slatted floor by region. Solid manure was disaggregated into two solid AWMS sub-systems: pack and pile, based on survey data. For each liquid subsystem, manure was separated by the presence or absence of crust formation based on data collected from the Livestock Farm Practices Survey (Sheppard et al., 2010b). Lastly, for each liquid and solid subsystem in a given province, manure was further divided based on the use of manure covers during storage.

All Other Animals

A survey of experts on the topics of manure management and animal production was conducted in 2003–2004 as part of the Tier 2 study by Marinier et al. (2004). National averages of results are summarized in Table A3.4–18. Briefly, among the dominant animal production categories across the country, poultry manure is stored as solid manure, and beef cattle manure is equally distributed between solid storage and deposition on pasture, except for British Columbia and Manitoba, where most manure is deposited on pasture.

For minor livestock categories where the default IPCC Tier 1 methodology is used to estimate manure management CH_4 emissions, AWMS distributions are reported in CRTs for consistency with reporting of manure management N_2O emissions (see A3.4.4.1), but are not incorporated in the calculations.

A3.4.3.4. Methane Conversion Factor (MCF)

The MCF describes the proportion of B_0 that is attained, depending on the storage system and climate region. The values published in the 2006 IPCC Guidelines were used for all animals, except for poultry and liquid/slurry manure for dairy and cattle. Where a range of temperature dependent MCFs were available, the value for cool climate and average annual temperature of 12ºC was used.

For poultry animals on liquid manure management systems, an MCF of 20%, consistent with all other livestock liquid manure management systems was used, as storage methods for liquid poultry manure in Canada do not differ significantly from storage systems used in dairy or swine production.

For the Dairy Cattle and Swine categories, MCF values from the 2006 IPCC Guidelines were assigned to each AWMS subsystem (section A3.4.3.3). In liquid subsystems, the liquid/slurry MCF values were derived using the methodology set out in the 2019 Refinement to the 2006 IPCC Guidelines, which relates monthly mean air temperature to manure temperature for tank, earthen basin, and pit storage below animal confinements. The provincial MCF values were aggregated from ecodistricts and weighted by manure C. As a result, the MCF for liquid systems varies based on regional monthly temperature variation (Figure A3.4–4) according to the location of livestock in the province. Additional regionalized parameters were incorporated in the estimation of liquid system MCFs including manure removal timing, damping factor, and minimum temperature, Additional detail on the algorithms used to calculate liquid MCFs are found in Hung et al. (2022). Provincial removal scenarios were estimated using data from the Farm Management Survey data (Ewen et al., 2025). Where natural crusts form on liquid storage systems, the MCF was set at 65 % of the corresponding no-crust value. The 65% reduction was modified from the 60% reduction in the IPCC 2019 Refinement and based on expert consultation.

For solid subsystems, the drylot MCF was used for Pack (MCF=1%), while the Solid Storage MCF was used for manure heaps (MCF=2%). For Dairy Cattle, the drylot MCF was also used for Exercise Yards. A full list of MCF values by livestock and manure system can be found in section A6.4.

Figure A3.4–4 **Methane Conversion Factor (MCF) by Province**

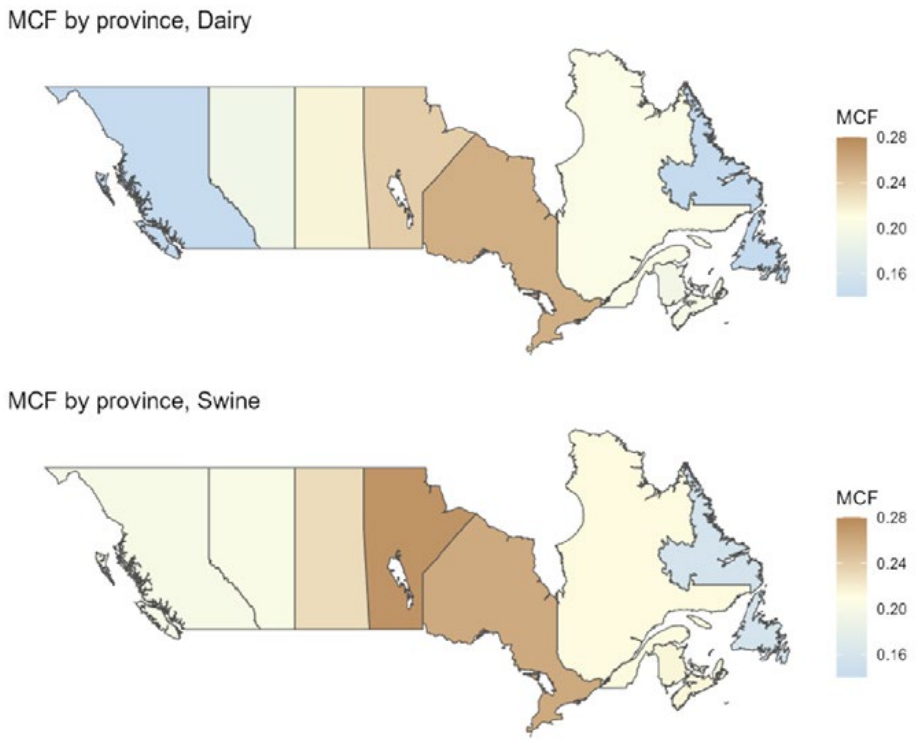


Table A3.4–18 **Percentage of Manure Handled by Animal Waste Management Systems (AWMS) in Canada (by Animal Category, Weighted Based on the Provincial Animal Populations in 2024)**

Animal Category	Liquid Systems	Solid Storage and Drylot	Pasture, Range and Paddock	Other Systems
Non-dairy cattle	5.1	45	45	4.4
Dairy cattle	64	18	16	3.0
Poultry	6.7	92	0.5	0.6
Sheep and lambs	0.1	33	67	0.02
Llamas and alpacas[a]	0.03	30	70	0.02
Swine	97	3	0	0
Goats	0	41	59	0
Horses	0	31	68	0.7
Bison	0.2	46	50	3.9
Deer and elk[b]	0	47	50	3.5
Fur-bearing animals[c]	0	100	0	0
Mules and asses[d]	0	32	68	0.7
Wild boars[c]	0	100	0	0

Notes:
Totals may not add up to 100% due to rounding.
a. Assumes that manure handled by AWMS is the same for llamas and alpacas as for sheep and lambs, at the provincial level.
b. Identical distributions to non-dairy cattle, except that liquid systems are distributed to pasture, range and paddock (PRP).
c. Assumed to be 100% solid manure.
d. Assumes that manure handled by AWMS is the same for mules and asses as for horses.

A3.4.3.5. Cattle Manure Management CH_4 Emission Factors

Cattle emission factors that are developed to calculate CH_4 emissions from manure management systems vary by animal subcategory and over time (Table A3.4–19). Volatile Solids were calculated based on the GE derived from the enteric fermentation cattle production approach and an emission factor time series was derived for cattle to reflect (1) the increase in milk productivity of dairy cows, (2) the variation in overall methane conversion rates as impacted by changes to manure storage practices, and (3) the change in live weight of beef cattle as explained in sections A3.4.1, A3.4.3.4 and A3.4.1.1, respectively. Emission factors are highest from dairy cattle, reflecting their high rates of confinement, use of liquid manure management systems and high dietary intake for sustained milk production. Dairy emission factors have more than doubled since 1990 due to the increasing use of liquid manure management systems. Beef cattle emission factors are lower, reflecting their lower rates of confinement, lower GE and because most manure is managed in a solid form with a low MCF.

Table A3.4–19 **Emission Factors to Estimate CH_4 Emissions from Manure Management for Cattle by Subcategory, from 1990 to 2024**

Year	$EF_{(MM)T}$ (kg CH_4 $head^{-1}$ yr^{-1})							
	Dairy Cows	Dairy Heifers[a]	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	13	9	4.5	4.1	3.2	1.9	1.8	2.2
2005	28	13	4.6	4.3	3.1	2.1	1.9	2.4
2018	40	18	4.8	4.5	3.2	2.2	2.0	2.9
2019	41	18	4.7	4.5	3.2	2.2	2.0	2.9
2020	41	18	4.7	4.5	3.2	2.2	2.0	2.9
2021	42	18	4.9	4.5	3.2	2.2	2.0	2.9
2022	42	18	4.7	4.5	3.2	2.2	2.0	2.9
2023	42	18	4.7	4.5	3.2	2.2	2.0	2.9
2024	42	18	4.8	4.6	3.3	2.3	2.0	2.9

Notes:
a. For dairy heifers, emission factors were estimated using the same B_0, MCF and manure management systems as for dairy cows.
b. Reported as kg $head^{-1}$ yr^{-1}, but emissions are calculated based on time to slaughter.

A3.4.3.6. Swine Manure Management CH_4 Emission Factors

Swine emission factors are developed to calculate CH_4 emissions from manure management systems and vary by animal subcategory and over time (Table A3.4–20).

A provincial emission factor time series was derived for swine to reflect (1) the variation in overall methane conversion rates as impacted by changes to manure storage practices, and (2) changes in the growth rates and live weights of market swine by weight class, as explained in sections A3.4.3.4 and A3.4.1.2, respectively. The swine emission factor is first calculated using VS derived from Marinier et al. (2004), and incorporating the latest scientific information available on B_0 and MCF taken from the 2006 IPCC Guidelines (IPCC, 2006). The annual VS excretion rates are then recalculated using animal mass from the Marinier survey year, and expressed as VS per 1000 kg animal mass. Lastly, VS is scaled over time using the swine Typical Animal Mass (TAM) time series. With increasing growth rates over time, VS for pigs in the lower weight classes (i.e. <20 kg, 20-60 kg) decreased slightly over the time series, while VS for pigs in the upper weight class (i.e. >60 kg) increased based on live weight.

Emission factors for pigs therefore vary over time due to increases in the rate of weight gain and the methane conversion factor from increased use of liquid manure storage systems. In contrast, a steady increase in the upper-weight class emission factor reflects increases in live weight. A small decrease in the emission factor for sows over time is the result of proportional changes to provincial animal populations, leading to an overall decrease in VS.

Table A3.4–20 **Emission Factors to Estimate CH_4 Emissions from Manure Management for Swine by Subcategory from 1990 to 2024**

Year	$EF_{(MM)T}$ (kg CH_4 $head^{-1}$ yr^{-1})				
	Boars	Sows	Pigs (<20 kg)	Pigs (20–60 kg)	Pigs (>60 kg)
1990	7.0	7.3	2.2	4.5	8.3
2005	7.0	7.1	2.2	4.4	8.5
2018	7.0	7.0	2.1	4.3	9.1
2019	7.0	7.0	2.2	4.3	9.2
2020	7.0	7.0	2.2	4.3	9.3
2021	7.0	7.0	2.1	4.3	9.4
2022	7.0	7.0	2.2	4.2	9.4
2023	7.0	7.0	2.2	4.3	9.5
2024	7.0	7.0	2.2	4.2	9.5

A3.4.3.7. Manure Management CH_4 Emission Factors for All Other Livestock

Manure management system emission factors for animals other than swine and cattle vary by animal subcategory but are constant over time (Table A3.4–21). For the largest other animal categories—sheep and poultry—growth stages for animals are considered. Emission factors for sheep, lambs, goat, horses, bison, llamas and alpacas, and poultry are calculated using the 2006 IPCC Tier 2 methodology. Volatile solids are derived from Marinier et al. (2004); however, since this report was based on the 2000 IPCC Guidelines, the emission factors were recalculated to incorporate the latest scientific information available on B_0 and MCF taken from the 2006 IPCC Guidelines (IPCC, 2006). Proxies are used for very minor livestock categories that account for less than 0.2% of total agricultural emissions, as described in A3.4.3.

Emission factors for other minor categories tend to be low due to the large portion of manure that is deposited either on pasture, range or paddock or in solid form in pens and holding yards. Default Tier 1 IPCC emission factors from Table 10.15 of Chapter 10 of the 2006 IPCC Guidelines are used for deer and elk, foxes, mink, rabbits, and mules and asses, and represent less than 0.1% of total agricultural emissions.

Table A3.4–21 **2024 CH_4 Emission Factors for Manure Management for All Other Livestock**

Non-Cattle Animal Categories	Manure Management Emission Factors $EF_{(MM)}$ (kg CH_4 $head^{-1}$ yr^{-1})
Other livestock	
Sheep	0.33
Lambs	0.22
Goats	0.32
Horses	2.6
Bison	2.1
Elk and deer	0.22
Wild boars[a]	0.56
Foxes	0.68
Mink	0.68
Rabbits	0.08
Mules and asses	0.76
Poultry	
Chickens	0.03
Hens	0.11
Turkeys	0.10

Note:
a. Emission factor based on swine VS, assuming 100% solid manure.

A3.4.3.8. Verification of Parameter Selection Against Canadian Research

The Manure Management source category was a part of a Tier 2 QA/QC for the Agriculture sector for the 2011 submission (MacDonald and Liang, 2011), including a review and compilation of Canadian literature related to methane production from manure storage.

Lacasse et al. (2025) reviewed 144 Canadian studies that measured emissions from manure storage in Canada from 1990 to 2023. Observed emission factors are highly variable, as are measurement techniques, regional, animal, and management types involved. The variability makes comparison of specific parameters used in Tier 2 calculations extremely difficult. Although the NIR methodology considered most studies on dairy and swine manure, additional research from Eastern Canada is required, where emissions are substantial (Lacasse et al., 2025). When the liquid storage MCF was estimated from in-situ measurements, it varied from more than 100% (suggesting that B_0 is also underestimated) to as low as 5.9 to 14% in the case of swine, and from 4% to 62% for dairy with no mitigation measures in place (Kaharabata et al., 1998; Massé et al., 2003, 2008; Wagner-Riddle et al., 2006; Laguë et al., 2005; Park et al., 2006, 2010; VanderZaag et al., 2009, 2010, 2022). Some studies exist in Canada on emissions from solid manures and other storage methods (composting) (Pattey et al., 2005; Xu et al., 2007; Hao, 2007; Hao et al., 2001b, 2008, 2009, 2010a, 2010b). As was the case with liquid manure systems, variability in emissions and methodology makes comparisons to IPCC parameters difficult.

Godbout et al. (2010) carried out an analysis on a small sample set from Eastern Canadian farms and suggested that the B_0 values for Swine, Non-Dairy Cattle and Dairy Cattle category livestock were 0.47–0.42, 0.21–0.19 and 0.35–0.30 m^3 CH_4 kg^{-1} VS, respectively. The values for Non-Dairy Cattle and Swine are consistent with IPCC default values, though dairy manure is the exception, with observed B_0 being 50% higher than the default value. In VanderZaag et al. (2018) B_0 for raw manure from two dairy farms was found to be 0.248 m^3 CH_4 kg^{-1} (SD=0.002) and 0.247 m^3 CH_4 kg^{-1} (SD=0.006). A recent study showed a slightly lower B_0 (0.335 m^3 CH_4 kg^{-1}) from a swine farm in western Canada (VanderZaag et al., 2022). Further analyses of B_0 are required for a wider range of regions and production practices.

Quantities of VS stored in the manure management systems for different animal categories tend to be consistent with quantities estimated in inventory calculations. The variability observed in studies is therefore likely linked to a combination of differences in measurement methodology, variability in manure characteristics (e.g., B_0) and differences in several physical and biochemical factors within each experiment that are not taken into account in the IPCC Tier 2 approach. These factors include temperature, manure composition, which includes bedding material and uneaten feed, storage dimension, storage duration and storage cleaning procedures—all of which may influence emissions from manure storage (Pattey et al., 2005; Laguë et al., 2005; Park et al., 2006, 2010; Wagner-Riddle et al., 2006; Massé et al., 2008; VanderZaag et al., 2009, 2010). Furthermore, these factors are not controlled in research, making comparisons even more difficult. More standardized factorial research is required to understand the relative weight of factors that influence emissions from manure storage and to refine estimation methodology.

Based on current research results, no specific bias can be determined in results for manure management systems, as there is no clear standard for evaluating whether IPCC parameters are appropriate for estimating emissions from manure management systems.

Desjardins et al. (2018) measured CH_4 flux for full farm systems, including emissions from both manure management and enteric fermentation processes using an aircraft-based platform and compared top-down estimates with a bottom-up footprint adjusted inventory estimate of emissions for an agricultural region in Eastern Ontario, Canada. They concluded that when a wetland area in the flux footprint was less than 10%, the top-down and bottom-up estimates were within the measurement error. They noted, however, that top-down CH_4 fluxes significantly overestimated methane emissions when contributions from wetlands were not considered in the potential sources. Fine-scale mapping of wetlands was required to effectively quantify natural methane emission sources. Where estimates from the two methods were inconsistent, the discrepancy was related to both increasing fractional area of wetlands in the flux footprint, scaling up of emission from varying time scales, and increasing surface temperature.

A3.4.3.9. Uncertainty in Manure Management CH_4 Emissions

Methane emissions from manure management systems were included in the comprehensive uncertainty analysis discussed in section A3.4.2.4. As was the case with the enteric fermentation process, the analysis built on the study by Karimi-Zindashty et al. (2012) and applied a precautionary principle such that for parameters with very little information, probability distributions were intentionally conservative (Table A3.4–22). Data on the probability distributions of the coefficients used in the agricultural manure management IPCC Tier 2 approach are scarce, and expert opinions were the main source of probability distributions, particularly those compiled in the Marinier et al. (2004) report. As was the case with the method for enteric fermentation, the relative uncertainty for the 2012 analysis was applied to the current year and no new uncertainty analysis was carried out for the changes to the methodology for dairy cattle livestock.

Population uncertainty for major animal categories was identical to that discussed in section A3.4.2.3, and the distributions used to define uncertainties can be found in Table A3.4–12.

The parameters used in the calculation of Tier 2 manure management system emission factors for all animals can be divided into two categories: those associated with volatile solid calculation and those specific to the calculation of IPCC Tier 2 emission factors. The confidence intervals assigned to coefficients used in the calculation of VS were relatively small compared to parameters used in the calculation of emission factors. With the exception of the ash content of manure, parameters tend to be under 10%, largely because parameters such as DMI and DE% are values with which producers are very familiar and which can provide some degree of confidence. In the case of cattle, VS vary according to the GE of consumption and are subsequently similar in variability to the enteric fermentation emission factor (±19%).

The probability distributions for coefficients used in IPCC Tier 2 equations to calculate the emission factors were taken, for the most part, directly from Karimi-Zindashty et al. (2012), who derived the distributions either from expert opinion within the Marinier et al. (2004) report or directly from the 2006 IPCC Guidelines. The uncertainty for B_0 was taken from Marinier et al. (2004), but no reliable source was available for the estimate of uncertainty around the MCF. In the current study, a large uncertainty range was used (±45% of the mean) based on expert opinions. However, the IPCC 2019 Refinement method was applied, which reduces the uncertainty. The actual value of the total uncertainty estimate for manure management systems must therefore be taken within the context that it is highly dependent on a value and a probability distribution function that is highly uncertain.

In contrast with the Karimi-Zindashty (2012) study, the current analysis was based on a provincial distribution of manure management systems, and uncertainty ranges were estimated from values observed in different provincial and national reports (Koroluk and Bourque, 2003; BPR-Infrastructure, 2008) and surveys (Sheppard et al., 2009, 2010b, 2011b; Sheppard and Bittman, 2011). In the case of dairy cattle livestock, the lower bound for liquid manure management systems was based on a comparison between reports that suggested that manure treated by liquid systems could vary by as much as 10% above or below the Marinier et al. (2005) estimate. Furthermore, it was reported that there has been a continual movement towards liquid manure systems over time. Therefore, the upper bound was set as 25% based on the rate of adoption of liquid systems from BPR-Infrastructure (2008) and the number of years that have elapsed since the survey conducted by Marinier et al. (2005). In the case of swine, liquid manure management systems' upper bounds were fixed at 100%. For all animal types, the lower bounds of other manure management systems were set at 0, thereby skewing the probability distributions. This approach resulted in non-symmetrical distributions for all manure management systems. While this approach increased the uncertainty of each individual manure management system, relative to the Karimi-Zindashty study, it likely reduced its impact on the national emission uncertainty because the manure systems were disaggregated to the provincial level, and the total manure management systems were held to 100%.

The trend analysis carried out using the ECSM quantified the uncertainty in the magnitude of the change in emissions over time for manure management systems. As was the case for the enteric fermentation method, for the long-term trend, emissions for 1990 and 2013 were calculated simultaneously, allowing only time-dependent parameters to vary independently in the estimates. A more detailed description of the trend analysis is found in section A3.4.2.4. The parameters that were allowed to vary independently for the manure management system trend analysis were animal populations, milk production and fat content in dairy cattle animals, body weights in beef cattle and AWMS (noted by a superscript 7 in Table A3.4–12 and superscript 5 in Table A3.4–22). Before 2004, lower boundaries for liquid AWMS were calculated based on the rate of adoption of liquid systems and the number of years that have elapsed since the survey by Marinier et al. (2005), as in the case of upper boundaries. This approach resulted in non-symmetrical distributions for all manure management systems; and for the trend analysis, it also modified the symmetry of probability distributions around liquid systems between the base year and the current year. Trend uncertainty for the 2018 inventory was based on the 2012 trend analysis.

The summary of results of the uncertainty analysis on emissions reported under Manure Management is reported in Chapter 5. Briefly, the uncertainty range used to derive the uncertainty reported in Chapter 5 for the 2014 emissions from manure management is 60% (-32% to +27% of the mean). As was the case with the enteric fermentation results, emission factors account for most of the uncertainty. Emission factors lie within an uncertainty range of -34% to +62% for the Non-Dairy Cattle category and a range of -60% to +50% for Dairy Cattle. The emission factors for the Swine category, the largest single contributor to manure management emissions, lie within an uncertainty range of -51% to +43%. A three-year study at a swine farm in western Canada justified the large uncertainty of manure methane emissions (VanderZaag et al., 2022). All other animals contribute little to the emission totals, i.e., 0.19 Mt CO_2 eq within an uncertainty range of 0.13 (-35% of the mean) to 0.23 (+15% of the mean). Overall, as was the case with enteric fermentation results, mean emissions for both the Dairy Cattle and Non-Dairy Cattle categories estimated using the stochastic model are slightly higher than those calculated from non-stochastic models and tend to be slightly skewed towards the lower boundary, indicating a tendency towards higher emissions. However, mean emissions from swine and other animals estimated using the stochastic model are slightly lower than emissions estimates, and the distribution of emission estimates tends to be slightly skewed towards the upper boundary, indicating a tendency towards lower emissions. This skewed distribution is evident when looking at the range of uncertainty around the emission factors (e.g., 34% to +62% for Non-Dairy Cattle). The asymmetry of the uncertainty range is likely due to a combination of the skewed probability distributions for manure management systems and the same factors that influenced the distribution of enteric fermentation emission estimates for cattle, specifically the skewed distributions for backgrounding of slaughter animals and the uniform distribution used for net energy mobilized from weight loss during lactation in Dairy Cattle.

Based on the trend analysis, in that publication there was greater uncertainty in the trend than the estimated difference in emissions from manure management since 1990, where change from 1990 could range from a decrease of 10% to an increase of 8%, though it is most likely that there has been an increase in emissions of roughly 5.5%. The assumption that liquid manure storage and other manure storages have increased over time affects the trend. For example, for dairy cattle livestock in Ontario in 1990, the triangular distribution used around the percentage of manure treated in liquid manure management systems had a lower boundary of 16%, a MLV of 40% and an upper boundary of 42%; in 2010, the lower boundary was 37%, the MLV was 40% and the upper boundary 59%. The use of a skewed distribution indicating a higher probability that fewer animals were raised on liquid manure management systems in the past balances the increase in animal populations. As a result, an overall increase in emissions is improbable in manure management emissions over time, particularly from cattle.

The uncertainty range of the analysis carried out in 2012 was slightly smaller than that of the previous analysis (2%), likely due to a combination of lower uncertainty for census animal populations and modifications in the uncertainty bounds around AWMS systems with the addition of two years from the time of the original survey. Overall, the uncertainty range around manure management emissions produced by this analysis is slightly smaller than the data reported by Karimi-Zindashty et al. (2012), as the proportions of manure treated by different manure management systems were distributed to the provincial level in this analysis, whereas a national average was used in the 2012 publication. Monni et al. (2007) estimated the emission factor uncertainty for CH_4 manure management to be roughly ±30%, based strictly on expert opinion. As was the case with enteric fermentation, Karimi-Zindashty et al. (2012) demonstrated that most uncertainty in the manure management quantification approach is associated with the use of default IPCC parameters that are applied at the national level, specifically the MCF. By deriving MCFs for different regions and different storage structures, uncertainty would be significantly reduced. Further work on uncertainty will focus on the development of trend uncertainty and the refinement of probability distributions around country-specific parameters already existing in the approach. As the MCF is driving uncertainty for the Manure Management category, it is not suspected that changes to the dairy or swine methodologies would have a large impact on the national manure management uncertainty. However, the introduction of a time series of AWMS for the Dairy and Swine sectors may play an important role in influencing the trend uncertainty for manure management system emissions.

Table A3.4–22 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used in Estimating Methane Emissions from Manure Management**

Parameter Category	Parameter / Animal Category or Subcategory	Distribution Type	Uncertainty Range		Spatial Allocation / Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[a]		
VOLATILE SOLID CALCULATIONS (EQUATION A3.4–6 AND EQUATION A3.4–7)						
Dry matter intake (DMI)						
- Swine		Triangular			National/Subcategory	Marinier et al. (2004)
	Boars		1.2–3.4	2.28		
	Sows		2.0–2.5	2.25		
	Pigs < 20 kg		0.55–0.72	0.68		
	Pigs 20–60 kg		0.63–2.1	1.75		
	Pigs > 60 kg		2.1–3.3	2.7		
- Poultry						
	Laying hens		7.4–9.9	9.85		
	Broilers		0.085–0.088	0.086		
	Turkeys		0.23–0.53	0.27		
- Other livestock						
	Sheep		1.2–3.0	2		
	Lambs		1.2–1.6	1.35		
	Goats		1.4–2.3	1.75		
	Horses		7.4–9.9	9.85		
	Buffalo		6.8–10.1	8.43		
Ash						
- Cattle		Triangular	3.9–11	8	National/Category[b]	Marinier et al. (2004)
- Swine			3.9–11	4.8–5.1		
- Poultry	Laying hens		3.9–11	10		
	Broilers		3.9–11	7		
	Turkeys		3.9–11	5		

Table A3.4–22 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used in Estimating Methane Emissions from Manure Management** (cont'd)

Parameter Category	Parameter / Animal Category or Subcategory	Distribution Type	Uncertainty Range		Spatial Allocation / Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[a]		
- Other livestock						
	Sheep		3.9–11	8		
	Lambs		3.9–11	8		
	Goats		3.9–11	8		
	Horses		3.9–11	4		
	Buffalo		3.9–11	8		
Digestible energy (DE)						
- Cattle		Normal	Pasture ±9% / Confined ±9% / Background ±7.5% / Prepared feed ±5.5%		Provincial/Production subcategory	Derived from raw data supplied by Valacta Dairy Services
- Swine			±9%		Provincial/Category	
- Poultry	Laying hens		±5.5%		National/Subcategory	
	Broilers					
	Turkeys					
- Other livestock						
	Sheep		±9%		Provincial/Category	
	Lambs				Provincial/Category	
	Goats				Provincial/Category	
	Horses				Provincial/Category	
	Buffalo				Provincial/Category	
EMISSION FACTOR CALCULATION (EQUATION A3.4–6)						
Methane conversion factor (MCF)						
	All animals	Normal	±45%		National	Karimi-Zindashty et al. (2012) – expert opinion
Maximum methane producing potential (B_0)						
	Dairy cattle	Triangular	0.1–0.24	0.24	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/ Marinier et al. (2004)
	Non-dairy cattle		0.19–0.33	0.19		
	Swine		0.32–0.48	0.48		
	Poultry		0.24–0.39	0.32		
	Sheep and lambs		0.19–0.36	0.19		
	Goats		0.15–0.19	0.18		
	Horses		0.30–0.36	0.3		
	Buffalo		0.19–0.33	0.19		
Animal waste management systems (AWMS)[d]						
	Dairy cattle	Triangular	LB: MLV-10% UB: MLV+25%	MLV from Marinier et al. (2005)	Provincial/Category	Expert opinion, bounds based on interpretation of multiple data sources Internally correlated variable[c] Liquid systems allowed to vary to non-symmetric triangular distributions
	Swine		LB: MLV-10% UB: 100%	MLV from Marinier et al. (2005)		
	Non-dairy cattle	Normal	±17%			Marinier et al. (2005). Internally correlated variable[c]
	Poultry					
	Sheep and lambs					
	Goats					
	Horses					
	Buffalo					

Notes:
MLV = most likely value; LB = lower bound; UB = upper bound
a. Most likely value when triangular distribution, normal distributions given as simple ±%.
b. Ash for swine varies among some provinces.
c. Internal correlation indicates values that vary in terms of a fraction of the whole, i.e., a fraction of a total equalling 100%.
d. Values that vary independently during trend analysis.

A3.4.4. N_2O Emissions from Manure Management

N_2O emissions from manure management systems result from mineralization of organic materials, and the nitrification and denitrification of mineral N directly and indirectly.

A3.4.4.1. Direct N_2O Emissions from Manure Management

Three factors are required to estimate N_2O emissions from manure management systems when using the IPCC Tier 1 method: (1) N excretion rates for various animal categories and subcategories; (2) AWMS types; and (3) the emission factors associated with manure management systems.

As previously described in section A3.4.3, default emission factors or country-specific information sources are sometimes used for minor livestock categories as logical proxies based on species similarities when no other information is available. The following proxies and expert judgments are used in the calculation of N_2O emissions, in addition to those already listed in A3.4.3:

- The N excretion rate for swine is used to represent wild boars.
- The N excretion rate for sheep is used to represent lambs, as well as llamas and alpacas.
- The N excretion rate for buffalo is used to represent bison.
- The N excretion rate for Other Cattle is used to represent deer and elk.

Nitrogen Excretion Rates for Various Domestic Livestock

For the Dairy Cattle category, the Tier 2 methodology from the 2006 IPCC Guidelines is used. Nitrogen retention from milk production and weight gain is calculated using Equation 10.33 in Volume 4, Chapter 10 of the 2006 IPCC Guidelines. Nitrogen retention from pregnancy was also estimated using a country-specific approach. The weight gain rate in the fetus was estimated based on the assumed average weight of a calf at birth of 40 kg (Farm & Food Care Ontario, 2013) and a 276-day gestation period. The N retention of a pregnant cow due to fetus growth was then weighted to 365 days to account for its contribution to the annual N excretion rate. Nitrogen intake from feed has increased steadily since 1990 to meet the protein requirements associated with increased milk production (Table A3.4–4) and, as a result, a corresponding increase in dairy cow N excretion rates (Table A3.4–23) was calculated.

For the Non-Dairy Cattle category, annual live weights (see section A3.4.1.1) were multiplied by the IPCC default N excretion rate (IPCC, 2006) to produce a time series of manure N excretion rates (Table A3.4–23).

For the Swine category, distinct parameters were used to estimate N excretion from subcategories of breeding animals and market animals. In the case of market swine, increases in growth rates and live weights were used to develop a country-specific time series of animal mass per production stage, which was multiplied by the N excretion rate from Table 10.19 in the 2006 IPCC Guidelines. For breeding animals, the IPCC default N excretion rate was multiplied by the IPCC default animal mass.

Annual manure N excretion rates for all other types of animals vary by livestock category according to IPCC Tier 1 default values (IPCC, 2006). Poultry have high N excretion rates (Table A3.4–25), while horses and bison have the lowest excretion rates. However, on a per-head basis, bison have the highest N excretion rates due to their size. Tier 1 default values for fur-bearing animals and rabbits have exceptionally high excretion rates relative to their size (Table A3.4–25), but are understood to be based on breeding stock and attribute all manure produced on the farm to the breeding stock.

Table A3.4–23 **Time Series of Manure N Excretion Rates for Cattle (kg N head^{-1} yr^{-1})**

Year	(kg N head^{-1} yr^{-1})							
	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[a]	Steers[a]	Calves
1990	107	72	88	58	45	45	48	27
2005	116	73	102	68	52	61	61	26
2018	122	76	108	75	57	66	67	26
2019	122	76	107	74	57	66	68	26
2020	122	76	107	74	57	67	68	27
2021	123	76	111	74	57	67	68	27
2022	122	76	105	75	57	67	69	27
2023	119	76	107	75	58	67	69	27
2024	119	76	109	79	60	76	71	27

Notes:
The N excretion rate for beef cattle is 0.31 kg N (1000 kg^{-1} day^{-1}) (IPCC, 2006, Table 10.19).
Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.
a. Values are adjusted to the lifespan of slaughter animals.

Table A3.4–24 **Time Series of Manure N Excretion Rates for Swine (kg N head^{-1} yr^{-1})**

Year	(kg N head^{-1} yr^{-1})				
	Sows	Boars	Pigs (<20 kg)	Pigs (20–60 kg)	Pigs (>60 kg)
1990	17	17	1.3	5.7	11.9
2005	17	17	1.3	5.7	12.4
2018	17	17	1.3	5.6	13.5
2019	17	17	1.3	5.6	13.6
2020	17	17	1.3	5.6	13.7
2021	17	17	1.3	5.6	13.8
2022	17	17	1.3	5.5	13.8
2023	17	17	1.3	5.6	14.0
2024	17	17	1.3	5.5	14.0

Notes:
The N excretion rates for breeding swine and market swine are taken from the latest version of Volume 4, Chapter 10 of the 2006 IPCC Guidelines, Table 10.19, in units of kg N (1000 kg body weight)$^{-1}$ day^{-1}.
Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

Table A3.4–25 **Manure N Excretion Rates for All Other Animals**

Animal Category	N Excretion Rate[a] (kg N 1000 kg^{-1} day^{-1})	Average Body Weight[b] (kg)	Annual Manure N (kg N head^{-1} yr^{-1})
Sheep	0.42	27	4.1
Lambs	0.42	27	4.1
Goats	0.45	64	10.5
Horses	0.3	450	49.3
Llamas and alpacas	0.42	112	17.2
Bison	0.32	578.5	67.7
Hens	0.83	1.8	0.5
Broilers	1.1	0.9	0.4
Turkeys	0.74	6.8	1.8
Elk and deer	0.31	120	13.6
Wild boars[c]	0.40	61	11.1
Foxes	12.1	1.8	7.9
Mink	4.6	1.8	3.0
Rabbits	8.1	1.6	4.7
Mules and asses	0.3	245	26.8

Notes:
a. Data source: IPCC, 2006
b. For buffalo, the average live weight was taken from the U.S. NIR.
c. Equivalent to overall swine excretion rate of 0.40 kg N (1000 kg^{-1} day^{-1}) (IPCC 2006, Table 10.19). Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

Emission Factors Associated with AWMS

The type of AWMS has a significant impact on N_2O emissions. Less-aerated systems, such as liquid systems, generate little N_2O, whereas drylots produce more. There have been few measurements of livestock N_2O emission factors for AWMS in Canada as research has focused on mitigation strategies and due to the challenges of estimating total N in solid manure systems (Lacasse et al., 2025). Therefore, IPCC default emission factors, as listed in Annex 6, were used to estimate emissions. For livestock from the Dairy and Swine sectors, weighted N_2O emission factors are calculated using the proportion of manure in each AWMS subsystem (see section A3.4.3.3) and the corresponding default emission factors (Annex 6), to produce a time series of N_2O emission factors by AWMS.

Table A3.4–18 summarizes the distribution of manure management systems in Canada by animal category. N_2O emissions from manure on pasture, range and paddock systems are not included under the Manure Management category, as they are reported under the Agricultural Soils category (section A3.4.5.1). Animal population data are detailed in section A3.4.1.

Direct N_2O emissions from manure management are estimated using the IPCC Tier-1 method (Equation A3.4–9), as follows:

Equation A3.4–9

$$N_2O_{D(mm)} = \sum_i \sum_{AWMS} \left(N_{i,T} \times N_{i,AWMS} \times N_{EX,T}\right) \times EF_{AWMS} \times \frac{44}{28}$$

$N_2O_{D(mm)}$	=	emissions for all AWMS and livestock categories, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O yr^{-1}
$N_{i,T}$	=	population for the Tth animal category or subcategory in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3.4–18)
$N_{EX,T}$	=	N excretion rate for the Tth animal category or subcategory (see Table A3.4–23 for cattle and Table A3.4–25 for non-cattle), kg N $head^{-1}$ yr^{-1}
EF_{AWMS}	=	N_2O emission factors from manure management for each specific AWMS (see Annex 6), kg N_2O-N kg N^{-1}
$44/28$	=	coefficient converting N_2O-N to N_2O

A3.4.4.2. Indirect N_2O Emissions from Manure Management

During manure storage and handling, losses of N occur through the following indirect pathways: (1) volatilization of manure N in the form of NH_3 and NO_x and subsequent re-deposition; and (2) leaching and runoff of N. Leaching is estimated only for the Dairy and Swine sectors, where country-specific information on the fraction of N loss due to leaching and runoff was available. These manure N losses can result in N_2O emissions (Equation A3.4–10 and Equation A3.4–11).

For the Dairy and Swine sectors, the introduction of a manure management time series that considers a wider variety of manure storage conditions results in changes in the fraction of manure N that is lost over the reporting period (Table A3.4–27). A shift from solid to liquid manure storage systems, an increase in the number of covered manure storage systems and, in the case of the Dairy sector, a shift in pasture time, resulted in a decrease in the proportion of total N lost to the environment over time. In the absence of available country-specific factors for the NO_x component of $Frac_{GasMS}$ for Dairy and Swine, nitric oxide losses from manure storage were estimated separately using the Tier 1 emission factors provided in Chapter 3 in Part B of the 2019 EMEP/EEA Air Pollutant Emission Inventory Guidebook (EEA, 2019).

Equation A3.4–10

$$N_2O_{G(mm)} = \sum_i \sum_{AWMS} \left(N_{i,T} \times N_{i,AWMS} \times N_{EX,T} \times Frac_{GasMS(T,AWMS)}\right) \times EF_4 \times \frac{44}{28}$$

$N_2O_{G(mm)}$	=	indirect N_2O emissions due to NH_3 volatilization for managed manure, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O yr^{-1}
$N_{i,T}$	=	population for livestock category or subcategory, T in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3.4–18)
$N_{EX,T}$	=	N excretion rate for livestock category or subcategory, T (see Table A3.4–23 for cattle and Table A3.4–25 for non-cattle), kg N $head^{-1}$ yr^{-1}
$Frac_{GasMS(T,AWMS)}$	=	fraction of managed manure N for livestock category, T that volatilizes as NH_3 and NO_x in the manure management system, AWMS (see Table A3.4–27 and Table A3.4–28)
EF_4	=	emission factor from atmospheric deposition of N (see Table A3.4–26)
$44/28$	=	coefficient converting N_2O-N to N_2O

Equation A3.4–11

$$N_2O_{L(mm)} = \sum_i \sum_{AWMS} \left(N_{i,T} \times N_{i,AWMS} \times N_{EX,T} \times Frac_{LeachMS(T,AWMS)}\right) \times EF_5 \times \frac{44}{28}$$

$N_2O_{L(mm)}$	=	indirect N_2O emissions due to leaching and runoff from managed manure, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O yr^{-1}
$N_{i,T}$	=	population for livestock category or subcategory, T in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3.4–18)
$N_{EX,T}$	=	N excretion rate for livestock category or subcategory, T (see Table A3.4–23 for cattle, Table A3.4–24 for swine, and Table A3.4–25 for all other livestock), kg N $head^{-1}$ yr^{-1}
$Frac_{LeachMS(T,AWMS)}$	=	fraction of managed manure N losses for dairy (see Table A3.4–28) and swine (see Table A3.4–29) and other livestock (see Table A3.4–27) for livestock category T due to leaching and runoff during solid and liquid storage of manure, AWMS
EF_5	=	emission factor associated with N leaching and runoff, 0.0075 kg N_2O-N (kg N leaching/runoff)$^{-1}$ (IPCC 2006)
$44/28$	=	coefficient converting N_2O-N to N_2O

Table A3.4–26 Application of Emission Factor EF_4 from the 2019 Refinement to the 2006 IPCC Guidelines, by Ecozone

Ecozone	EF_4 kg N_2O-N (kg NH_3-N + NO_X-N volatilized)$^{-1}$
Taiga Plains	0.005
Boreal Shield	0.014
Atlantic Maritime	0.014
Mixedwood Plains	0.014
Boreal Plains	0.005
Prairies	0.005
Pacific Maritime	0.014
Montane Cordillera	0.005

Notes:
Ecozones represent one level within Canada's National Ecological Framework.
Values taken from Table 11.3 of the 2019 Refinement to the 2006 IPCC Guidelines, Volume 4, Chapter 11.

Table A3.4–27 Total N, NH_3 and NO_x N Losses Associated with Various Livestock and Manure Management Systems

Animal Category	Manure Management Systems	$Frac_{(LossMS)}$ (%)[a]	NH_3-N and NO_x-N Loss (%)[a, b, c] ($Frac_{GasMS}$)
Non-dairy cattle	Liquid	40 (15–45)	40 (15–45)
	Solid storage	40 (20–50)	30 (20–50)
	Pasture and range	-	20 (5–50)
Sheep, lamb, llamas and alpacas	Solid storage	15 (5–20)	12 (5–20)
	Pasture and range	-	20 (5–50)
Goats and horses	Solid storage	15 (5–20)	12 (5–20)
	Pasture and range	-	20 (5–50)
Elk and deer	Solid storage	15 (5–20)	12 (5–20)
Wild boars	Solid storage	15 (5–20)	12 (5–20)
Foxes	Solid storage	15 (5–20)	12 (5–20)
Mink	Solid storage	15 (5–20)	12 (5–20)
Rabbits	Solid storage	15 (5–20)	12 (5–20)
Mules and asses	Solid storage	15 (5–20)	12 (5–20)
Poultry	Liquid	50	50
	Solid storage	53 (20–80)	48 (10–60)
	Pasture and range	-	20 (5–50)

Notes:
a. Numbers in parentheses indicate a range.
b. Data sources: Hutchings et al. (2001); U.S. EPA (2004); Rotz (2004).
c. Leaching losses from pasture, range and paddock is reported under indirect N_2O emissions from agricultural soils and is calculated using the same parameters as manure N spread on agricultural soils.

Table A3.4–28 Total N, NH_3 and NO_x-N Losses Associated with Manure Management Systems for Dairy Cattle

Year	$Frac_{(LossMS)}$ (%)			Leaching Loss (%) ($Frac_{LeachMS}$)			NH_3-N and NO_x-N Loss (%) ($Frac_{GasMS}$)		
	Liquid	Solid	Other[a]	Liquid	Solid	Other	Liquid	Solid	Other
1990	12	23	0	0	3	0	11	17	0
2005	13	23	37	0	3	7	12	17	23
2018	10	23	35	0	3	5	8	17	24
2019	10	23	35	0	3	5	8	17	24
2020	10	23	35	0	3	5	8	17	24
2021	10	23	35	0	3	5	8	17	24
2022	10	23	35	0	3	5	8	17	24
2023	10	23	35	0	3	5	8	17	24
2024	10	23	35	0	3	5	8	17	24

Note:
a. For the Dairy Cattle category, other refers solely to the composting of solid manures.

Table A3.4–29 **Total N, NH_3- and NO_x-N Losses Associated with Manure Management Systems for Swine**

Year	$Frac_{(LossMS)}$ (%)		Leaching Loss (%) ($Frac_{LeachMS}$)		NH_3-N and NO_x-N Loss (%) ($Frac_{GasMS}$)	
	Liquid	Solid	Liquid	Solid	Liquid	Solid
1990	22	31	0	3.3	21	24
2005	23	31	0	3.3	21	23
2018	20	30	0	2.9	18	23
2019	20	30	0	2.9	18	23
2020	20	30	0	2.9	18	23
2021	20	30	0	2.9	18	23
2022	20	30	0	2.9	18	23
2023	20	30	0	2.9	18	23
2024	20	30	0	2.9	18	23

A3.4.5. N_2O Emissions from Agricultural Soils

Emissions of N_2O from agricultural soils result from anthropogenic N inputs and occur through direct and indirect pathways. Direct emissions originate from (1) addition of organic and inorganic N to soils, (2) cultivation of organic soils, and (3) irrigation and indirect pathways through (1) volatilization of inorganic N fertilizers and manure N as NH_3 and NO_x and subsequent deposition, and (2) leaching and runoff of N.

Nitrogen is allocated to the landscape according to the following procedure: (1) Region-specific N application rates are calculated for each crop type based on weighted average soil class. (2) Based on crop type and their distribution, the total N requirement for each ecodistrict is calculated. (3) N available from manure is calculated from livestock populations for each ecodistrict. (4) N available from human biosolids are calculated, and assigned to specific crop types. (5) Organic N (manure + biosolids) is applied to crops within each ecodistrict, followed by inorganic fertilizer N. Fertilizer N is adjusted against provincial N fertilizer shipments reported by Statistics Canada.

A3.4.5.1. Direct N_2O Emissions from Agricultural Soils

Direct sources of emissions from agricultural soils include inorganic N fertilizers; organic N fertilizers; urine and dung deposited on pasture, range, and paddock by grazing animals; crop residues; and N mineralization associated with the loss of soil organic matter and the cultivation of organic soils. Tillage practices and irrigation can also influence soil N_2O emissions. The N_2O emission factors for most direct emission sources are country-specific and take account of the influence of moisture regimes, landscape position, soil texture, cropping systems and N sources on rates of N_2O production and emissions. The methodology described in this section follows the approach described in Liang et al. (2020), with changes based on expert consultation with the Canadian scientific community.

The approach involves determining a base emission factor (EF_Base) for each of the 405 ecodistricts[8] based on long-term growing season precipitation. Each EF_Base is subsequently modified to reflect site-specific practices and conditions. Data on long-term climate normals and topographic characteristics are used to develop each EF_Base (Equation A3.4–12).

Equation A3.4–12

$$EF_Base_i = [EF_CT_{i,P = PE} \times FR_Topo_i + EF_CT_{i,P} \times (1 - FR_Topo_i)] \times RF_TX_i$$

EF_Base_i	=	weighted average of emission factors for ecodistrict i, considering moisture regimes, topographic conditions, and soil texture, kg N_2O-N kg^{-1} N yr^{-1}
$EF_CT_{i,P}$	=	emission factor, estimated at actual P in ecodistrict i, kg N_2O-N kg^{-1} N (see)
$EF_CT_{i,P=PE}$	=	emission factor, estimated at P=PE in ecodistrict i, kg N_2O-N kg^{-1} N
FR_Topo_i	=	fraction of the area of ecodistrict i that is in the lower toposequence (Liang et al., 2020)
P	=	long-term mean precipitation from May 1 to October 31 in the ecodistrict i, mm
PE	=	long-term mean potential evapotranspiration from May 1 to October 31 in the ecodistrict i, mm
RF_TX_i	=	weighted soil texture ratio factor of N_2O for ecodistrict i

8 "Ecodistrict" represents one level within Canada's National Ecological Framework. The country includes 1027 ecodistricts, each characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies and fauna.

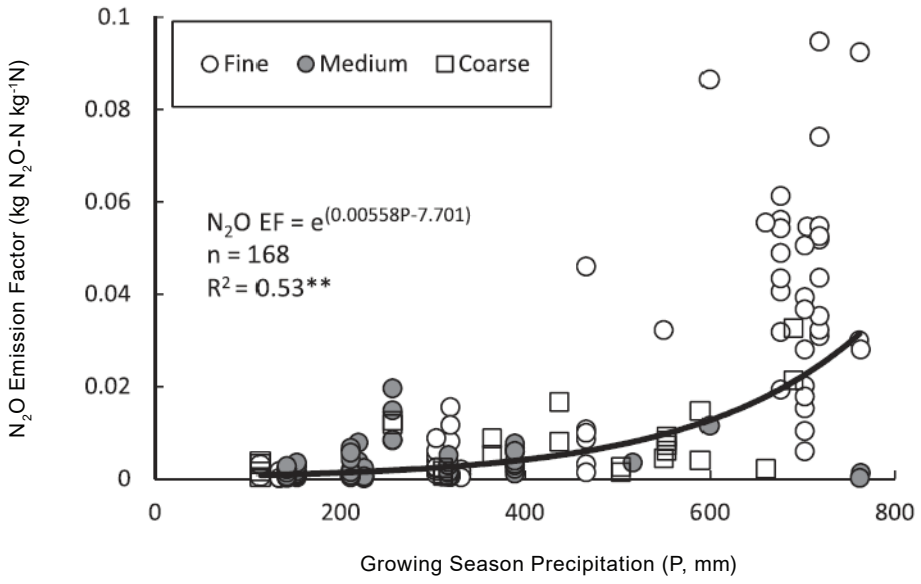
Base N_2O Emission Factor (EF_Base)

Soil N_2O is produced mainly during denitrification and is therefore greatly influenced by soil oxygen status. Accordingly, in moisture-limited conditions, N_2O emission factors have been shown to increase with greater rainfall amounts (Dobbie et al., 1999), and climate-variable emission factors have been used in estimating soil N_2O inventories (Flynn et al., 2005). Similarly, this methodology is used to estimate emission factors at the ecodistrict level as a function of the long-term growing season precipitation (P) from May 1 to October 31 (Figure A3.4–5). The AAFC-archived weather database contains information on 958 weather stations. These stations (80º00′N–41º55′N, 139º08′W–52º40′W) which are located across Canada (758 stations) and the United States (200 stations), were used to interpolate precipitation and potential evapotranspiration from May to October of 1981 to 2010 to the ecodistrict centroids. The Meteorological Service of Canada, Environment and Climate Change Canada (ECCC), provided the Canadian weather data.

The EF_Base factors were determined using the same approach by Liang et al. (2020). The EF_CT was derived from an approach based on a meta-analysis of recent Canadian studies (Rochette et al., 2018). The method assumes an exponential relationship between emission factors and growing season precipitation.

For ecodistricts in which P/PE is greater than 1, EF_CT was calculated at P and topographical effect (FR_Topo) was not considered in Equation A3.4–12. For ecodistricts in which P/PE is lower than or equal to 1, topographical effects were considered and each EF_CT was calculated at P=PE (long-term potential evapotranspiration from May to October) for the lower sections of the landscapes (Liang et al., 2020). This condition was applied to different fractions of the landscape depending on the landscape type. Landscape segmentation data were incorporated in the calculation of the national N_2O emission estimates, based on the observation that N_2O emissions are greater in lower sections of the landscape, where the intermittently saturated soil conditions favour denitrification (Corre et al., 1996, 1999; Pennock and Corre, 2001; Izaurralde et al., 2004). The fraction of the landscape occupied by these sections (FR_Topo) was identified as concave portions of the landscape (i.e., lower and depressional landscape positions) where soils are likely to be regularly saturated for significant periods of time and where they are imperfectly and poorly drained with mottles[9] within 50 cm of the land surface. MacMillan and Pettapiece (2000) used digital elevation models to characterize the areas of the upper, middle, lower and depressional portions of the landscape and their associated characteristics (slope and length). These results were then used to determine the proportional distribution of different landforms (such as lower sections) in the Soil Landscapes of Canada database, which was used as the basis for determining the proportion of the landscape to which FR_Topo would be applied to derive the N_2O emission estimates (Rochette et al., 2008).

Figure A3.4–5 **EF_CT as a Function of Long-Term Growing Season Precipitation (P) in Fine, Medium and Coarse Soil Textures**



9 Mottles are the product of intermittent oxidation/reduction cycles of (generally) iron present in the soil profile. The prevalence, size and colour of mottles are indicative of the soil materials being intermittently saturated for significant periods.

Non-Growing Season N_2O Emissions

Field measurements of N_2O flux using chambers in Eastern Canada are usually made during the snow-free period (Gregorich et al., 2005). The average annual snowfall in Eastern Canada varies between 1.0 and 4.5 m (Environment Canada, 2002). Snowmelt in the spring creates wet soil conditions that often stimulate N_2O production (Grant and Pattey, 1999; Wagner-Riddle and Thurtell, 1998). The intensity of soil freezing was also found to influence spring thaw emissions (Wagner-Riddle et al., 2007). Limiting emission estimates to the snow-free period therefore underestimates total annual N_2O emissions in that region. Emissions of N_2O during spring thaw also occur on the Prairies but are usually lower than in Eastern Canada (Lemke et al., 1999). Pelster et al. (2022) compiled all published and unpublished data comparing growing season and non-growing season soil N_2O fluxes and reported an overall mean of 64.54% of soil N_2O emissions that occurred during the growing season in Canada. A ratio factor (RF_NSE) of 1/0.645 was therefore used to modify the EF_Base value to estimate annual emissions.

Soil Texture and N_2O Emissions

Soil texture does not directly influence N_2O production in soils. However, it is correlated with several physical and chemical parameters that control N_2O production and transport in the soil profile (Arrouays et al., 2006; da Sylva and Kay, 1997; Minasny et al., 1999). Consequently, variables related to soil texture are often correlated with N_2O emissions from agricultural soils (Hénault et al., 1998; Corre et al., 1999; Chadwick et al., 1999; Bouwman et al., 2002a; Freibauer, 2003).

The impact of soil texture on N_2O emissions from agricultural soils was incorporated in the emission factor using a ratio factor (RF_TX) defined as the ratio of N_2O emissions from a given textural class of soils to the mean emissions from soils of all texture classes (Equation A3.4–13). Liang et al. (2020) reported an RF_TX of 0.49 for coarse- and medium-textured soils, and 2.55 for fine-textured soil. On the basis of a recent publication containing long-term micro-meteorological data on a site with medium-textured soil in southern Ontario (Baral et al. 2022) and a scientific review by AAFC scientists, the approach was modified to apply ratio factors of 0.49, 1.0, and 2.55 nationally to coarse-, medium- and fine- textured soils, respectively, as it was determined that the diversity of medium-textured soils was not fully represented in the data in the literature.

Equation A3.4–13

$$RF_TX_i = \sum_i \left(RF_TX_j \times FR_TX_{i,j} \right)$$

RF_TX_i	=	weighted soil texture ratio factor for N_2O in ecodistrict i
RF_TX_j	=	ratio factor of N_2O for soil texture j
$FR_TX_{i,j}$	=	fraction of soil texture j in ecodistrict i

Organic Nitrogen Fertilizers

Soil N_2O emissions from organic N sources include emissions from the application of sewage sludge (biosolids), manure from drylots, solid and liquid storage and other waste management systems on agricultural soils. A Tier 2 methodology with country-specific emission factors was used for estimating N_2O emissions from organic N fertilizers.

Equation A3.4–14

$$N_2O_{ON} = \sum [F_{ON(i,m)} \times (EF_Base_i \times RF_NSE \times RF_NS_{k=ON,m} \times RF_CS_m)] \times 44/28$$

N_2O_{ON}	=	emissions from organic N fertilizer applied to cropland, kg N_2O yr^{-1}
$F_{ON(i,m)}$	=	organic N (i.e., biosolids, animal manure) applied as N fertilizer in ecodistrict i, for each cropping system m as shown in Table A3.4–30, in units of kg N yr^{-1}
EF_Base_i	=	weighted average emission factor for ecodistrict i described in Equation A3.4–12, kg N_2O-N kg N yr^{-1}
RF_NSE	=	ratio factor of 1/0.645 for non-growing season soil N_2O emissions, unitless
$RF_NS_{k=ON,m}$	=	ratio factor for source of N, for organic N source k=ON in cropping system m as shown in Table A3.4–30, unitless
RF_CS_m	=	ratio factor for cropping system, m (annual or perennial) as shown in Table A3.4–30, unitless
$44/28$	=	coefficient converting N_2O-N to N_2O

Table A3.4–30 **Soil N_2O Ratio Factors for Cropping Systems and Nitrogen Sources**

Cropping System (CS)	RF_CS[a]	Nitrogen Source (NS)	RF_NS[a]
Annual	1.00	Inorganic Fertilizer N (IN)	1.00
Annual	1.00	Organic Fertilizer N (ON)	0.84
Annual	1.00	Crop Residue N (CN)	0.84[b]
Perennial	0.19	Inorganic Fertilizer N (IN)	1.00
Perennial	0.19	Organic Fertilizer N (ON)	1.00
Perennial	0.19	Crop Residue N (CN)	1.00

Notes:
a. Source: Liang et al. (2020), except where noted
b. Modified based on expert consultation

Manure Nitrogen

The methodology used is based on the quantity of manure N produced by domestic animals (see section A3.4.4.1) and the value of the country-specific EF_Base, considering the moisture regime and topographic conditions at the ecodistrict level. Manure was allocated to crops preferentially, based on a modified version of the method used in Yang et al. (2011), to better reflect practices and to ensure consistency in the manure allocation methodology used in environmental indicators in Canada. Estimates of N_2O emissions from this source were calculated using Equation A3.4–14, in combination with other organic N sources.

The amount of animal manure applied as fertilizer at an ecodistrict level was calculated using Equation A3.4–15. It was assumed that all manure, excluding that deposited on pasture, range and paddock, is applied to cropland soils.

Equation A3.4–15

$$F_{ON=MN,i} = \sum_{i} \left(N_{T,i} \times N_{EX(T)}\right) \times \left(1 - N_{PRP(T)}\right) \times \left(1 - Frac_{LossMS(T,i)}\right)$$

$F_{ON,i}$ = animal manure nitrogen (MN) applied to agricultural soils as organic N fertilizer in ecodistrict i, kg N yr^{-1}
$N_{T,i}$ = population of animal category or subcategory T in ecodistrict i,
$N_{EX(T)}$ = N excretion rate for animal category or subcategory (Table A3.4–23, Table A3.4–24, Table A3.4–25)
$N_{PRP(T)}$ = fraction of manure N on pasture, range and paddock for each animal category or subcategory T by province (see Table A3.4–18)
$Frac_{LossMS(T,i)}$ = fraction of manure N loss during storage and handling (volatilization, leaching, etc.) for each animal category or subcategory T excluding pasture, range and paddock, in ecodistrict i (Table A3.4–27, Table A3.4–28, Table A3.4–29)

Animal population data sources are detailed in section A3.4.1. Annual livestock population data from each animal category or subcategory at the provincial level are disaggregated into ecodistricts based on the livestock population distribution reported from the COA. Livestock population proportions at the ecodistrict level between two consecutive census years are interpolated.

Biosolids Nitrogen

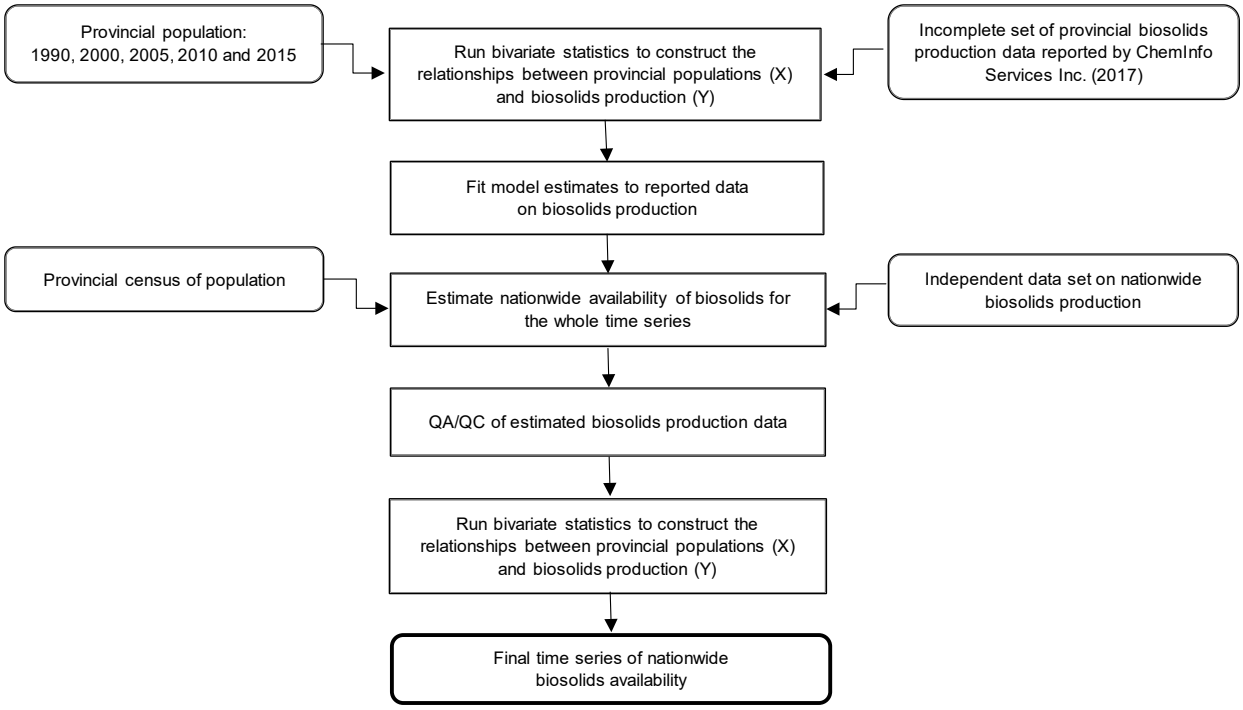
Data on the production and management of biosolids were derived from an Environment and Climate Change Canada–commissioned report (Cheminfo Services Inc., 2017). The data set was generated through a combination of telephone surveys and reports from municipal wastewater treatment services in 33 Census Metropolitan Areas (CMAs) and from municipal and provincial environment departments/ministries across Canada. The data were compiled at five-year intervals (1990–2015) and had gaps and inconsistencies owing to a lack of complete management information and changes in provincial regulations on biosolids. Nevertheless, this report is the only known source of data for the quantitative analysis of biosolids at a national scale.

Biosolids production data were produced through a series of analytical steps (Figure A3.4–6, Table A3.4–31). First, a provincial-level per capita methodology was constructed to establish a “baseline biosolids production.” Production was assumed to be directly proportional to the population of a geographical area. Different spatially scaled roll-ups of Statistics Canada population estimates were evaluated for best fit of the data. Population estimates used for testing included CMA populations, aggregated CMA populations and provincial populations. Upon regression analysis, the provincial population-based approach was chosen based on the strength of the correlation coefficients. Fortunately, the data generated using this approach were not significantly different from the data reported during the years that Cheminfo Services Inc. (2017) was doing the reporting. Therefore, the smoothed annual provincial biosolids production was derived using the linear approach. For PEI, annual estimates for biosolids production were developed based on expert opinion and using a national average per capita figure (22.5 kg $person^{-1}$ yr^{-1}). This analysis created a complete time series of biosolids production at a provincial scale.

Table A3.4–31 **Data Sources Used for Determination of Annual Biosolids Production and Characteristics at the Provincial Scale**

Category	Data Source	Notes/Comments
Biosolids production	Cheminfo Services Inc. (2017)	Survey data on biosolids production, fractions of biosolids land-filled, incinerated, land applied, and laws in land reclamation.
CMA populations	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710013501	Statistics Canada. Population estimates, July 1, by census metropolitan area and census agglomeration, 2016 boundaries.
Provincial populations	https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E	Statistics Canada. Census Profile 2016.
Federal and provincial regulations	CCME (2010)	CCME. A Review of the Current Canadian Legislative Framework for Wastewater Biosolids.
Biosolids – fractions by digestive processes	Cheminfo Services Inc. (2017)	British Columbia commissioned work.
	Hydromantis Ltd. (2007). GPS-X 5.0 software. General Purpose Simulator – default parameters.	
	Environmental Dynamics Inc. (2017). Beneficial Reuse of Biosolids Jurisdictional Review	
Nutrient content of biosolids under varied digestion/treatment processes	Dad et al. (2018)	N/A

Figure A3.4–6 **Schematic Details of the Procedures and Data Sources Used to Determine the Time Series of Biosolids Production at a Provincial Scale**



Secondly, the regional rates of land application of biosolids (dry tonnes) were derived using the proportions reported in Cheminfo Services Inc. (2017) adjusted for federal, provincial and municipal regulations, bylaws and restrictions (Table A3.4–31). At the federal level, the regulations imposed by the CCME were applied. Afterwards, provincial restrictions based on the nutrient content of the biosolids and any restrictions on the frequency of biosolids application to lands were incorporated (Table A3.4–31).

Biosolids are typically subject to various digestion and decomposition methods in Wastewater treatment plants prior to land application. These methods have significant implications for the nutrient content of the biosolids and therefore influence the emission potential when land-applied. Accordingly, as the final step, a combination of survey results and literature analyses was used to identify the major digestion processes, and estimates from Dad et al. (2018) were used to establish the nutrient content of the biosolids.

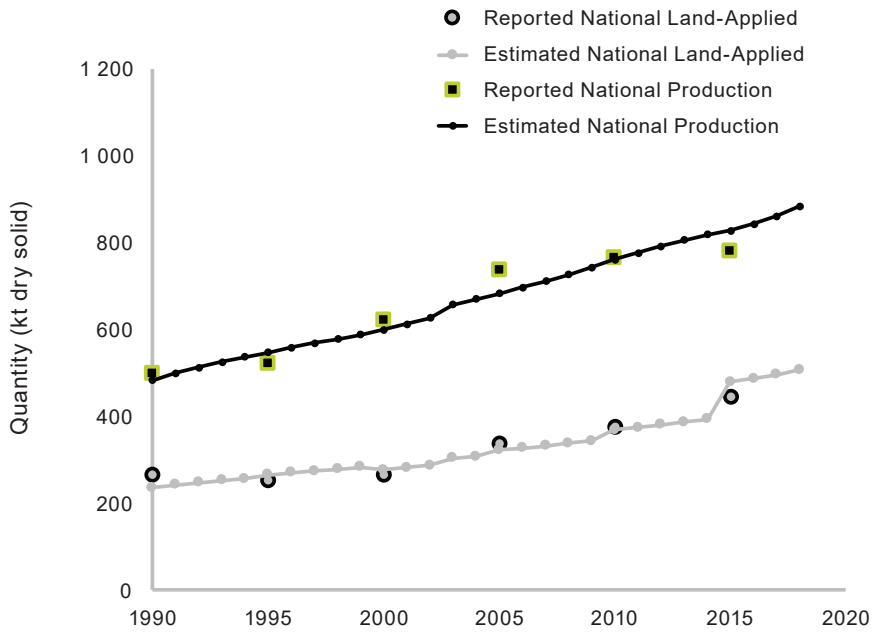
Quality Control and Quality Assurance

For the production data, quality control was conducted at the provincial and national levels. To verify the validity of our data, comparisons were made between the estimated values against independent data points available from literature and from other data sources at the national level. Our data reasonably reflected the production volume of biosolids at the provincial level and represented the changes in provincial regulations that occurred at specific years (Table A3.4–32). At the national level, the data aligned well with the national figures (Figure A3.4–7).

Table A3.4–32 **Comparison Between Estimated Biosolids Production Data and Figures Reported by Individual and Provincial CMAs**

Location	Reported Production (kt)	Estimated Production (kt)	% Deviation	Year	Source
Calgary CMA, AB	20.5	23	12.2	Annually	EDI (2017)
City of Edmonton, AB	18	15.6	13.33	1990 to 2004	City of Edmonton (2012)
Halifax CMA, NS	30	13	56.67	Since 2014	EDI (2017)
City of North Battleford, SK	3.5	0.6	82.86	2003–2004	EDI (2017)
City of Toronto, ON	55	64	16.36	Since 2007	AECOM (2009)
City of Kelowna, BC	36.4	3.7	89.84	Since 2006	EDI (2017)

Figure A3.4–7 **National Biosolids Production (kt dry solids) Versus Estimated Total Biosolids Production**



Allocation of Biosolids to Ecodistricts and Crops

The amount of biosolids applied as fertilizer at an ecodistrict level was calculated using Equation A3.4–16. Human population was used as a proxy to distribute provincial land-applied biosolids N to the ecodistrict spatial scale. To avoid over-application of N in an ecodistrict, a correction procedure was implemented to coordinate the application of manure and biosolids with recommended crop application rates per ecodistrict. First, the total amount of manure N within each ecodistrict was subtracted from the total amount of N required for crop growth, and compared with the amount of biosolids N initially allocated to the ecodistrict. In cases where biosolids N exceeded remaining crop N requirements, the required amount was applied, and the excess N was reallocated to other ecodistricts in the province. Next, biosolids N was applied to select crops within each ecodistrict as per provincial and municipal regulations and by-laws limiting the application of biosolids. The amount of biosolids N applied to each crop in a given ecodistrict was then subtracted from the initial crop N requirements, and the modified parameter was used to distribute manure N to crops, following the manure application methodology.

Equation A3.4–16

$$N_{ON=BN,i} = \sum_{i} \left[Prod_p \times Frac_{LAND,p} \times Frac_{POP,i} \times \sum (TN_r \times Frac_{TYPE(r,p)}) \times Frac_{CROP(i,m)} \right]$$

$N_{ON=BN,i}$	=	biosolids nitrogen (BN) applied as organic N fertilizer on cropland in ecodistrict i, kg N yr^{-1}
$Prod_p$	=	biosolids production in province p, kg
$Frac_{LAND,p}$	=	fraction of provincial biosolids that are land-applied in province p, unitless
$Frac_{POP,i}$	=	fraction of provincial human population in each ecodistrict i, unitless
TN_r	=	total N content (%) for biosolids type r, percentage
$Frac_{TYPE(r,p)}$	=	fraction of each biosolids treatment type r, in province p, unitless
$Frac_{CROP(i,m)}$	=	fraction of biosolids N applied to crop type m, in ecodistrict i

Inorganic Nitrogen Fertilizers

The method for estimating N_2O emissions from inorganic N fertilizers applied to agricultural soils takes account of moisture regimes and topographic conditions. Equation A3.4–17 is used to estimate N_2O emissions by ecodistrict. Estimated provincial and national emissions are obtained by aggregating estimates at the ecodistrict level.

Equation A3.4–17

$$N_2O_{FSN} = \sum [N_{FERT(i,m)} \times (EF_Base_i \times RF_NSE \times RF_NS_{k=IN,m} \times RF_CS_m)] \times 44/28$$

N_2O_{FSN}	=	emissions from inorganic N fertilizer applied to cropland, kg N_2O yr^{-1}
$N_{FERT(i,m)}$	=	inorganic N fertilizer in ecodistrict i, applied to cropping system m as shown in Table A3.4–30, in units of kg N yr^{-1}
EF_Base_i	=	weighted average emission factor for ecodistrict i described in Equation A3.4–12, kg N_2O-N kg N yr^{-1}
RF_NSE	=	ratio factor of 1/0.645 for non-growing season soil N_2O emissions, unitless
$RF_NS_{k=IN,m}$	=	ratio factor for source of N, for organic N source k=IN in cropping system m as shown in Table A3.4–30, unitless
RF_CS_m	=	ratio factor for cropping system, m (annual or perennial) as shown in Table A3.4–30, unitless
$44/28$	=	coefficient converting N_2O-N to N_2O

Data on inorganic N fertilizer shipments are available by province only (Statistics Canada, n.d. [h], Statistics Canada, n.d. [i]) and were disaggregated to the ecodistrict level. The approach used (Equation A3.4–18) assumes that the amount of inorganic N fertilizers applied (N_{APPLDP}) is equal to the difference between recommended N rates (N_{RCMD}) and organic N available for application on cropland ($N_{ON,CROPS}$).

Equation A3.4–18

$$N_{APPLDP,i} = N_{RCMD,i} - N_{ON,CROPS,i}$$

$N_{APPLDP,i}$	=	total N fertilizer potentially applied in ecodistrict i, kg N yr^{-1}
$N_{RCMD,i}$	=	recommended fertilizer application in ecodistrict i, kg N yr^{-1}
$N_{ON,CROPS,i}$	=	N from organic N applied to crops in ecodistrict i, kg N yr^{-1}

N_{RCMD} was estimated as the sum of the products of each crop type and the recommended fertilizer application rate for that crop in an ecodistrict (Equation A3.4–19) (Yang et al. 2007).

Equation A3.4–19

$$N_{RCMD,i} = \sum_{ij} \left(CROPA_{ij} \times N_{RECRT,ij} \right)$$

$N_{RCMD,i}$ = recommended fertilizer application in ecodistrict i, kg N yr^{-1}
$CROPA_{ij}$ = area of crop type j in ecodistrict i, ha
$N_{RECRTij}$ = recommended annual N application rate for crop type j in ecodistrict i, kg N ha^{-1} yr^{-1}

Because the potential amount of fertilizer must be reconciled with the total amount sold in the province (N_{SALES}) to estimate the actual amount applied (N_{FERT}), N_{APPLD} is adjusted in each ecodistrict as follows (Equation A3.4–20):

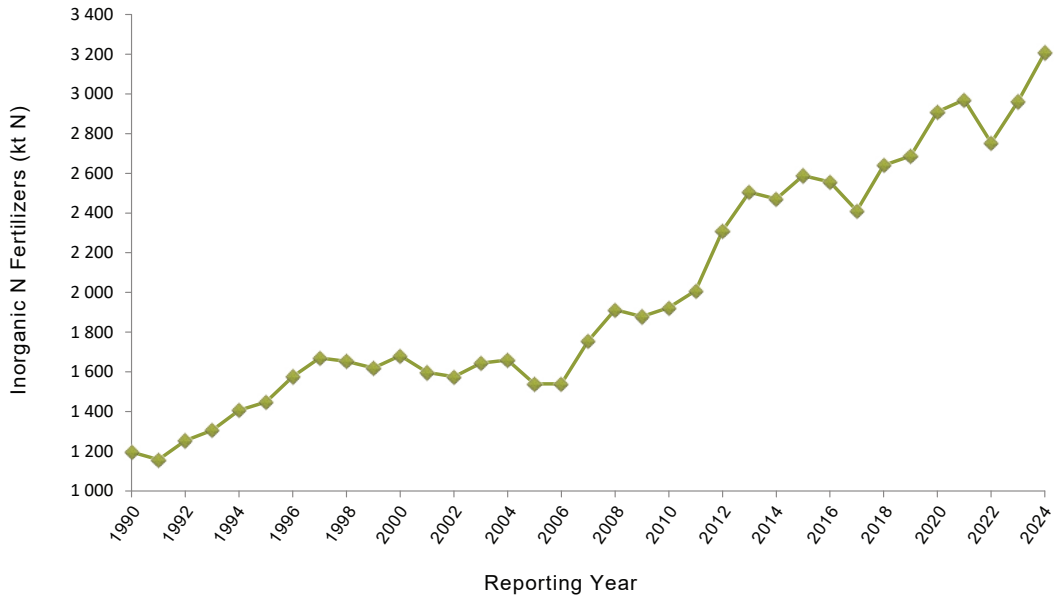
Equation A3.4–20

$$N_{FERT,i} = N_{APPLDi} \times \left[\frac{N_{SALESp}}{\sum_i^n N_{APPLDi}} \right]$$

N_{FERTi} = total fertilizer N actually applied to all crops in ecodistrict i, kg
N_{SALESp} = total amount of fertilizer N sold in province p, kg
$\sum_i^n N_{APPLDi}$ = total fertilizer N potentially applied to all crops in all ecodistricts in a province, kg

For years between census years (census years were 1991, 1996, 2001, 2006, 2011, 2016, and 2021), N_{RCMD} was linearly interpolated to estimate annual values of N_{APPLD} and N_{FERT} successively at the ecodistrict level. The consumption of inorganic N fertilizers in Canada has significantly increased since 1990, from 1.2 Mt to 3.0 Mt N, mainly because of the intensification of cropping systems from 1991 to 1997 and increased conversion from perennial to annual crops due to favourable grain prices since 2007 (Figure A3.4–8).

Figure A3.4–8 **Inorganic Nitrogen Fertilizer Shipments in Canada from 1990 to 2024**



From 1990 to 2002, AAFC collected data on the annual consumption of fertilizer N at the provincial level and published a report for each fertilizer year, *Canadian Fertilizer Consumption, Shipments and Trade*. From 2003 to 2006, fertilizer N data were collected and published by the Canadian Fertilizer Institute.[10] Since 2007, Statistics Canada has collected and published fertilizer shipment data annually (Statistics Canada, n.d. [h]).

Urine and Dung Deposited on Pasture, Range and Paddock by Grazing Animals

Canada uses a country-specific method for estimating N_2O emissions from urine and dung deposited on pasture, range and paddock by grazing animals. The N_2O emission factors for all livestock types were determined based on a research project carried out between 2009 and 2011 for dairy cows in Eastern Canada and for beef cattle in Western Canada. Results from dairy manure in Eastern Canada are available in Rochette et al. (2014). Results from beef manure in Western Canada are summarized in Table A3.4–33 (Lemke et al. 2012; Lemke et al. 2023). In comparison with the IPCC default EF for major livestock (2%), emission factors were 3.2 times lower in Eastern Canada and 46.5 times lower in Western Canada. Lower emission factors observed on the Canadian Prairies compared with the more humid climate in Eastern Canada are consistent with the findings of Rochette et al. (2008), who reported that moisture deficit—defined as the ratio of precipitation to potential evapotranspiration during the growing season—is a major contributing factor for N_2O emissions on arable cropland in Canada. For Ontario, Quebec and the Atlantic provinces, N_2O EFs are 0.0078 kg N_2O-N kg N^{-1} for fine-textured soil, 0.0062 kg N_2O-N kg N^{-1} for medium-textured soil and 0.0047 kg N_2O-N kg N^{-1} for coarse-textured soil (Rochette et al., 2014). A weighted N_2O EF based on soil texture is calculated for each ecodistrict based on Equation A3.4–13, assuming 75% of excreted N in urine (Rochette et al., 2014). In Western Canada, the N_2O EF is 0.00043 kg N_2O-N kg N^{-1} (Table A3.4–33). N_2O emissions are calculated using a fixed emission factor-based approach (Equation A3.4–21).

Equation A3.4–21

$$N_2O_{PRP} = \sum[(N_{T,i} \times N_{EX,T} \times N_{PRP,T} \times EF_{PRP,i})] \times 44/28$$

N_2O_{PRP} = emissions from urine and dung deposited on pasture, range and paddock from grazing animals, kg N_2O yr^{-1}
$N_{T,i}$ = animal population of category or subcategory T in ecodistrict i, head
$N_{EX,T}$ = annual N excretion rate for animal category or subcategory T, kg N $head^{-1}$ yr^{-1} (Table A3.4–23 and Table A3.4–25)
$N_{PRP,T}$ = fraction of manure N excreted on pasture, range and paddock by animal category or subcategory T (Table A3.4–18)
$EF_{PRP,i}$ = emission factor for manure N deposited by animals on pasture, range and paddock in ecodistrict i
$44/28$ = coefficient converting N_2O-N to N_2O

Details on animal population data and data sources are provided in section A3.4.1.

Table A3.4–33 **Nitrous Oxide Emissions from Beef Urine and Dung on Pasture in Western Canada**

Site	Treatment	Flux	Target N Rate	Standard Deviation	Emission Factor
		kg N ha^{-1}			kg N_2O-N kg^{-1} N
Swift Current, SK	Control	0.07		0.04	
	Dung	0.07	500	0.05	0.000002 ± 0.00003
	Urine	0.79	750	1.56	0.001 ± 0.002
Lacombe, AB	Control	0.59		0.33	
	Dung	0.50	500	0.41	0 ± 0.0002
	Urine	0.72	750	0.58	0.0002 ± 0.0003
Overall mean	Dung				0 ± 0.0001
	Urine				0.0006 ± 0.0012

Note:
Lemke et al. 2023

10 Available online at http://www.statcan.gc.ca/daily-quotidien/150213/dq150213f-eng.htm.

Crop Residue Decomposition

The transformation (nitrification and denitrification) of N released during the decomposition of crop residues results in N_2O emissions in the atmosphere. A Tier 2 method with country-specific emission factors similar to that for inorganic and organic N fertilizers is used to estimate N_2O emissions from crop residues, based on Equation A3.4–22, Equation A3.4–23 and Equation A3.4–24. The amount of N contained in the above-ground crop residues subjected to field burning at the provincial level is removed from the emission estimate to avoid double counting (see section A3.4.7).

Equation A3.4–22

$$N_2O_{CRN} = \sum [F_{CR(i,m)} \times (EF_Base_i \times RF_NSE \times RF_NS_{k=ON,m} \times RF_CS_m)] \times 44/28$$

N_2O_{CRN}	=	emissions from crop residue decomposition, kg N_2O yr^{-1}
$F_{CR(i,m)}$	=	total amount of crop residue N that is returned to soils in ecodistrict i, excluding N losses due to residue burning, in cropping system m as shown in Table A3.4–30, in units of kg N yr^{-1} (see Equation A3.4–23)
EF_Base_i	=	weighted average emission factor for ecodistrict i described in Equation A3.4–12, kg N_2O-N kg N yr^{-1}
RF_NSE	=	ratio factor of 1/0.645 for non-growing season soil N_2O emissions, unitless
$RF_NS_{k=ON,m}$	=	ratio factor for source of N, for organic N source k=ON in cropping system m as shown in Table A3.4–30, unitless
RF_CS_m	=	ratio factor for cropping system, m (annual or perennial) as shown in Table A3.4–30, unitless
$44/28$	=	coefficient converting N_2O-N to N_2O

Equation A3.4–23

$$F_{CR(i,m)} = \sum_{T,i} [P_{T,i} \times FRAC_{RENEW,T,i} \times (R_{AG,T} \times N_{AG,T} + R_{BG,T} \times N_{BG,T})]$$

$F_{CR(i,m)}$	=	total amount of crop residue N that is returned to soils in ecodistrict i and cropping system m, excluding N losses due to residue burning, kg N yr^{-1}
$P_{T,i}$	=	total production of the Tth crop type that is renewed annually in ecodistrict i, kg DM yr^{-1} (see Equation A3.4–24)
$FRAC_{RENEW,T,i}$	=	fraction of total area under crop T that is renewed annually in ecodistrict i
$R_{AG,T}$	=	ratio of above-ground residues to harvested yield for crop T, kg dry matter (DM) kg^{-1} DM
$N_{AG,T}$	=	N content of above-ground residues for crop T, kg N kg^{-1} DM^{-1}
$R_{BG,T}$	=	ratio of below-ground residues to harvested yield for crop T, kg DM kg^{-1} DM
$N_{BG,T}$	=	N content of below-ground residues for crop T, kg N kg^{-1} DM

Equation A3.4–24

$$P_{T,i} = \frac{A_{T,i} \times Y_{T,i}}{\sum_{i=1}^{n}(A_{T,i} \times Y_{T,i})} \times P_{T,p} \times (1 - H_2O_T)$$

$P_{T,i}$	=	total production of the Tth crop type that is renewed annually in ecodistrict i, kg DM yr^{-1}
$A_{T,i}$	=	area under crop type T in ecodistrict i, ha
$Y_{T,i}$	=	average crop yield for crop type T in ecodistrict i, kg ha^{-1} yr^{-1}
$\sum_{i=1}^{n}(A_{T,i} \times Y_{T,i})$	=	sum of total production of crop type T in all ecodistricts (i) in the province
$P_{T,p}$	=	total production of crop type T in province p, kg DM yr^{-1}
H_2O_T	=	water content of crop T, kg kg^{-1}

Statistics Canada collects and publishes data on annual field crop production by province (Statistics Canada, n.d. [g]). The crops covered include wheat, barley, corn/maize, oats, rye, mixed grains, flaxseed, canola, buckwheat, mustard seed, sunflower seed, canary seed, fodder corn, sugar beets, tame hay, dry peas, soybean, dry white beans, coloured beans, chickpeas and lentils. The area seeded and the yield of each crop are reported at the census agricultural region and provincial levels, and the yields are allocated to Soil Landscapes of Canada polygons through area overlays by AAFC. Specific parameters for each crop type are listed in Janzen et al. (2003). The Statistics Canada survey data are based on the COA, and therefore general revisions to the survey time series may occur when COA data are modified due to refinements of the calibration model or other changes. In addition, Statistics Canada occasionally revises survey data for error correction purposes, and alignment with other supply and disposition statistics such as exports.

Mineralization Associated with Loss of Soil Organic Matter

The N in mineral soils that is mineralized in association with the loss of soil organic matter as a result of changes to land management practices can result in additional N_2O emissions in the Cropland Remaining Cropland category. An average C:N ratio of 11 with a standard deviation of 1.9 was derived from a database containing information on soil organic carbon and

N content in all major soil types in Saskatchewan (a data set of about 600). The C:N ratio in agricultural soils is considered consistent among regions. The 2006 IPCC Guidelines propose a range of C:N ratios from 8 to 15. A Tier 2 method with country-specific emission factors is used for emission estimates (see Equation A3.4–25 and Equation A3.4–26).

Equation A3.4–25

$$F_{SOM,i} = \sum_{LM}\left[\left(\Delta C_{Mineral,LM} \times \frac{1}{R}\right) \times 1000\right]$$

$F_{SOM,i}$ = net annual amount of N mineralized in mineral soils in ecodistrict i as a result of loss of soil organic carbon due to changes in land management practices, kg N

$\Delta C_{Mineral,\ LM}$ = average annual loss of soil organic carbon for each land management practice (LM), Mg C

R = C:N ratio of soil organic matter (11.0±1.9)

Equation A3.4–26

$$N_2O_{FSOM} = \sum_{i}\left(F_{SOM,i} \times EF_Base_i \times RF_NSE \times RF_NS_{k=ON,m=A} \times RF_CS_{m=A}\right) \times \frac{44}{28}$$

N_2O_{FSOM} = emissions associated with loss of soil organic matter due to changes in land management practices, kg N_2O yr^{-1}

$F_{SOM,i}$ = net annual amount of N mineralized in mineral soils as a result of loss of soil organic carbon due to changes in land management practices in ecodistrict i, kg N

EF_Base_i = weighted average emission factor for ecodistrict i described in Equation A3.4–12, kg N_2O-N kg N yr^{-1}

RF_NSE = ratio factor of 1/0.645 for non-growing season soil N_2O emissions, unitless

$RF_NS_{k=ON,m=A}$ = ratio factor for source of N, for organic N source k=ON for annual cropping system (m=A), as shown in Table A3.4–30, unitless

$RF_CS_{m=A}$ = ratio factor for annual cropping system as shown in Table A3.4–30, unitless

$44/28$ = coefficient converting N_2O-N to N_2O

The activity data on soil organic carbon loss at the ecodistrict level over the time series reported in the LULUCF Cropland Remaining Cropland category are used for estimating the amounts of soil N_2O associated with the loss of soil organic matter.

Cultivation of Organic Soils (Histosols)

Cultivation of organic soil (histosols) for annual crop and perennial forage production produces N_2O. The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils (Equation A3.4–27 and Table A6.5–7).

Equation A3.4–27

$$N_2O_H = \sum_{p}\left(A_{OS,p} \times EF_{HIST}\right) \times \frac{44}{28}$$

N_2O_H = emissions from cultivated histosols, kg N_2O yr^{-1}

$A_{os,p}$ = area of cultivated organic soils in province p, ha

EF_{HIST} = the default emission factor of 13 and 9.5 kg N_2O-N $ha^{-1}yr^{-1}$ was used for annual crop and perennial forage crops, respectively (IPCC, 2014)

$44/28$ = coefficient converting N_2O-N to N_2O

Areas of cultivated histosols at a provincial level are not collected as part of the COA. Consultations with numerous soil and crop specialists across Canada indicate that the total area of cultivated organic soils in Canada was 50 kha (Liang et al., 2004) with 16 kha used for annual crop production and 34 kha for perennial forage production.

Changes in N_2O Emissions Due to the Adoption of No-Till and Reduced Tillage

This category is specific to Canada and does not derive from additional N inputs such as fertilizer, manure and crop residue, but rather is implemented as changes to EF_Base due to the switch from conventional to conservation tillage practices—namely no-till and reduced tillage (Equation A3.4–28).

To quantify the impact of tillage practices on N_2O emissions, a tillage ratio factor (RF_Till), defined as the ratio of mean N_2O fluxes of no-till or reduced till to mean N_2O fluxes of intensive tillage (IT) (N_2O_{NT}/N_2O_{IT}), is used (Table A3.4–34). The fraction of cropland under no-till and reduced tillage ($FRAC_{NT\text{-}RT}$) in each ecodistrict is derived from the COA and is identical to that used in the LULUCF Cropland Remaining Cropland category for no-till and reduced tillage practices (see section A3.5.4 – Cropland in Annex 3.5). These data are published at the census agricultural region, census division, provincial and national levels. Annual values for $FRAC_{Till}$ in years between two consecutive census years are interpolated.

Table A3.4–34 **Soil N_2O Ratio Factors for Conservation Tillage by Ecozone**

Ecozone	RF_Till
Taiga Plains	0.73[a]
Boreal Shield	1[b]
Atlantic Maritime	1[b]
Mixedwood Plains	1[b]
Boreal Plains	0.73[a]
Prairies	0.73[a]
Pacific Maritime	1[b]
Montane Cordillera	0.73[a]

Notes:
a. Source: Liang et al. (2020)
b. Modified from Liang et al. (2020), based on expert consultations with the Canadian scientific community

Equation A3.4–28

$$N_2O_{Till} = \sum_{i,z}[(F_i \times FRAC_Till_i)(EF_Base_i \times RF_Till_z - EF_Base_i)] \times \frac{44}{28}$$

N_2O_{Till} = change in N_2O emissions resulting from the adoption of no-till and reduced tillage, kg N_2O yr^{-1}
F_i = total amount of N applied in ecodistrict i, kg N yr^{-1}
$FRAC_Till_i$ = proportion of land that has adopted conservation tillage in ecodistrict i, unitless
EF_Base_i = weighted average emission factor for ecodistrict i described in Equation A3.4–12, kg N_2O-N kg N yr^{-1}
RF_Till_z = ratio factor for conservation tillage (reduced and no-till) in ecozone z (see Table A3.4–34), unitless
$44/28$ = coefficient converting N_2O-N to N_2O

N_2O Emissions Resulting from Irrigation

Higher soil water content under irrigation increases N_2O emissions by amplifying anaerobic respiration and reducing soil aeration (Jambert et al., 1997). Consequently, the highest N_2O emissions from agricultural soils in the northwestern United States (Liebig et al., 2005) and Western Canada (Hao et al., 2001a) were observed on irrigated cropland, followed by non-irrigated cropland and rangeland. Field studies directly comparing N_2O emissions under irrigated and non-irrigated conditions are lacking in Canada. Therefore, an approach was adopted based on the assumptions that: (1) irrigation water stimulates N_2O production in a way similar to rainfall; (2) irrigation is applied to eliminate any moisture deficit such that "precipitation + irrigation water = potential evapotranspiration"; and (3) the effect of irrigation on N_2O emissions is in addition to effects of the non-irrigated area within an ecodistrict. Consequently, the effect of irrigation on N_2O emissions from agricultural soils was accounted for by using an EF_Base value estimated at P=PE for the irrigated areas of an ecodistrict (Equation A3.4–29):

Equation A3.4–29

$$N_2O_{Irri} = \sum_{i}[(F_i \times FRAC_Irri_i)(EF_Base_i \times RF_Irri_i - EF_Base_i)] \times \frac{44}{28}$$

N_2O_{Irri} = emissions from irrigation, kg N_2O yr^{-1}
F_i = total amount of N applied in ecodistrict i, kg N yr^{-1}
$FRAC_Irri_{,i}$ = fraction of irrigated cropland in ecodistrict i
EF_Base_i = weighted average emission factor for ecodistrict i described in Equation A3.4–12, kg N_2O-N kg N yr^{-1}
RF_Irri_i = ratio factor for irrigation in ecodistrict i (see Equation A3.4–30), unitless
$44/28$ = coefficient converting N_2O-N to N_2O

Equation A3.4–30

$$RF_Irri_i = \frac{EF_CT_{P=PE,i}}{EF_CT_{P,i}}$$

RF_Irri_i = emissions from irrigation, kg N_2O yr^{-1}
$EF_CT_{P,i}$ = Soil N_2O emission factor calculated at P for ecodistrict i, kg N_2O-N kg^{-1} N (see Figure A3.4–5)
$EF_CT_{P=PE,i}$ = Soil N_2O emission factor calculated at P=PE for ecodistrict i, kg N_2O-N kg^{-1} N

The fraction FRAC_Irri is derived from the COA values for each ecodistrict (see section A3.5.4). The annual FRAC_Irri for years between two consecutive census years is adjusted through interpolation.

A3.4.5.2. Indirect N_2O Emissions from Agricultural Soils

Volatilization and Re-deposition of Nitrogen

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from the volatilization and re-deposition of inorganic and organic N. The emission calculation is shown in Equation A3.4–31.

Equation A3.4–31

$$N_2O_{VD} = \sum_i \left[\left(F_{IN,i} \times FRAC_{GASF\,NT,i}\right) + \left(MN_{PRP,iT} \times FRAC_{GasMS-PRP,T}\right) + \left(F_{ON,i} \times FRAC_{GASM,i}\right)\right] \times EF_4 \times \frac{44}{28}$$

N_2O_{VD}	=	emissions from volatilization and re-deposition of N, kg N_2O yr^{-1}
$F_{IN,i}$	=	inorganic N consumption for each type of N fertilizer—including urea, urea ammonium nitrate, anhydrous ammonia and others—in ecodistrict i, kg N yr^{-1}
$FRAC_{GASF\,NT,i}$	=	fraction of inorganic N fertilizers applied to soils that volatilizes as NH_3-N, kg NH_3-N kg^{-1} N, determined by a country-specific method in ecodistrict i (see Equation A3.4–32)
$MN_{PRP,iT}$	=	amount of urine and dung N excreted on pasture, range and paddock by animal category or subcategory T in ecodistrict i, kg N yr^{-1}
$FRAC_{GasMS-PRP,T}$	=	fraction of volatilized manure N deposited on pasture, range and paddock by animal category or subcategory T: 0.2 kg (NH_3-N + NO_x-N) kg^{-1} N (IPCC, 2006) for all livestock categories except Dairy Cattle (Table A3.4–40)
$F_{ON,i}$	=	organic N fertilizers applied on cropland in ecodistrict i, kg N yr^{-1} (see Table A3.4–38)
$FRAC_{GASM,i}$	=	fraction of volatilized organic N fertilizers in ecodistrict i: 0.21 kg (NH_3-N + NO_x-N) kg^{-1} N for all livestock (IPCC, 2019) except the Dairy Cattle (Table A3.4–38) and Swine (Table A3.4–39) categories
EF_4	=	emission factor from atmospheric deposition of N (see Table A3.4–26)
$44/28$	=	coefficient converting N_2O-N to N_2O

A country-specific method was used to estimate ammonia emissions from inorganic N applications. The method for deriving ammonia emission factors closely follows the approach used by Sheppard et al. (2010a), who applied the regression model developed by Bouwman et al. (2002b) to obtain regionally specific emission factors for different ecoregions in Canada. This approach derives ammonia emission factors based on the type of inorganic N fertilizer, the degree of incorporation into soil, crop type and soil chemical properties (Equation A3.4–32).

Equation A3.4–32

$$FRAC_{GASF\,NT,\,i} = 100 \times EXP\,(sum\ of\ relevant\ coefficients)$$

$FRAC_{GASF\,NT,\,i}$	=	ammonia emission factor for each type of inorganic N fertilizer in ecodistrict i, %
$sum\ of\ relevant\ coefficients$	=	coefficients for crop type, type of inorganic N fertilizer, method of N application, soil chemical properties and climate, unitless (see Table A3.4–35)
100	=	conversion of fraction to percent
EXP	=	exponential

Table A3.4–35 **Coefficients for Crop Type, Inorganic N Fertilizer Type, Method of Fertilizer Application, Soil Chemical Properties and Climate Developed by Bouwman et al. (2002b)**

Conditions Under Which Coefficient Used		Coefficients
Crop type	Annual crops	-0.045
	Perennial crops	-0.158
Fertilizer type	Urea	0.666
	Urea ammonium nitrate	0.282
	Anhydrous ammonia	-1.151
	Other N sources	-0.238
Method of application	Broadcast onto surface	-1.305
	Incorporated	-1.895
Soil chemical properties	Soil pH < 7.25	-1
	Soil pH 7.25 ~ 8.5	-0.608
	Soil CEC < 250 mmol kg^{-1}	0.0507
	Soil CEC > 250 mmol kg^{-1}	0.0848
Climate	Temperate	-0.402

The method of application for each type of inorganic N fertilizers for Eastern and Western Canada is provided in Sheppard et al. (2010a). Soil properties, pH and cation exchange capacity (CEC) are derived from CANSIS soil polygon information and are based on fractional distributions of soil series having pH < 7.25 and CEC < 250 me kg^{-1}, pH < 7.25 and CEC > 250 me kg^{-1}, pH > 7.25 and CEC < 250 me kg^{-1}, and pH > 7.25 and CEC > 250 me kg^{-1}. Statistics Canada collects and publishes annual inorganic N fertilizer shipment data including urea, urea ammonium nitrate, anhydrous ammonia and others (Statistics Canada, n.d. [h], Statistics Canada, n.d. [i]). The application of this equation results in spatially specific emission factors for inorganic N fertilizers applied to annual crops. Provincial averages by fertilizer type (Table A3.4–36) are calculated based on the spatial distribution of soil chemical properties and climate for each individual ecodistrict in each province and, as a consequence, the fraction ($FRAC_{GASF}$) of ammonia volatilized by province varies slightly from year to year based on fertilizer sales (Table A3.4–37). More detail on methods of estimating ammonia emission factors from inorganic N fertilizers can be found in Sheppard et al. (2010a), and simplifications used to convert monthly emissions calculated in the original publication to an annual estimate are documented in Liang (2014). Briefly, based on the data provided in Sheppard et al. (2010a), it is assumed that inorganic N fertilizers are applied in either spring or fall when temperatures are similar. Therefore, a single temperature representing annual applications per ecoregion is used to estimate emissions. According to this approach, the fraction of fertilizers emitted during fertilizer application ranges from roughly 5% to a maximum of 10% (Table A3.4–37), depending on the year and province.

Table A3.4–36 **Ammonia Emission Factors for Inorganic Nitrogen Fertilizers Applied to Annual Crops, Weighted Based on Soil Properties for Each Province (%)**

Province	Annual			
	Urea	Anhydrous NH_3	UAN[a]	Other
AB	5	4.2	3.8	5.4
BC	4.8	4	3.7	5.2
MB	5.8	4.9	4.5	6.3
NB	7.4	3.9	4.5	4.5
NL	7.4	3.9	4.5	4.5
NS	7.3	3.9	4.4	4.4
ON	8.2	4.4	5	4.9
PE	7.3	3.9	4.4	4.4
QC	7.4	4	4.5	4.5
SK	5.1	4.2	3.9	5.5

Note:
a. UAN = Urea ammonium nitrate

Table A3.4–37 **Fractions of N Volatilized ($FRAC_{GASF}$) as Ammonia Resulting from the Application of Inorganic N Fertilizer, from Select Years (1990–2024) at a Provincial Scale**

Year	Implied EF (kg NH_3-N volatilized / kg inorganic fertilizer N applied)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.060	0.087	0.065	0.067	0.078	0.077	0.081	0.063	0.089	0.055
2005	0.062	0.101	0.068	0.060	0.069	0.070	0.086	0.056	0.073	0.058
2018	0.060	0.083	0.066	0.049	0.066	0.057	0.078	0.046	0.077	0.056
2019	0.060	0.083	0.065	0.057	0.000	0.065	0.075	0.054	0.077	0.056
2020	0.061	0.086	0.066	0.064	0.000	0.074	0.073	0.061	0.074	0.056
2021	0.061	0.086	0.066	0.061	0.000	0.070	0.073	0.057	0.074	0.057
2022	0.061	0.085	0.066	0.064	0.000	0.075	0.074	0.061	0.074	0.057
2023	0.061	0.085	0.066	0.067	0.000	0.078	0.076	0.062	0.079	0.057
2024	0.062	0.087	0.066	0.074	0.096	0.086	0.074	0.068	0.078	0.057

Table A3.4–38 **Fractions of Dairy Cattle N Volatilized as Ammonia Resulting from the Application of Manure N Fertilizer, from Select Years, 1990–2024, at a Provincial Scale**

Year	Implied EF (kg NH_3-N volatilized / kg manure N applied)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.13	0.10	0.16	0.20	0.19	0.20	0.18	0.18	0.17	0.15
2005	0.11	0.08	0.14	0.17	0.19	0.16	0.17	0.18	0.15	0.13
2018	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2019	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2020	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2021	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2022	0.11	0.10	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2023	0.11	0.10	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2024	0.11	0.10	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12

Table A3.4–39 **Fractions of Swine N Volatilized as Ammonia Resulting from the Application of Manure N Fertilizer, from Select Years, 1990–2024, at a Provincial Scale**

Year	Implied EF (kg NH_3-N volatilized / kg manure N applied)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.14	0.22	0.14	0.28	0.22	0.28	0.21	0.28	0.26	0.15
2005	0.12	0.22	0.11	0.25	0.22	0.24	0.20	0.25	0.24	0.12
2018	0.13	0.22	0.11	0.24	0.22	0.25	0.20	0.25	0.24	0.12
2019	0.13	0.22	0.11	0.24	0.22	0.25	0.20	0.25	0.24	0.12
2020	0.13	0.22	0.11	0.24	0.23	0.26	0.20	0.25	0.24	0.12
2021	0.13	0.23	0.11	0.25	0.22	0.25	0.20	0.25	0.24	0.12
2022	0.13	0.23	0.11	0.25	0.22	0.25	0.20	0.25	0.24	0.12
2023	0.13	0.23	0.11	0.25	0.22	0.25	0.20	0.25	0.24	0.12
2024	0.13	0.23	0.11	0.25	0.22	0.25	0.20	0.25	0.24	0.12

Table A3.4–40 **Fractions of Dairy Cattle N Volatilized as Ammonia Resulting from Deposition on Pasture, Range and Paddock, in 2024, at a Provincial Scale**

Province	Implied EF (kg NH_3-N volatilized / kg manure N)
Alberta	0.035
British Columbia	0.042
Manitoba	0.036
New Brunswick	0.039
Newfoundland and Labrador	0.036
Nova Scotia	0.039
Ontario	0.042
Prince Edward Island	0.039
Quebec	0.036
Saskatchewan	0.037

Leaching and Runoff

A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from the leaching and runoff of inorganic and organic N fertilizers, and crop residue N from agricultural soils:

Equation A3.4–33

$$N_2O_L = \sum_i \left[\left(N_{FERT,i} + N_{ON,i} + MAN_{PRP,i} + N_{RES,i} \right) \times FRAC_{LEACH,i} \times EF_5 \right] \times \frac{44}{28}$$

N_2O_L	=	emissions from leaching and runoff of N, kg N_2O yr^{-1}
$N_{FERT,i}$	=	inorganic N fertilizers applied for ecodistrict i, kg N
$N_{ON,i}$	=	organic manure and biosolids N applied for ecodistrict i, kg N
$MAN_{PRP,i}$	=	urine and dung deposited on pasture, range and paddock for ecodistrict i, kg N
$N_{RES,i}$	=	crop residue N for ecodistrict i, kg N
$FRAC_{LEACH,i}$	=	fraction of N that is lost through leaching and runoff for ecodistrict i, as defined below
EF_5	=	leaching/runoff emission factor: 0.0075 kg N_2O-N kg N^{-1} (IPCC, 2006)
$44/28$	=	coefficient converting N_2O-N to N_2O

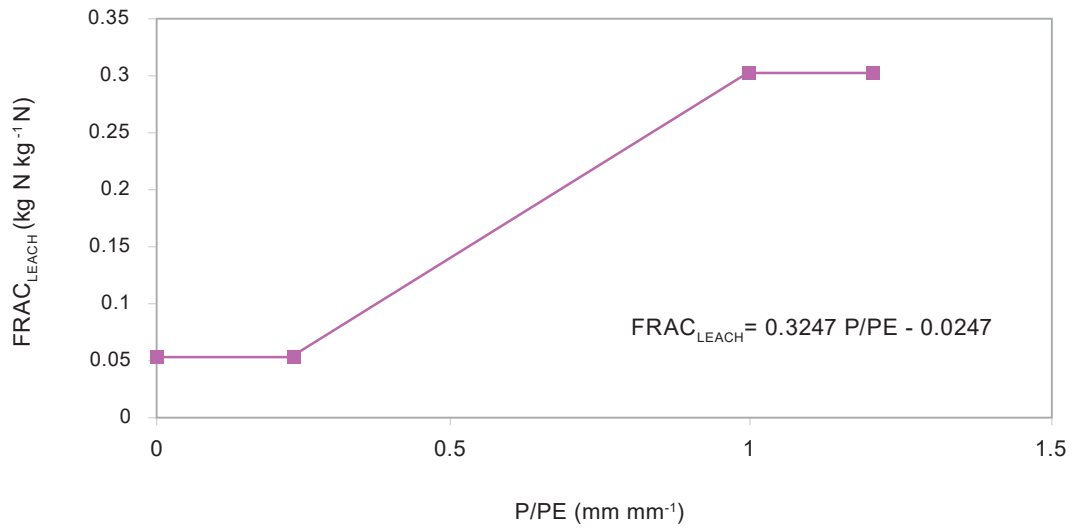
Determining the Fraction of Nitrogen that is Leached ($FRAC_{LEACH}$) at the Ecodistrict Level in Canada

In Canada, leaching losses of N vary widely among regions. In some farming systems of southern British Columbia, high N inputs in humid conditions may lead to losses greater than 100 kg N ha^{-1} $year^{-1}$ (Paul and Zebarth, 1997; Zebarth et al., 1998). Those farming systems, however, represent only a small fraction of Canadian agroecosystems. In Ontario, Goss and Goorahoo (1995) predicted leaching losses of 0 to 37 kg N ha^{-1}, representing between 0% and 20% of N inputs. Leaching losses in most of the Prairies region may be smaller due to lower precipitation and lower N inputs on a per area basis. Based on a long-term experiment in central Alberta, Nyborg et al. (1995) suggested that leaching losses were minimal, and Chang and Janzen (1996) found no evidence of N leaching in non-irrigated, heavily manured plots, despite large accumulations of soil nitrate in the soil profile.

The values for $FRAC_{LEACH}$ can be as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration, such as in the Prairies region of Canada, or as high as 0.3 in humid regions (IPCC, 2006) of Eastern Canada. Accordingly, it was assumed that $FRAC_{LEACH}$ would vary from 0.05 to 0.3, depending on the ecodistrict.

For ecodistricts with a P/PE value for the growing season (May through October) greater than or equal to 1, the maximum $FRAC_{LEACH}$ value of 0.3 (IPCC, 2006) was assigned. For ecodistricts with the lowest P/PE value (0.23), a minimum $FRAC_{LEACH}$ value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged from 0.23 to 1, $FRAC_{LEACH}$ was estimated by the linear function that joins the two-end points (P/PE, $FRAC_{LEACH}$) = (1,0.3; 0.23,0.05) (Figure A3.4–9).

Figure A3.4–9 **Determination of Ecodistrict $FRAC_{LEACH}$ Values**



Data sources for N_{FERT}, $N_{MAN\text{-}CROPS}$, MAN_{PRP} and N_{RES} (section A3.4.5.1) at the ecodistrict level are provided in the previous sections.

Long-term normals of monthly precipitation and potential evapotranspiration from May to October, 1981–2010 (AAFC-archived database) were used to calculate $FRAC_{LEACH}$ at the ecodistrict level.

A3.4.6. QA and Validation of Soil N_2O Emission Methodologies

The method used to estimate soil N_2O emissions reflects recent results from several meta-analyses of Canadian studies published between 1990 to 2022 (Rochette et al., 2018; Pelster et al., 2023). Rochette et al. (2018) compiled soil N_2O flux data from agricultural soils across Canada collected since 1990 to identify key soil and climate factors, and management practices, that explain variations in N_2O emissions and in EF. Building on these results, Liang et al. (2020) developed a country specific method for estimating N_2O emissions from agricultural soils in Canada. This method incorporates spatial elements such as soil texture, topography, and climate based on management factors, including tillage practice, irrigation, crop type (perennial versus annual), and N sources (synthetic N, manure/biosolid N, crop residual N). These two studies represent 69 publications, 65 sites and 1312 measurements.

Recognizing the significant contribution of non-growing season soil N_2O emissions, Pelster et al. (2023) compiled Canadian studies measuring year-round soil N_2O emissions from agricultural systems. They determined that the proportion of these emissions that occurred during the non-growing season and concluded that the proportion of annual N_2O emissions occurring during the non-growing season varied widely, from −4% to 119% with a mean of 35.5%. This method incorporates all relevant literature available to track and report soil N_2O emissions from agricultural soils in Canada.

In some cases expert judgement is still relied upon, however, these instances are clearly documented in the peer-reviewed publications that describe the methodologies. For example, the ratio factor used for irrigation is based on limited observations and relies on expert judgement (Rochette et al., 2008). Direct field measurements are required to validate this factor, although irrigation is a minor source of soil N_2O emissions, and the area of irrigated cropland has remained relatively small and stable (~700 kha annually) throughout the entire time series.

The fraction of leached N ($Frac_{LEACH}$), from 5 to 30% as a linear function of P/PE, has also been developed based on expert judgement rather than measurement, although this method is consistent with default values used in the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019). Refining $Frac_{LEACH}$ is further necessary to improve estimates of soil N_2O emissions resulting from soil N leaching.

Further, the ratio factor, $RF_{NS=ON}$=0.84 was developed with limited observations and does not account for manure type (i.e., liquid, semi-solid, or solid). Most data were collected in the temperate and humid regions of Eastern Canada. Additional field studies are needed, particularly in on the Canadian Prairies, to evaluate different manure types, including municipal-based biosolids.

There is evidence, that the use of Enhanced Efficiency Fertilizers (EEFs) and adoption of improved nitrogen management practices in Canada have increased in recent years. However, only limited evidence exists on the response of soil N_2O emissions to EEFs, and complete time series activity data for these practices are lacking. Therefore, mitigation estimates have not been developed for this NIR.

Sokolov et al. (2026) conducted a meta-analysis and found that, compared with conventional synthetic N, soil N_2O emission reductions were 23% for nitrification inhibitors, 15% for dual inhibitors, 6% for slow N release fertilizers, and -9% for urease inhibitors. This study suggests that it is feasible to develop ratio factors for various EEFs and to estimate soil N_2O emission reductions using time series activity data for EEFs collected by Fertilizer Canada in the NIR. The same study also documented the effect of N management practices, including timing of N use, split applications, placement, rate, and method of application, and fertilizer type on soil N_2O emission reductions. Currently, there are two main challenges that hinder implementation in the NIR: 1) many nutrient management practices are used in combination, whereas only impacts of individual practice are available (Sokolov et al., 2026); and 2) time series activity data for the nutrient management practices are lacking.

Uncertainty Estimates of N_2O Emissions

A comprehensive uncertainty analysis was completed for all methodologies used in the calculation of N_2O from livestock and agricultural soils for 2010 (Karimi-Zindashty et al., 2014). The analysis has not yet been published, and limited depth of analysis could be carried out due to the size and complexity of the Canadian N_2O quantification approach and the upper limits of the data processing capability of the Analytica software. However, the analysis did provide the uncertain bounds around the principal emission source categories. For this submission, the uncertainty ranges (percentages) developed for 2010 means were applied to means for the current year. In the analysis, a stochastic reproduction of the complete N_2O emission methodology was built in Analytica© at the ecodistrict scale, and a MCS was run according to the methodology proposed in the Good Practice Guidance (IPCC, 2000). A sensitivity analysis was carried out to identify the parameters that contributed most to the different emission source categories.

The parameters used in the calculation of N_2O emissions can be divided into three categories: (1) those associated with information at the ecodistrict scale, (2) provincial-scale data and (3) IPCC/national-scale parameters (Table A3.4–41). Many national-scale parameters are taken directly from the 2006 IPCC Guidelines (IPCC, 2006) or from the original country-specific methodological development work carried out by Rochette et al. (2008), derived either analytically or through expert opinion based on a panel of four experts in agricultural GHG emissions. Provincial-scale parameters include fertilizer sales and characteristics of crop production, the source of uncertainty being the Statistics Canada survey uncertainty and expert opinion on characteristics of crop production. The uncertainty of livestock populations and management parameters for animal categories were identical to that discussed in sections A3.4.2.4 and A3.4.3.9; the distributions used to define uncertainties can be found in Table A3.4–12 and Table A3.4–22. Landscape-scale parameters were derived from the agricultural soil landscape parameter database developed by AAFC and used in the production of cropland estimates for LULUCF. Specific landscape-parameter uncertainty was based on the general rules used in the production of uncertainty estimates for cropland C, which postulates that the uncertainty of a parameter at the landscape scale is inversely proportional to the relative size of the landscape unit, i.e., smaller parameters associated with smaller ecodistricts have greater uncertainty. The bounds of the uncertainty for different parameters varied. For example, uncertainties around animal distribution were ±30% for small ecodistricts and ±5% for large ecodistricts, whereas for the fraction of lowland soil in a given ecodistrict, variability was bounded as ±10% for small ecodistricts and ±1.25% for large ecodistricts. The current analysis does not include new country-specific emission factors for N_2O emissions from animal manure deposited on pasture, range and paddock, but does include the analysis of emissions considering the 2006 IPCC Guidelines leaching emission factor.

The summary results of the uncertainty analysis on emissions of N_2O are reported in Chapter 5. The relative uncertainty range for N_2O emissions from agricultural sources is 56% (-27% to +29% of the mean). Most uncertainty is associated with indirect emissions and specifically with the indirect emission factors for volatilized and leached N, with the estimate of indirect emissions uncertainty of 126% (-58% to +68% of the mean). The emissions are skewed to the lower end of the emission probability distribution, because emission factor uncertainty is bounded by zero and emission factor variability is expressed as a factor on the lower scale; a change from 1% to 0.2% has a smaller impact on total emissions than a change from 1% to 5% at the upper end of the probability distribution. The uncertainty range of direct N_2O emissions from agricultural soils is 69% (-31% to +38% of the mean). There have been few complete studies of uncertainty from emissions of N_2O in the literature. In a study directly comparable to this particular uncertainty analysis, Monni et al. (2007) estimated that total N_2O emissions in Finland ranged from -50% to +70% of the mean emission estimate. Their methodology included a mixture of country-specific and default Tier 1 methodology to produce emission estimates. In a recent study of uncertainty in the United Kingdom, Milne et al. (2014) observed high uncertainty ranges for direct, indirect and total N_2O emissions, specifically -56% to +140%, -91% to +370%, and -55% to +110%, respectively. Our parameter uncertainty was similar to that used by the UK researchers, but it is suspected that the high degree of spatial disaggregation in the Canadian N_2O quantification approach resulted in slightly lower overall uncertainty. The uncertainty associated with the fraction of emission(s) from inorganic N fertilizers would be reduced from ±200% by the IPCC default (IPCC, 2006) given the country-specific approach applied in this submission.

Sensitivity analysis indicated that indirect EF uncertainties were the largest contributors to overall uncertainty. Uncertainty of direct soil emissions was dominated by the use of uncertainty in the Tier 1 emission factor for emissions from PRP, the slope of P/PE regression equation and the emission factor modifier for tillage and texture (RF_Till, RF_TX). The EF for solid manure systems was the largest source of uncertainty in the estimate of N_2O emissions from AWMS. Reduction of uncertainty will require the replacement of Tier 1 default emission factors and modifiers in the methodology.

Table A3.4–41 **Uncertainty Parameters Used in the Calculation of Agricultural N_2O Emissions**

Parameter	Coefficient/Parameter Source	Distribution Type	Uncertainty Range	Most Likely Value[b]	Uncertainty Distribution Source and Notes
IPCC and national-scale parameters					
Animal populations and characterization data[a]					Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication
N excretion	2006 IPCC Guidelines	Normal	±50%	IPCC default	
$FRAC_{GAS}/FRAC_{LOSSMS}$		Triangular	IPCC default	IPCC default	See Table 10.22/10.23 of 2006 IPCC Guidelines
AWMS emission factor		Triangular	Liquid 0.0005–0.002 PRP -0.007–0.06	Minimum liquid 0.001 Maximum PRP -0.02	2006 IPCC Guidelines variable depending on the manure storage type
Crop characteristics					
H_2O content	Janzen et al. (2003)	Normal	±15%		Expert consultation
Relative DM allocation of residue (product, above-ground and below-ground)					
$FRAC_{Renew}$ (duration)					
N concentration in residue (above-ground and below-ground)					
Direct and indirect emission factors/modifiers					
P/PE regression parameters	Rochette et al. (2008)	Normal	Intercept ±54% Slope ±21%		Expert consultations
$FRAC_{LEACH}$ calculation parameters			Intercept ±54% Slope ±21%		
RF_Till			±100%		
RF_TX			±30%		
EF5	2006 IPCC Guidelines	Triangular	0.002–0.12	0.025	2006 IPCC Guidelines
EF_4			0.002–0.05	0.01	
EF_{HIST}			2–24	8	
Provincial-scale parameters					
Fertilizer application rate (kg/ha)	Factors are drawn from those commonly used in AAFC[c] literature and modelling studies	Normal	±15%		Expert consultation
Provincial fertilizer sales	Statistics Canada	Normal	±15%		Interpretation of data quality evaluation in Statistics Canada Report
Ecodistrict-scale parameters					
P and PE	Weather station data	Normal	5–15%		Based on individual weather station data, 30-year average
Total ecodistrict area	AAFC's[c] geographically referenced soil landscape agricultural database, derived from the *Census of Agriculture*, 1990–2011	Normal	Function of relative ecodistrict size: maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter		Based on the uncertainty methodology used in the carbon quantification methodology for croplands
Crop areas					
Animal population distribution for ecodistrict					
RF_TOPO (proportion of lowland soils in ecodistrict)					
Extent of organic soils					
Irrigated soil area					
Annual soil texture					
Perennial soil texture					

Notes:
a. The uncertainty associated with most livestock parameters is described in sections A3.4.2.4 and A3.4.3.8, and the distributions used to define uncertainties can be found in Table A3.1–7 and Table A3.2–8.
b. Reported where applicable when using a triangular distribution.
c. Agriculture and Agri-Food Canada

A3.4.7. CH_4 and N_2O Emissions from Field Burning of Agricultural Residues

Crop residues are sometimes burned in Canada, for convenience and as a means of disease control through residue removals, although expert opinion suggests that this practice has declined in recent years because of soil quality and environmental issues.

Field burning of agricultural residues emits CH_4 and N_2O. The quantity of crop residue burning in Canada can be estimated as follows:

Equation A3.4–34

$$Q_{BURN} = \sum_{T} (PRODUCTION_T \times (1 - MOISTURE_T) \times RatioAR/P_T \times PCB_T \times RATIO_{SCALE})$$

Q_{BURN}	=	quantity of crop residue burned from crop T for each province, Mg DM yr^{-1}
$PRODUCTION_T$	=	total production of crop T, Mg yr^{-1}
$MOISTURE_T$	=	moisture content of the product from crop T, fraction
$RatioAR/P_T$	=	ratio of above-ground crop residue to the crop product for crop T, unitless
PCB_T	=	percent of crop residue that is subject to field burning for crop T, fraction
$RATIO_{SCALE}$	=	a scaling factor or an intensity factor adjusted for burning in 2006, unitless

Data collected in 2001 and 2006 by Statistics Canada through its Farm Environmental Management Survey (FEMS)[11] include crop residue burning. The type of crop and the extent of crop residue burning for each province were only available for 2006; these data were collected in FEMS and are summarized in Table A3.4–42. To establish a complete time series of activity data, additional information on crop residue burning for 1991 and 1996 has been gathered through expert consultations (Coote et al., 2008). Thus, a crop that was subject to field burning in 2006 was also assumed to be subject to field burning for the entire time series.

The intensity of crop residue burning in each province for 1991, 1996 and 2001 was adjusted as a ratio based on the average burning for 2006 (Table A3.4–43). Janzen et al. (2003) report basic characteristics of crops, such as moisture content of crop product and ratio of aboveground crop residue to crop product. Annual production of each crop subject to residue burning is available (Statistics Canada, n.d. [g]). Other parameters, such as fraction of biomass burned, and emission factors required for emission estimates, were obtained from the 2006 IPCC Guidelines.

Table A3.4–42 **Burning of Crop Residues by Crop Types in 2006**

Province/Territory	Spring Wheat	Winter Wheat	Oats	Barley	Mixed Grains	Flaxseed	Canola
	% of Crop Residue Burned (by Weight)						
AB	0	0	0	0	0	8	0
BC	0	0	0	0	0	0	0
MB	2	3	3	1	0	17	1
NB	0	0	1	0	0	0	0
NL	0	0	0	0	0	0	0
NS	33	0	0	0	0	0	0
ON	0	0	0	1	2	0	0
PE	3	0	0	1	0	0	0
QC	0	0	1	0	0	0	0
SK	0	0	0	0	0	15	1

11 Available at http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5044.

Table A3.4–43 **Crop Residue Burning by Province in Canada for 1991, 1996, 2001 and 2006**				
Province/Territory	1991[a]	1996[a]	2001[b]	2006[b]
	% of Crop Residue Burned (by Weight)			
AB	0.8	0.7	0.2	0.2
BC	0	0	0	0
MB	12.6	10.1	8.9	2.3
NB	0.5	0.5	0.5	0.5
NL	0	0	0	0
NS	0.5	0.5	0.5	0.5
ON	0.7	0.7	0.7	0.3
PE	0.4	0.4	0.4	0.4
QC	0.4	0.4	0.4	0.3
SK	8.1	5.8	3.9	1.5

Notes:
a. Data were obtained from consultations by Coote et al. (2008).
b. Data extracted from the Farm Environmental Management Survey (2001) and (2006), conducted by Statistics Canada.

N_2O and CH_4 emissions from crop residue burning are estimated using the following equation:

Equation A3.4–35

$$EMISSION_{BURN} = \sum (Q_{BURN,p} \times C_F \times G_{EF})/1000$$

$EMISSION_{BURN}$ = emissions of N_2O or CH_4 from the burning of crop residues in Canada (kt N_2O or CH_4)
$Q_{BURN,\,p}$ = quantity of crop residues burned in province p, Mg, DM yr^{-1}
C_F = combustion efficiency of fuel F (IPCC, 2006), unitless
G_{EF} = emission factors (IPCC, 2006), 0.00007 kg N_2O or 0.0027 kg CH_4 kg^{-1} of DM burned
1000 = coefficient for converting Mg to kt

A3.4.8. CO_2 Emissions from Liming and Urea Fertilization

A3.4.8.1. CO_2 Emissions from Liming

Limestone ($CaCO_3$) is often used to neutralize acidic soils, increase the availability of soil nutrients, in particular phosphorus, reduce the toxicity of heavy metals and improve the crop growth environment. During this neutralization process, CO_2 is released in bicarbonate equilibrium reactions that take place in the soil.

The rate of CO_2 release varies with soil conditions and the types of compounds applied. In most cases, lime is applied repeatedly. Thus, for the purposes of the inventory, it is assumed that the annual rate of lime is in near equilibrium with the consumption of lime in previous years. Emissions associated with lime application are calculated from the amount of lime applied annually.

The amount of C released from limestone/dolomite application is calculated using the default IPCC Tier 1 approach (IPCC, 2006).

Equation A3.4–36

$$CO_2 - C = \sum (M_{Limestone/dolomite,p} \times EF_{Limestone/dolomite})$$

$CO_2 - C$ = annual C emissions from lime application, Mg C yr^{-1}
$M_{Limestone/dolomite,p}$ = annual amount of limestone and dolomite consumption in province p, Mg yr^{-1}
$EF_{Limestone/dolomite}$ = 0.12, limestone emission factor or 0.13 dolomite emission factor, kg C kg^{-1} of limestone/dolomite

The quantity of lime and dolomite used for agricultural purposes is not collected through the COA by Statistics Canada, but rather through Natural Resources Canada's *Canadian Minerals Yearbook* (1990 to 2006). For more recent years, this information is only available on request.[12] This data source provides a consistent and complete time series of activity data on agricultural lime consumption in Canada. As this data source provides no information on the ratio of dolomite to limestone, the ratio from data collected through consultation with the Canadian Fertilizer Institute was used. A 95% purity is used, based on data developed in the IPPU section of the inventory for both limestone and dolomite applications.

The 95% confidence limits associated with annual lime consumption data were estimated to be ±30%. This uncertainty was assumed to include the uncertainty of lime sales, the uncertainty of when lime sold is actually applied, and thus the uncertainty in the timing of emissions. The uncertainty in the emission factor was assumed to be -50% based on the 2006 IPCC Guidelines.

A3.4.8.2. CO_2 Emissions from Urea Fertilization

When urea or urea-based N fertilizer is applied to soil to augment crop production, CO_2 is released upon hydrolysis as follows:

$$(NH_2)_2CO + H_2O \rightarrow NH_4^+ + OH^- + CO_2$$

In addition to urea, Canadian farmers also use significant amounts of urea ammonium nitrate (28-0-0) with a mixture of 30% $CO(NH_2)_2$. Carbon dioxide emissions from urea fertilization can be estimated using Equation A3.4–37:

Equation A3.4–37

$$CO_2 - C = \sum (M_{Urea,p} \times EF_{Urea})$$

$CO_2 - C$	=	annual C emissions from urea application, Mg C yr^{-1}
$M_{Urea,p}$	=	annual amount of urea fertilization, Mg yr^{-1} in province p
EF_{Urea}	=	0.20, emission factor, kg C kg^{-1} of urea

Statistics Canada collects and publishes annual fertilizer shipment data, including urea and urea ammonium nitrate (Statistics Canada, n.d. [h], Statistics Canada, n.d. [i]). The uncertainty estimate associated with the emissions is assessed based on simple error propagation using survey uncertainty of ±15% for the activity data and an uncertainty of ±50% associated with the EF specified in the 2006 IPCC Guidelines.

12 [NRCan] Natural Resources Canada. 2007–2016. Canada, Production of Limestone – Stone. Unpublished data. Natural Resources Canada, Mineral & Mining Statistics Division.

A3.5. Methodology for the Land Use, Land-Use Change and Forestry Sector

The Land Use, Land-Use Change and Forestry (LULUCF) sector of the inventory includes estimates of greenhouse gas (GHG) emissions and removals associated with managed lands and with the conversion of land from one category to another.

As in Chapter 6, the structure of this annex attempts to maintain the land-based reporting categories, while grouping together related data collection and estimate development methodologies. Section A3.5.1 summarizes the spatial framework for estimate development and area reconciliation. The general approach for estimating carbon (C) stock changes, emissions and removals in all forest-related categories, including Forest Land, Forest Land converted to other land uses and Land Converted to Forest Land, is briefly described in section A3.5.2; this description is not repeated under the Forest Land Converted to Cropland, Forest Land Converted to Wetlands and Forest Land Converted to Settlements subcategories. Section A3.5.3 describes the approach for estimating emissions associated with the use and disposal of harvested wood products (HWP) from wood harvested in Canada and section A3.5.4 describes the methods used to quantify the effect of management practices on agricultural land for the Cropland category. Likewise, the sections on the Grassland (A3.5.5), Wetlands (A3.5.6) and Settlements (A3.5.7) categories focus on category-specific estimation methodologies.

A3.5.1. Spatial Framework for LULUCF Estimate Development and Area Reconciliation

Canada's monitoring system for LULUCF draws on the close collaboration among several scientists and experts in different disciplines. Early on, it was recognized that the approaches, methods, tools and data that are available and most suitable for monitoring human activities in one land category are not always appropriate for another. Differences exist in the spatial framework specific to each land category, and these differences create a risk that activity data and estimates would be spatially inconsistent. A hierarchical spatial framework was agreed upon by all partners contributing to the LULUCF sector to ensure the highest possible consistency and spatial integrity of inventory estimates.

The LULUCF sector of the GHG inventory reports information in 18 reporting zones (Chapter 6, Figure 6–1). These reporting zones are essentially the same as the ecozones of the National Ecological Framework, a hierarchical, spatially consistent national ecosystem classification system (Marshall et al., 1999). For the purpose of reporting LULUCF estimates, three ecozones are split into smaller land units: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones, and the Prairies ecozone is divided into a semi-arid and a subhumid component (McGovern, 2014). These subdivisions do not alter the hierarchical nature of the spatial framework.

Analysis units are the finest level of spatial resolution and are specific to each estimation system. In managed forests, the analysis units are the geographic intersection of reporting zones (Chapter 6, Figure 6–1) and provincial/territorial forest management units. For the purpose of this assessment, managed forests were classified into 607 analysis units across 12 provinces and territories; Nunavut was excluded because there is no managed forest area in this northern region (Table A3.5–1). Changes in the number of spatial analysis units may occur from one submission to the next and reflect refinements in the integration of multiple spatial layers. For example, the modification of administrative boundaries, timber areas and parks can result in units that do not meet the criteria for separate analysis; these units are therefore regrouped.

Table A3.5–1 **Number of Spatial Analysis Units of Managed Forests per Province and Territory**

Province/Territory	Number of Analysis Units
Newfoundland and Labrador (NL)	24
Prince Edward Island (PE)	1
Nova Scotia (NS)	1
New Brunswick (NB)	1
Quebec (QC)	129
Ontario (ON)	52
Manitoba (MB)	70
Saskatchewan (SK)	40
Alberta (AB)	181
British Columbia (BC)	65
Yukon (YT)	13
Northwest Territories (NT)	30
Nunavut (NU)	0
CANADA	**607**

The most suitable spatial framework for monitoring cropland GHG is provided by the polygons of the Soil Landscapes of Canada[1] (SLC). A soil landscape describes a group of soils and their associated landscapes and provides information, such as surface form, slope, typical soil C content under native and dominant agricultural land use, and water table depth. Soil landscapes are spatially associated with SLC polygons (the analysis units) that may contain one or more distinct soil landscape components. SLC polygons are also the basic units of Canada's National Ecological Framework, a hierarchical, spatially consistent national classification system within which ecosystems of various scales can be described, monitored and reported on (Marshall et al., 1999). The 12 353 SLC polygons are nested in the next level of generalization (1027 ecodistricts), which are further grouped into 194 ecoregions and 15 ecozones. SLC polygons span in the order of 1000 to 1 000 000 hectares (ha) and are appropriate for mapping at the scale of 1:1 million.

Analysis units for estimating the areas of forest converted to other land uses are the result of the spatial intersection of forest conversion strata (Figure A3.5–6) with ecological and administrative boundaries. Forest conversion strata were developed on the basis of expected conversion rates and characteristics. The sampling approach used to monitor forest conversion requires analysis units to be as consistent as possible with the patterns of forest conversion and large enough to provide an acceptable sample size, given the predetermined sampling rate.

The analysis units of different land-use categories can overlap. Most often, the exact location of events within a unit is not known. Therefore, the activity data pertaining to different land-use categories cannot be harmonized at the level of analysis units. The spatial harmonization is conducted within 60 reconciliation units (RUs), which are derived from the spatial intersection of reporting zones with provincial and territorial boundaries. Quality control and quality assurance procedures are conducted at the level of analysis units during estimate development and at the level of RUs during estimate compilation.

The total land mass of Canada reported in Common Reporting Tables (CRT) Table 4.1 is estimated using geomatics layers based on the SLC polygons and quality checked using data from the National Atlas,[2] and includes land area (estimated at 906 676.55 kha) and the area covered by fresh water (estimated at 89 680.51 kha). Estimates of managed and unmanaged forest areas in Canada are based on estimation procedures from Canada's National Forest Inventory (NFI) reconciled with forest areas provided by other data sources described in A3.5.2.2. Reconciliation of total forest area estimates is required due to differences in canopy closure definitions and methods used to develop estimates used in the National Forest Carbon Monitoring, Accounting and Reporting System (NFCMARS) modelling framework and methods used by the NFI. Total national area figures vary for Canada depending on the data source. However, since the SLC polygons serve as the base layer for the National Ecological Framework for Canada, this data source is considered the most appropriate to ensure the consistency of LULUCF areas.

To further support the reconciliation of land areas across managed and unmanaged categories, supplementary spatial datasets have been incorporated into the framework. The Statistics Canada Land Cover Register (Statistics Canada, 2025) provides updated national land cover classifications, while Agriculture and Agri-Food Canada's Land Use Change maps (AAFC, 2021) supply detailed information on agricultural transitions and land use dynamics. These datasets serve as additional inputs to refine estimates of unmanaged lands within the land representation matrix (Chapter 6, Table 6–4, CRT 4.1), complementing the SLC-based framework. Their integration represents an initial step toward addressing gaps in unmanaged land representation within the spatial framework for LULUCF estimate development and area reconciliation.

A3.5.2. Forest Land and Forest-Related Land-Use Change

A3.5.2.1. Carbon Modelling

The estimation of C stock changes, emissions from and removals by managed forests, forest conversion to other land uses and land converted to forest land is conducted using the Carbon Budget Model of the Canadian Forest Sector version 3 (CBM-CFS3; Kurz et al., 2009), implemented on an improved computing architecture. This is the most recent of a family of models whose development dates back to the late 1980s (Kurz et al., 1992). The model integrates forest inventory information (stand age, area and species composition), curves of merchantable volume over age, equations to convert stand merchantable volume into total biomass, data on natural and anthropogenic disturbances, and simulations of C transfers between pools and exchanges with the atmosphere that are associated with ecosystem processes and various events.

The ecosystem processes modelled by the CBM-CFS3 to generate the estimates submitted in this report are growth, litterfall, non-disturbance tree mortality and decomposition. The CBM-CFS3 also models events, such as management activities, forest conversion and natural disturbances. Management activities represented are clear-cut, shelterwood harvest, seed tree harvest, selection harvest, commercial thinning, precommercial thinning, salvage logging, residential firewood harvest and the burning of harvest residues. Different practices of forest conversion are also simulated, including controlled burning.

The forest C pools represented in the CBM-CFS3 can be matched with the Intergovernmental Panel on Climate Change (IPCC) forest C pools (Table A3.5–2). Although not directly referenced in the table, living biomass pools are further subdivided into two sets, for each of hardwood and softwood tree species.

1 Available online at http://sis.agr.gc.ca/cansis.

2 Available online at: https://www.nrcan.gc.ca/maps-tools-and-publications/maps/atlas-canada/10784.

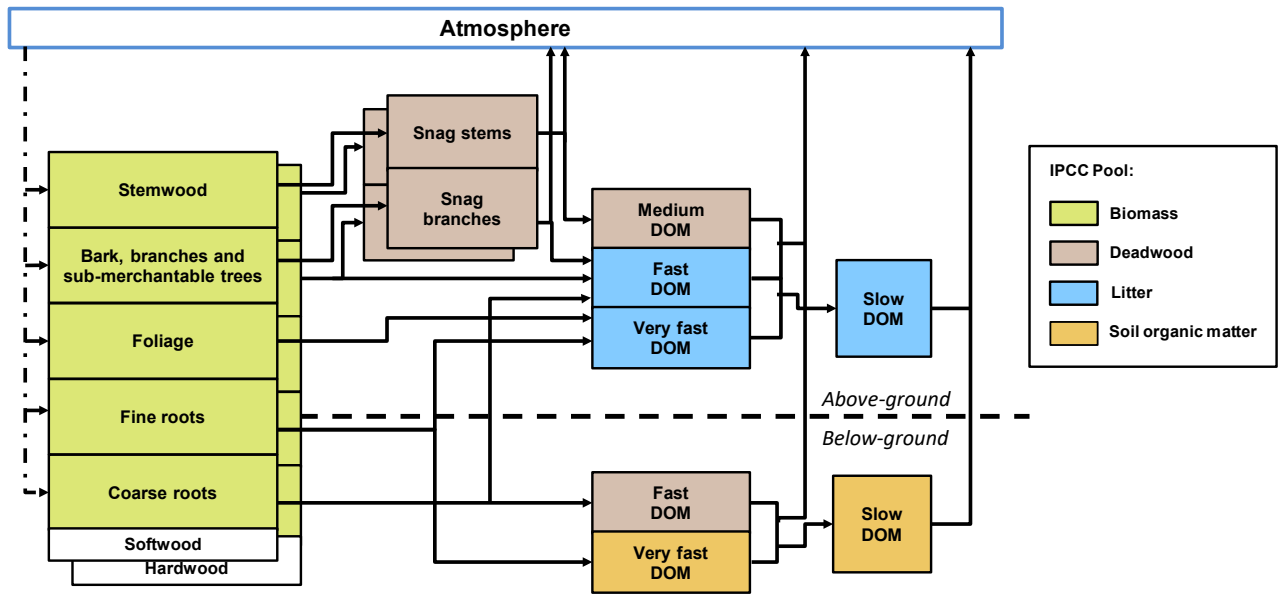
Annual ecosystem process events are simulated as C transfers between C pools executed at each time step (annually) in every inventory record (Figure A3.5–1). During annual processes, C is taken up in the biomass pool and some biomass C is transferred to dead organic matter (DOM) pools. The CBM-CFS3 represents ten live biomass pools, seven deadwood pools, two litter pools, and two soil pools. Carbon transfers are defined for each pool based on sets of pool-specific parameters. For live biomass pools, these represent annual turnover (i.e., the rate of fall or mortality) and, in some cases, the proportions of material transferred to various DOM and soil pools. For DOM and soil pools, decomposition is modeled as an exponential decay process governed by three key parameter categories: (i) decay rates at a mean annual temperature of 10°C; (ii) temperature sensitivity coefficients (Q_{10}), which scale decay rates with mean annual temperature; and (iii) transfer fractions, specifying the proportion of decomposed C emitted directly to the atmosphere through heterotrophic respiration versus that transferred to more stable DOM or soil pools. Together, these parameters determine the residence time of C in each pool and the timing of emissions and transfers among pools within the CBM-CFS3 framework (Kurz et al., 2009).

Table A3.5–2 **Forest Carbon Pools in IPCC Guidelines and CBM-CFS3 Modelling**

IPCC Carbon Pools		Pool Names in CBM-CFS3
Living biomass	Above-ground biomass	Merchantable stemwood Other (sub-merchantable stemwood, tops, branches, stumps, non-merchantable trees) Foliage
	Below-ground biomass	Fine roots Coarse roots
Dead organic matter (DOM)	Deadwood	Above-ground fast Below-ground fast Medium Softwood stem snag Softwood branch snag Hardwood stem snag Hardwood branch snag
	Litter	Above-ground very fast Above-ground slow
Soils	Soil organic matter	Below-ground very fast[a] Below-ground slow Black carbon[b] Peat[b]

Notes:
a. The below-ground very fast pool includes dead and decaying fine roots, which in practice cannot be separated from soil.
b. Black carbon and peat are currently not estimated.

Figure A3.5–1 **Carbon Pools and Transfers Simulated by CBM-CFS3**



Note:
Source: White et al. (2008)

Annual turnover rates can be very high (e.g., 95% for hardwood foliage) or very low (e.g., < 1% for stemwood). Annual decay rates at 10°C vary between 33% (very fast DOM pools, such as dead fine roots) and 0.4% (slow soil pool) and are further adjusted using the Q_{10} values mean annual temperature (Table A3.5–3).

Table A3.5–3 **Parameters governing biomass turnover, root allometry and slow pool mixing rate in CBM-CFS3**

			Previous values	NIR 2026[1]
Biomass turnover	Proportion of the litterfall from "other" pool (stumps, branches, and small trees including bark) that becomes snag branches		0.250	0.352
	Fall rate of the softwood and hardwood stem snags		0.032	0.065
	Fall rate of the softwood and hardwood branch snags		0.100	0.081
	Death rate of coarse roots		0.020	0.018
	Death rate of fine roots		0.641	0.846
	Fraction of dead coarse roots sent to the above-ground fast pool		0.500	0.536
	Fraction of dead fine roots sent to the above-ground very fast pool		0.500	0.664
Root allometry	Parameter in the equation which determines root biomass in softwood trees[2]	a	0.222	0.222
	Parameters in the equation which determines root biomass in hardwood trees[3]	a	1.576	1.557
		b	0.615	0.615
	Parameters in the equation which determines the fraction of fine root[4]	a	0.072	0.066
		b	0.354	0.385
		c	-0.060	-0.055
Slow pool mixing rate	Rate of C transfer from above-ground slow to below-ground slow pool		0.006	0.004

Notes:
1. Values are rounded for clarity; full-precision parameters were used in all CBM simulations.
2. $BGB = a \cdot AGB$, where BGB is the below-ground (root) biomass, and AGB is the above-ground biomass (Hararuk et al., 2017).
3. $BGB = a \cdot AGB^b$, where BGB is the below-ground (root) biomass, and AGB is the above-ground biomass (Hararuk et al., 2017).
4. $P_{fr} = a + b \cdot e^{c \cdot BGB}$, where P_{fr} is the proportion of fine root, and BGB is the below-ground (root) biomass (Hararuk et al., 2017).

Calibration/Validation of Turnover and Decomposition Parameters

In previous NIR submissions, decomposition parameters were largely based on literature syntheses, parameterizations from other models and expert judgment. Evaluation against National Forest Inventory (NFI) ground plots revealed that while CBM-CFS3 accurately simulated above-ground biomass, it tended to overestimate deadwood and soil carbon stocks (Shaw et al., 2014). To address this, Hararuk et al. (2017) applied Bayesian Markov Chain Monte Carlo inversion to calibrate 45 parameters regulating litterfall, carbon allocation to roots and their mortality rate, dead organic matter decay rates and their temperature sensitivity using NFI-measured carbon stocks in six deadwood and soil pools. This data-driven approach reduced reliance on subjective estimates and strengthened the empirical basis of the model. The new parameters (Table A3.5–4) are unique to each carbon pool that is being simulated by the model.

Forest growth and carbon dynamics

Growth is simulated as an annual process. Each of the records (roughly 3 million) in the 607 analysis units of the forest inventory is associated with a yield curve that defines the dynamics of gross merchantable volume over time. Assignment of an inventory record to the appropriate curve is based on a classifier set that includes province, ecological stratum, leading species, site productivity class and several other classifiers that differ between provinces and territories. Curve libraries for each province and territory in Canada are similar to those used by resource management agencies in the forest planning processes and are derived from permanent or temporary sample plots or from forest inventory information.

Conversion of gross merchantable volume curves to above-ground biomass curves is performed with a set of equations developed for Canada's National Forest Inventory (Boudewyn et al., 2007). These equations derive the above-ground biomass of each stand component from merchantable stemwood volume (per ha), for each province and territory, ecozone, leading species or forest type. Finally, belowground biomass pools are estimated using regression equations (Li et al., 2003) that relate belowground biomass to aboveground biomass through root-to-shoot ratios.

Modelling of C transfers triggered by disturbances is based on the disturbance type and severity, the forest ecosystem affected and the ecological region. For modelling purposes, different practices of forest conversion are also implemented as disturbances. The impact of a disturbance is represented by a disturbance matrix, which specifies, for one or more disturbance types, the proportion of C in each ecosystem pool that is transferred to other pools, released to the atmosphere or transferred to the HWP pool (Figure A6.5–1). The number of different disturbance matrices is dependent on the availability of activity data (e.g., the spatial and temporal resolution of disturbance data) and on the knowledge required to parameterize the matrices for more distinct regions or intensities of disturbance and can range between 100 and 220 being used in a given submission.

Table A3.5–4 **Parameters governing DOM decomposition in CBM-CFS3**

		Previous values[a]			NIR2026[a]		
		Decay rate[b]	Q_{10}[c]	Proportion to atmosphere[d]	Decay rate[b]	Q_{10}[c]	Proportion to atmosphere[d]
Deadwood	Above-ground fast	0.14	2.00	0.83	0.22	1.15	0.88
	Below-ground fast	0.14	2.00	0.83	0.23	1.94	0.82
	Medium	0.04	2.00	0.83	0.07	1.60	0.79
	Softwood stem snag	0.02	2.00	0.83	0.01	1.90	0.53
	Softwood branch snag	0.07	2.00	0.83	0.05	2.37	0.47
	Hardwood stem snag	0.02	2.00	0.83	0.05	1.77	0.68
	Hardwood branch snag	0.07	2.00	0.83	0.07	1.97	0.65
Litter	Above-ground very fast	0.36	2.65	0.82	0.35	2.37	0.79
	Above-ground slow	0.02	2.65	1.00	0.02	2.19	1.00
Soil organic matter	Below-ground very fast	0.50	2.00	0.83	0.33	1.97	0.65
	Below-ground slow	0.003	1.00	1.00	0.004	1.25	1.00

Notes:
a. Values are rounded for clarity; full-precision parameters were used in all CBM simulations.
b. Decay rate at 10°C
c. Temperature sensitivtiy coefficient (Q_{10})
d. Proportion of decayed C lost to atmosphere

Within disturbed lands, the amount of C emitted as CO_2 from each pool at the time of disturbance, documented in each disturbance matrix, can be specific to the pool, the types of forest and disturbance intensity, and the ecological zone. There are therefore no CO_2 emission factors applicable to all disturbances of a given type, such as fires. With a few exceptions, the proportion of total C emitted in each C-containing GHG (CO_2, CO and CH_4) due to fire is constant: 90% of C is emitted as CO_2, 9% as CO and 1% as CH_4 (Cofer et al., 1998; Kasischke and Bruhwiler, 2003).

Carbon emissions emitted as CO oxidize in the atmosphere resulting in indirect CO_2 emissions. Amounts of C emitted as CO and indirect CO_2 are calculated by multiplying total C by, respectively, 28/12 and 44/12. More details on the reporting of these indirect CO_2 emissions can be found in Chapter 6 and Annex 7.

While the CBM-CFS3 can model C fluxes at various spatial scales, generating national estimates involves harmonizing, integrating and ingesting vast quantities of data from a large variety of sources. Section A3.5.2.2 documents the key data sources used for this submission.

Post-Wildfire Regeneration

Analysis using remote sensing techniques has demonstrated that regeneration of portions of the forest undergoing severe disturbance may be delayed (White et al., 2017; White et al., 2022). Based on these observations average regional (RU-level) regeneration delays were developed and applied to 25% of the area burned by wildfires in each year, using the available national scale remote-sensing derived information (Hafer et al., 2022; White et al., 2017; White et al., 2022). The remaining 75% of burned areas immediately start regrowing from age 0 on the pre-disturbance yield curve. This approach provides an estimate of the scale of regeneration delay and the impacts of the delay on net flux in the managed forest.

Reforestation

The representation of reforestation activities in the GHG inventory uses certain approaches consistent with afforestation activities (see A3.5.2.5) and others that are very different. A key difference is that “reforestation” occurs on land base that was previously forest and thus must be incorporated into the existing NFCMARS project infrastructure to ensure alignment with provincial/territorial forest inventories and the prevention of complicated double-counting situations.

The basic premise of reforestation is that it takes place on forested land that is not naturally regenerating in an optimal manner (e.g., delayed re-establishment, low density and poor tree resilience). Most reforestation from 2021 to 2024 was targeted for forest that had been burned by wildfire and were not expected to recover naturally due to the severe nature of certain fire events and associated impacts to seed stock and soil quality. A simplifying assumption was established that all reforestation events happen on previously burned forest that is in a state of regeneration delay (see Post-Wildfire Regeneration section). The post-fire delayed regeneration state was considered an acceptable first approximation proxy for forest not recovering naturally. Where insufficient area was in a state of regeneration delay, reforestation was applied in areas that were deemed to be below a biomass threshold. Based on site preparation records of reforestation sites, events were assigned to a residue treatment category and a soil preparation intensity level. Seventeen new disturbance types and associated disturbance matrices were created to represent the range of possible site preparation combinations. More details can be found in Hafer et al. (2022).

Forest Drainage

Forest drainage is used to lower the water table, thereby improving soil aeration and promoting root development and tree growth on low-productivity organic soils. A consultation with forestry industry experts and an extensive literature review carried out in 2015 and 2016 suggested that the only province in Canada where operational drainage of organic soils for forestry occurred was Quebec (Gillies, 2016). This management activity occurred from the 1980s through to the mid-2010s on a small percentage of peatlands corresponding to three RUs (11, 12 and 15) on both private and public lands. Forest drainage has progressively declined since 2003 due to the end of government subsidies and changes to Quebec's forest management tenure.

Data on forest drainage were compiled from a combination of historical documents, expert consultations and provincial statistics to develop a time series from 1980 to 2018 of annual peatland areas drained for forestry on both private and publicly owned forests of Quebec. Provincial statistics (Gouvernement du Québec, 2021) were reported by administrative region (AR) for 1994–2008 and by province for 1986 to 1993 and for 2009 to 2017. Drainage data for 1980 to 1985 were assumed to be constant, resulting in a cumulative area drained equivalent to the 1986 value reported by Quebec statistics, which was also consistent with values cited in Hillman (1987). Given the absence of drainage activity data for 2018 (Gouvernement du Québec, 2021) and the fact that there were no areas drained in 2016 and 2017, drained areas were assumed to be zero after 2017. Estimates of drained areas by AR (1994–2008) were allocated to the three RUs by overlaying the AR to create a spatially weighted area average that was applied to the provincial values for all years.

Emissions of CO_2, CH_4 and N_2O from drained organic soils were calculated using a Tier 1 method and emission factors from tables 2.1, 2.2 and 2.3, respectively, of the 2013 Wetland Supplement to the 2006 IPCC Guidelines (IPCC, 2014). Emission factors are associated with the temperate (RUs 11 and 12) and boreal (RU 15) climate zones. The fraction of area covered by ditches was also determined using the default values for drainage ditches from Table 2.3 of the 2013 Wetland Supplement (IPCC, 2014).

A3.5.2.2. Data Sources

Managed Forest Land

Canada's forests are classified as "managed" or "unmanaged" based on the occurrence of management activities for timber or non-timber and on the level of protection against disturbances (Figure A3.5–2). Managed forests occur within all provinces and territories of Canada, except for Nunavut (Figure A3.5–3). The estimation of the managed forest area required the spatial delineation and combination of boundaries of many different forest areas, including all operational forest management units, timber supply areas, tree farm licences, industrial freehold timberland, private woodlots and any other land in the Forest Land category where there is active management for timber or non-timber resources, as well as forest areas where there is intensive protection against natural disturbances. All these layers are aggregated and intersected with underlying forest inventory data. The procedures are documented in Stinson et al. (2011).

The CBM-CFS3 model initialization procedure (Kurz et al., 2009) establishes steady-state aboveground and belowground dead organic matter C stocks, and then simulates one final stand replacing disturbance (harvest or fire) for every inventory record, that results in an initial age-class distribution that is consistent with current forest inventory records at the end of 1989 and subsequently establishes the initial conditions for all carbon stocks for each CBM-CFS3 simulation run. The choice of final stand replacing disturbance impacts the relative proportion of carbon in different DOM pools at the beginning of the simulation (see section A3.5.2.1), thereby having a significant effect on residual emissions from decomposition. Further, whether the final stand replacing disturbance prior to 1990 is assumed to be wildfire or harvest will also determine if the stand will be reported in the natural or anthropogenic partition of the managed forest, thereby also influencing the initial anthropogenic forest area (Figure A3.5–2). For most jurisdictions in Canada, where both harvest and wildfire are significant disturbances, the most reliable pre-1990 sources of data are provincial forest harvest records. Therefore, for the provinces of British Columbia, Alberta, Saskatchewan, Ontario, and Quebec historic harvest data are used to assign the proportion of stands with harvest as the final stand replacing disturbance prior to 1990, and the remainder of the forest stands in these provinces are assumed to have been historically initiated by wildfire (Kurz et al., 2024). For some jurisdictions, it is assumed that all disturbances prior to 1990 are either 100% wildfire (Labrador, the Yukon, and Northwest Territories), or 100% harvest (New Brunswick, Nova Scotia, and Prince Edward Island) based on the most likely pre-1990 disturbance type for those regions (Kurz and Apps, 1999). In the case of Newfoundland and Manitoba, the CBM-CFS3 used a combination of fire and harvest historical records to assign a proportion of the forest area to wildfire (Kurz and Apps, 1999) as the final stand replacing disturbance prior to 1990 (Kurz et al., 1999) as updates to the forest inventory are required before the historic harvest data can be used as the default assumption for those jurisdictions (Table A3.5–5).

Table A3.5–5 **Main Data Sources Used to Determine Pre-1990 Forest Disturbance**

Jurisdiction	Dataset
BC	Historic harvest data 1920–1989 (Kurz et al., 1996)
AB	Historic harvest data 1937–1989 (Murphy et al. 2006)
SK	Historic harvest data from 1899–1989 (Unpublished, Ministry of the Environment)
MB	Historic harvest and fire data (Kurz et al. 1999)
ON	Historic harvest data from 1867–1989 (Ontario Ministry of Natural Resources, 2007)
QC	Historic harvest data from 1920–1989 (Government of Quebec public spatial data warehouse, https://www.donneesquebec.ca/recherche/dataset/recolte-et-reboisement)
NB	Assumed 100% harvest (Kurz et al. 1999)
NS	Assumed 100% harvest (Kurz et al. 1999)
PE	Assumed 100% harvest (Kurz et al. 1999)
NL	Historic harvest and fire data (Kurz et al. 1999)
LA	Assumed 100% wildfire (Kurz et al. 1999)
YT	Assumed 100% wildfire (Kurz et al. 1999)
NWT	Assumed 100% wildfire (Kurz et al. 1999)

Post-1989 forest management activities are documented in the National Forestry Database[3] and, as required, additional information on specific activities is obtained directly from provincial and territorial forest management agencies. The Canadian provincial and territorial governments, whose jurisdiction includes natural resource management, provide essential information—notably detailed forest inventory data, details on forest management activities and practices, disturbance information including prevention or control, regional yield tables (volume/age curves), site indices—and regional expertise (Table A3.5–5). The forest inventory data in Canada's NFI (Power and Gillis, 2006) were used for New Brunswick, Manitoba, Saskatchewan, Yukon and the Northwest Territories. More recent and higher-resolution inventory data were provided by Prince Edward Island, Newfoundland and Labrador, Nova Scotia, Quebec, Ontario, British Columbia and Alberta. A series of method papers describe the compilation process for each provincial and territorial forest inventory. Since forest inventory data were not collected in the same years, additional steps were necessary to synchronize the inventory data to the year 1990 (Stinson et al., 2011).

Activity data for the burning of harvest residues are obtained from the National Forestry Database for all regions except specific areas of British Columbia where, proportions derived from high-resolution imagery are used.[4] In British Columbia, these data refer to slash burning (broadcast burning, slash pile burning or a combination of both), but in other regions of Canada, may also include prescribed burning for fuel management.

Harvesting firewood for residential heating is a common practice in Canada, with an estimated 93% of annual firewood volumes taken from forested lands and the rest from agricultural woodlands and urban trees. To estimate the impact of this activity on the C balance of Canadian forests, a set of rules was developed to disaggregate these volumes into several components (Hafer et al., 2020; Doyon et al., 2019): softwood, hardwood and mixedwood harvested from forested lands; woody biomass harvested from croplands; urban trees from settlement lands; pellets; and manufactured logs (the last four components were modelled under HWP, see A3.5.3). For the targeted forested land components, a list was developed based on survey data for the spatial analysis units within each RU from which the firewood is assumed to be harvested.

Regional firewood harvesting practices in Canada were represented in CBM-CFS3 and regionally differentiated disturbance matrix parameters were input in the model for three conceptual firewood harvesting zones: (i) Mixedwood-Acadian, comprising the Atlantic Maritime and Mixedwood Plains ecozones; (ii) agricultural, comprising the Sub-humid and Semi-arid Prairie ecozones; and (iii) Boreal-Montane, comprising all other forest ecozones. Firewood harvesting in both the Mixedwood-Acadian and agricultural zones is assumed to occur via light thinning (30% removal), while firewood harvesting in the Boreal-Montane zone is assumed to occur via clear-cut harvesting (85% removal). The selected forest inventory records for firewood harvesting are disturbed in decreasing order of total snag content, to ensure that a reasonable (though unspecified) proportion of the firewood is harvested as deadwood.

Data on the biomass used as residential firewood are obtained from surveys on residential wood use and origin. Sections A3.1.4.1.4 and A3.5.3 of this report provide additional information on these surveys and the methodology used to convert consumption and use data to firewood volumes. The forest land areas specifically attributed to firewood harvest are determined through a spatial allocation exercise that identifies specific forest units within each RU where firewood is sourced based on Statistics Canada Census Units.

3 National Forestry Database, available online at http://nfdp.ccfm.org/en/index.php.

4 In British Columbia, slash burning is used on 15% of clear-cut areas on the coast and on 59% of clear-cut areas in the rest of the province, according to expert opinion.

Areas disturbed by wildfires were extracted from the Canadian Wildland Fire Information System's National Burn Area Composite (NBAC) database for the years from 1990 to the current inventory year (Table A3.5–6). The NBAC is a composite of low- and medium-resolution remote sensing data and fire mapping data prepared by the Canadian Forest Service and combined with data from resource management agencies from across Canada. The NBAC provides a complete mapping of wildfires using medium-resolution remote sensing data when available, with data from resource management agencies given second priority and low-resolution remote sensing data used only in the absence of other fire mapping data.

Insect disturbances are monitored by aerial surveys (Table A3.5–6), which record the area impacted by the disturbance and assign an impact severity class that indicates the degree of tree mortality or defoliation. The area of impact is assigned to the appropriate analysis unit and host species within it, and the severity of the impact is reflected in the parameters of the disturbance matrix applied (Kurz et al., 2009).

Areas drained for forestry (Table A3.5–6) in private and publicly owned forests in Quebec are estimated using historical documents, consultations and provincial statistics. Spatial allocation by RU was performed using Quebec statistics.

Table A3.5–6 **Main Sources of Information and Data on Managed Forests**

Description	Source	Spatial Resolution	Temporal Coverage	Reference
Climate data	CFS	Analysis units	1961–1990	McKenney et al. (2001)
Forest inventories and merchantable volume data[a]	Canada's National Forest Inventory (CanFI)	CanFI grid cell	1949–2004	Power and Gillis (2006)
	NL	Analysis units	1991–2006	Provincial experts
	PE	Analysis units	2000	Provincial experts
	NS	Analysis units	2006	Provincial experts
	QC	Analysis units	2000	Provincial experts
	ON	Analysis units	2000	Provincial experts
	AB[b]	Analysis units	1949–1999	Provincial experts
	BC	Analysis units	2011	Provincial experts
Conventional harvest data[c]	National Forestry Database	Provincial boundaries	1990–2023	http://nfdp.ccfm.org/en/index.php
Prescribed burning	National Forestry Database, for jurisdictions other than BC	Provincial boundaries	1990–2021	http://nfdp.ccfm.org/en/index.php
Slash burning	BC	Sub-provincial boundaries	1990–2024	Provincial experts
Residential firewood harvest data	Energy sector data for residential firewood use	Reconciliation units	1990–2024	Sections A3.1.4.1 and A3.5.3
Industrial fuelwood data	Energy sector data for industrial fuelwood use	Provincial boundaries	1990–2023	Sections A3.1.4.1 and A3.5.3
Wood waste incineration data[d]	Waste sector data for wood waste	Provincial boundaries	1941–2023	Sections A3.6.3 and A3.5.3
Insect data	Forest Insect and Disease Survey	Spatially explicit	1990–2017	Atlantic Forestry Centre and Pacific Forestry Centre
	NL	Spatially explicit	2000–2003	Provincial experts
	QC	Spatially explicit	1990–2024	Provincial experts; https://www.donneesquebec.ca/recherche/fr/dataset/donnees-sur-les-perturbations-naturelles-insecte-tordeuse-des-bourgeons-de-lepinette
	MB	Spatially explicit	1990–2020	Provincial experts and provincial forest health aerial overview surveys; National Forest Pest Strategy Information System
	SK	Spatially explicit	1990–2013	Provincial experts; National Forest Pest Strategy Information System
	AB	Spatially explicit	1990–2024	Provincial experts; Alberta Forest Health Aerial Overview
	BC	Spatially explicit	1990–2024	Provincial experts; BC Forest Insect and Disease Survey; BC Aerial Overview Survey
	YT	Spatially explicit	1994–2018	Provincial experts; Yukon Forest Health Aerial Overview
	NT	Spatially explicit	1990–2024	Provincial experts; Northwest Territories Forest Health Survey
Fire data	National Burned Area Composite	Spatially explicit	1990–2024	https://cwfis.cfs.nrcan.gc.ca/datamart
Drainage data[e]	QC	Province of Quebec boundaries	1980–1985	Provincial experts; historical records; Hillman (1987); Gillies (2016)
	Ministère des Forêts, de la Faune et des Parcs du Québec	Province of Quebec boundaries	1986–1994	https://www.quebec.ca/agriculture-environnement-et-ressources-naturelles/forets/entreprises-industrie/publications-statistiques-industrie-forestiere/portrait-statistique
	Ministère des Forêts, de la Faune et des Parcs du Québec	Administrative regions of Quebec	1994–2008	https://www.quebec.ca/agriculture-environnement-et-ressources-naturelles/forets/entreprises-industrie/publications-statistiques-industrie-forestiere/portrait-statistique
	Ministère des Forêts, de la Faune et des Parcs du Québec	Province of Quebec boundaries	2008–2018	https://www.quebec.ca/agriculture-environnement-et-ressources-naturelles/forets/entreprises-industrie/publications-statistiques-industrie-forestiere/portrait-statistique

Notes:
a. Forest inventory and merchantable wood volume yield data were obtained from Canada's National Forest Inventory and/or from provincial experts where specified.
b. Alberta's forest inventory database comprises provincial forest inventory data for the province's Forest Management Areas, and CanFI inventory data for the remainder of the managed forest landbase.
c. Given the absence of complete harvest data for the most recent reporting year for all provinces and territories, 2024 harvest data were estimated by assuming them to be equal to 2023 values.
d. 1941 represents the longest time series, start dates vary by region.
e. No new drainage activity data are available in the Province of Quebec since 2016.

Figure A3.5–2 **Decision Tree for the Determination of Managed Forest Area**

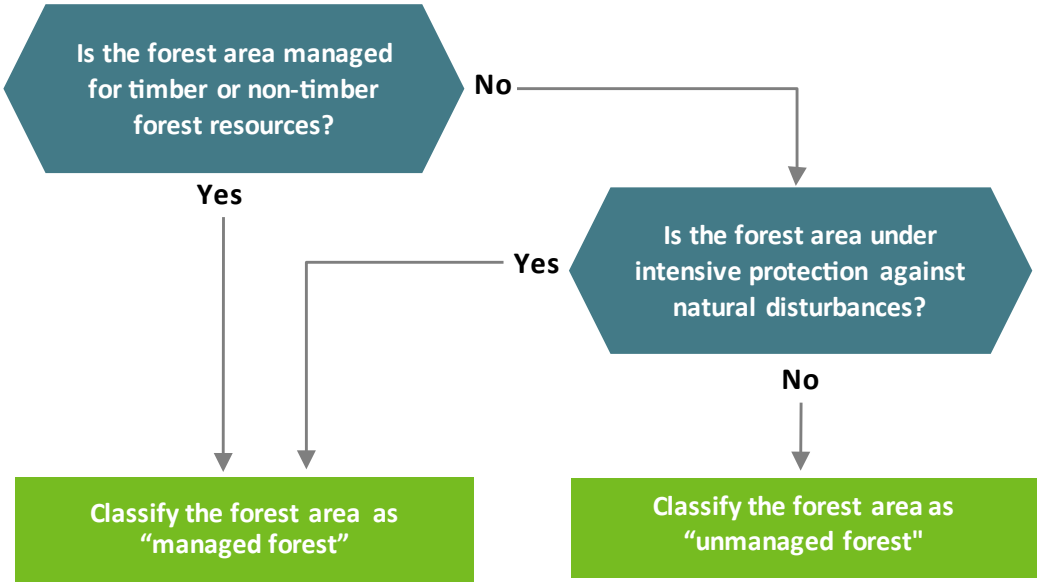
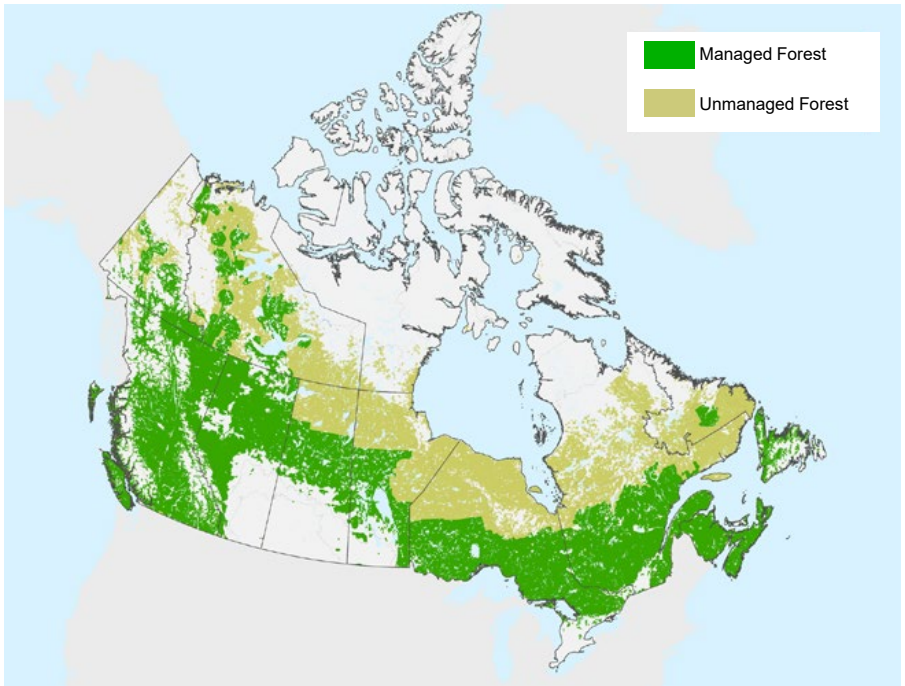


Figure A3.5–3 **Managed and Unmanaged Forests in Canada**



A3.5.2.3. Quantifying Anthropogenic Emissions and Removals

Interannual variations and trends in emissions and removals from managed forests in Canada are dominated by the impact of wildfires and periodic forest insect outbreaks, making it difficult to detect trends resulting from human actions in the forest (Kurz et al., 2008a, 2018; Stinson et al., 2011; Kurz et al., 2013).

The 2006 IPCC Guidelines do not provide default methods for separating anthropogenic emissions and removals from those occurring due to natural disturbances. However the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2019) provide supplementary methods, a generic approach to report on disaggregation of the contribution of natural disturbances in reporting on total emissions and removals on managed lands. Canada's approach is included as a country-specific example of methodological approaches to disaggregating anthropogenic effects and natural disturbances on managed lands. CBM-CFS3 has the capability to track and separate emissions and removals in managed forest stands dominated by the impact of significant and relatively recent natural disturbances that have masked the legacy of human management and affected the commercial value and ecological function of the stand from the rest of the area that is subject to active human management activities.

Forest fires are tracked under the natural disturbance component because annual variations in total area burned in Canada are mostly driven by climate and weather conditions. Although human-caused fires make up the largest proportion of fire occurrences, they have been responsible for less than 10% of the total area burned in Canada since 1959 (Hanes et al., 2019). About 3% of fires in Canada are responsible for 97% of the area burned (Stocks et al., 2002; Hanes et al., 2019), and generally occur on just a few critical days with extreme weather conditions that are conducive to fire (Wang et al., 2017), regardless of the source of ignition. Fires that are caused by lightning occur chiefly in remote areas where fire detection and suppression systems are often delayed, compared with human-caused fires that generally take place in more populated, full-suppression zones.

A recent meta-analysis of twelve dendroecological fire history reconstructions, suggested that since 1850, climate and weather were the most important drivers of burned areas in northern temperate and boreal forests of eastern Canada, overwhelming the influence of settlements, as potential sources of ignitions, and that of fire suppression (Danneyroles et al., 2021). The dominance of climatic drivers has also been demonstrated in the temperate and boreal forests of western North America (Holden et al., 2018; Gaboriau et al., 2020). Moreover, trend analyses demonstrate that total annual area burned has increased in most of Canada since 1959, despite the relatively constant number of human-initiated fires (Hanes et al., 2019; Danneyroles et al., 2021). Fires from lightning ignition, which have increased since 1975, have been demonstrated to explain more than 55% of the interannual variability in burned area (Veraverbeke et al., 2017). Fire activity has generally increased in Canada since 1980 after a period of relatively low fire activity during most of the 20th century. Some divergent regional trends were observed, but those changes were usually synchronized in time providing additional evidence that large spatial patterns of atmospheric conditions were more important drivers, compared to regional changes in land use, logging activity and fire suppression, which occurred at different times across regions (Chavardès et al., 2022).

Evidence of human influence on fire activity are still detected locally (Robinne et al., 2016; Parisien et al., 2016). These can, however, be negative and positive—both as agents of ignition (accidentally or intentionally in the case of management activities) and by actively suppressing fires and controlling fuel. Their net effects on total area burned remain difficult to quantify and separate from other drivers and, perhaps most importantly, remain difficult to generalize in such a way that can be implemented in a consistent and scientifically sound methodology. Consequently, the current default assumption that human activity has neither a positive nor a negative impact on the natural fire regime across the country avoids introducing a bias that is not supported by long-term data and scientific understanding. Although this methodology separately tracks land areas that are dominated by either natural or anthropogenic influences, the evolving balance between those areas over time will capture long-term trends in the natural fire regime in managed forest areas.

This reporting approach ensures that emissions from stands affected by uncontrollable natural disturbances and the subsequent removals due to the regrowth of these stands back to a mature condition are tracked separately from those from commercially mature managed stands, allowing for the improved differentiation of emissions and removals associated with direct forest management actions from non-anthropogenic emissions and removals occurring due to natural disturbances.

The history of management activities and natural disturbances in each individual stand (inventory record) in managed forest areas is used to assign stands to two groups. Emissions and removals are identified as being anthropogenic when (i) a stand's growth trajectory has been significantly modified by human intervention—this definition includes commercial clear-cut and partial harvests, commercial and pre-commercial thinning, salvage logging, site preparation, and rehabilitation of and planting on stands that have undergone stand replacement or partial natural disturbances; and when (ii) regardless of its origin, a stand has attained an age-based commercial maturity threshold and therefore is actively considered in forest management planning scenarios (eligible to be scheduled for harvest). Once a stand originating from natural disturbance has reached this age, emissions and removals are switched to the reported category. Regionally specific return periods based on regional differences in forest management practices, species distributions and stand dynamics are used (Kurz et al., 2018).

In contrast, emissions and removals are identified as resulting from natural disturbances when they originate from stands (i) that have been affected by a stand-replacing natural disturbance up to the period that they reach commercial maturity; or (ii) that have been affected by a partial disturbance resulting in reduced standing biomass until that stand has attained biomass equivalent to pre-disturbance values. Only disturbances causing more than 20% mortality are included in the natural disturbance category.

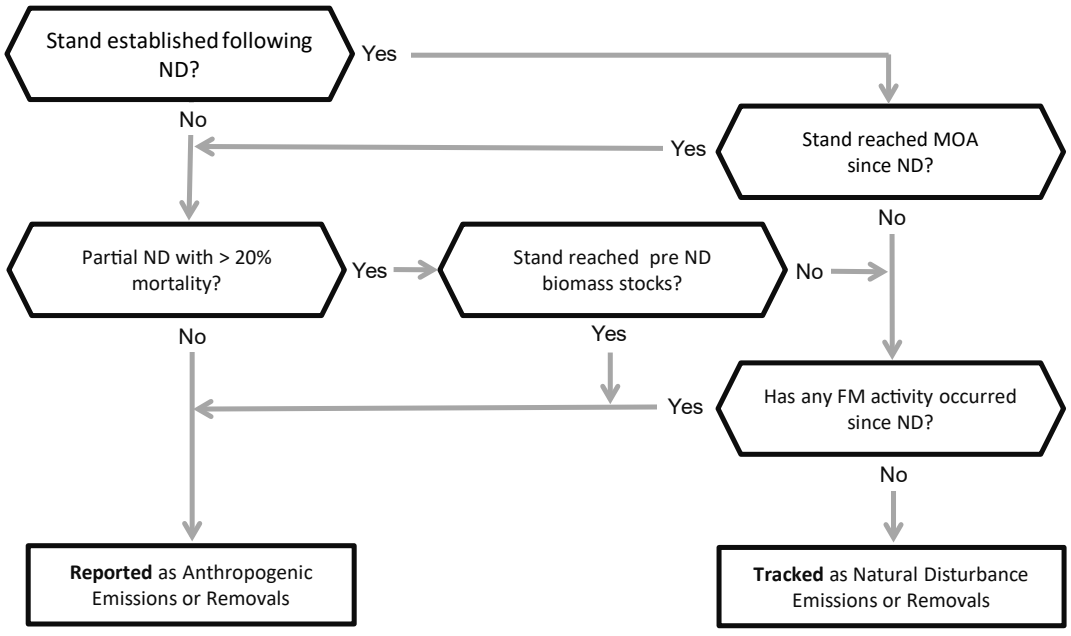
To develop regionally representative definitions of commercial maturity, a questionnaire was distributed to provinces and territories in March 2017. The objective of this consultation process was to document forest management practices across Canada, with a focus on the treatment of naturally disturbed forest stands in operational planning. As such, work with provincial experts provided a minimum return period to commercial maturity ranging from 45 to 99 years, with an average of 76 years. In most cases, provincial agencies defined species-specific commercial maturity based on the maximum mean annual increment of species-specific yield curves for a high productivity site class in a given region. Other provincial agencies used empirical data based on observed regional minimum harvest ages or an age to achieve a specific piece size. Based on the species-specific commercial age, a weighted minimum return period was determined for each reporting zone using the proportional breakdown of the commercial species that were attributed a minimum operable age, or minimum harvest age, in that area. Greater detail on the methodological approach used to track anthropogenic emissions and removals, as well as commercial maturity thresholds can be found in Kurz et al. (2018).

In the current modelling framework, partial natural disturbances occur mainly due to insect infestations. In these cases, above-ground biomass recovery was used to define the recovery period, since the growth trajectory of the stand is only temporarily modified. Stands that undergo insect disturbances causing biomass mortality of 20% or less are not deemed to be dominated by natural disturbances; at this low mortality level, disturbances are considered agents that contribute to stand density reductions. While the 20% threshold has been established for practical purposes, further research on insect dynamics is required to better understand mortality thresholds that lead to significant deviations from pre-infestation growth trajectories.

Stands in which emissions and removals are dominated by natural disturbance dynamics are tracked by querying model results based on a decision-tree approach in which key decision points are based on stand origin, type of disturbance (partial or stand replacing) and an annual assessment of post-disturbance status, based on whether the commercial maturity threshold or pre-disturbance biomass has been reached (Figure A3.5–4).

After exclusion of the non-anthropogenic emissions and removals, the final reported values represent all forest stands in the managed forest land base that have attained commercial maturity or have had their growth trajectory modified by a direct anthropogenic management action in the forest. The area temporarily excluded from reporting varies between +10/-17 million hectares (Mha), as stands undergoing natural disturbance in a given year are removed from reporting and lands that were disturbed historically re-enter reporting. The total of each of the stand categories included and excluded is equivalent to the sum of emissions and removals quantified using the methodological approach for reporting total emissions from the managed forest in inventory submissions, prior to implementing the partitioned reporting approach.

Figure A3.5–4 **Decision Tree for Differentiating Between Emissions and Removals of Anthropogenic and Natural Origin**



Notes:
ND = natural disturbance
MOA = minimum operable age
FM = forest management

A3.5.2.4. Land Converted to Forest Land

Records of land conversion to forest land in Canada were available for 1990–2002 from the Feasibility Assessment of Afforestation for Carbon Sequestration initiative (White and Kurz, 2005). Conversion activities for 1970 to 1989 and 2003 to 2008 were estimated based on activity rates observed in the data from this initiative. Additional information from the Forest 2020 Plantation Demonstration Assessment was included for 2004 and 2005, and an environmental scan was performed to identify additional sources of information on afforestation rates from 2000 to 2008. Additional afforestation activity data representing 13 466 ha of afforestation events from 2007 to 2020 were obtained through a data-sharing agreement with Forests Ontario (Magnus et al., 2021).

For jurisdictions other than Ontario, no afforestation activity data for the period 2008-2020 have been identified. Changes in land-use dynamics in Canada during this period suggest that it is not reasonable to assume that afforestation activities would be similar to those before 2008. Since 2021, federal afforestation programs have tracked tree planting and these events are included as an initial estimate of recent afforestation activities in Canada. The estimates are prepared based on a methodology developed to capture and track the change in pre-planting C stocks that results from the planting events (Hafer et al., 2022).

Each event, regardless of the date, source, type or location, was converted to an inventory record for C modelling purposes. All events were compiled in a single data set on afforestation activities in Canada from 1970 to the current inventory year. For 1990 to the most recent inventory year, the area planted was stratified by ecozone, province and tree species. The total area planted by province and ecozone, in conjunction with the proportion of species planted in each province, was used to calculate the area planted by species, resulting in estimates of the area converted to forest, by species, in each RU.

Yield curves are not always available for some plantation species or growing conditions (stocking level or site history); those used to estimate growth increments were taken from a variety of sources, including directly from provincial experts and a growth curve compendium prepared for use in Drever et al. (2021). Growth curves for the Forests Ontario plantation sites were developed using the Forest Vegetation Simulator Ontario (Woods and Robinson, 2007), which is a variant of the United States Forest Service's simulator that is adapted for use in Ontario. For all afforestation plantings, species without a yield curve were assigned the yield curve of another species with similar growth characteristics or the species most likely to have been historically present in that area. It was assumed that no woody biomass was present on the site prior to afforestation. Changes in soil C stocks are highly uncertain. The limited time frame of this analysis and the scale of the activity relative to other land use and land-use change activities suggest that the impact of this uncertainty is minimal.

A3.5.2.5. Estimation of Carbon Stock Changes, Emissions and Removals

At the beginning of each annual time step and when an afforestation or forest conversion event is processed, the CBM-CFS3 first assigns the new land-use classification before the impacts of the event are recorded to ensure that the impacts of land-use change (conversion to forests and conversion of forests) are reported in the new land-use category. The selection of forest stands affected by disturbances, whether related or not to land-use change, is based on eligibility rules (Kurz et al., 2009).

Once the model has computed the immediate effect of disturbances on all forest stands, it simulates forest growth, litter fall, and biomass turnover and decomposition, as well as the associated C transfers (annual processes) for all records (managed forest, land converted to forest and land converted from forest), including both stocked and non-stocked stands. The model output consists of C stock changes, fluxes and immediate emissions from burning, allowing the net GHG balance of managed forests to be calculated. Components of fluxes include growth, immediate emissions due to disturbances (C stock changes, and C losses to the atmosphere and to forest products), and decay of both DOM and soil organic matter, including on stands affected by disturbances. During this stage, inventory records that have been in the categories involving land converted to other land uses for 20 years (10 years for land converted to reservoirs) are transferred to the category for land remaining in its final land classification, and the simulation of C dynamics—usually decay—continues in this new category.

When afforestation occurs in Croplands, CBM-CFS3 estimates the biomass C stock changes and subsequent emissions or reductions in Forest Lands. However, the biomass C stocks that are lost and emitted from cropland before afforestation during the conversion year are estimated using a Tier 2 method. For Croplands, country-specific biomass values were estimated based on grain yields, harvest index, and root-shoot ratios (Fan et al., 2017; Jansen et al., 2003; Thiagarajan et al., 2018), aligning with SOC methodology. Net emissions or reduction due to biomass changes from afforestation are calculated as the difference between the biomass C stocks in Cropland and Forest Land during the conversion year.

The same data outputs are available for converted forest lands (except tree growth), but are reported in the new land subcategories—e.g., the Forest Land Converted to Cropland (CRT Table 4.B subcategory 2.a), Land Converted to Wetlands (CRT Table 4.D subcategories 2.a and 2.b.i) and Forest Land Converted to Settlements (CRT Table 4.E subcategory 2.a) subcategories. Exceptions consist of estimates of soil organic matter emissions from the conversion of forest land to cropland and from peat extraction sites, which are performed separately; methods are described in sections A3.5.4.3 and A3.5.6.1. Similarly, methods for estimating emissions (as opposed to C stock changes) from the conversion of forest land to flooded land are described in section A3.5.6.2, while methods for estimating emissions from the use and disposal of forest products are described in section A3.5.3.

A3.5.2.6. Uncertainties

Good practice recommends the use of numerical methods for assessing uncertainties within complex modelling frameworks with multiple interactions between data and parameters. These methods are data-intensive and computational requirements can quickly become a limiting factor. Not all model parameters or input data have equal influence on model outputs. Careful consideration must therefore be given to balance available computing capacity and the inclusion in the uncertainty assessment of input data, parameters and other functions with a significant influence on model outputs.

There are two approaches to uncertainty assessment that are used: full calculation and extrapolation. Full calculation is a computationally intensive process that involves Monte Carlo simulations, as described in Metsaranta et al. (2017). This process was conducted for the 2018 and 2021 submissions. In the intervening submission years (including the current submission 2026), statistical extrapolation approaches are used instead. This involves a series of multiple linear regression models developed from a full Monte Carlo analysis, using the reported value for a category and the reporting calendar year to predict the uncertainty quantiles of relevance (2.5th and 97.5th). The reporting category values and years from the current submission are then used to estimate these quantiles. The differences between the full analysis quantiles and extrapolated quantiles are typically very small. The decision on whether to conduct a full analysis in any given submission depends on several factors, including resource availability, and the type and significance of data changes implemented.

The general approach to uncertainty assessment emphasizes model inputs and parameters as the main sources of uncertainty. The specific uncertainty sources are forest inventory data, influential model parameters and the initialization of soil and DOM C stocks prior to model runs. Additional randomization steps are also included in the development of confidence intervals, by randomly selecting 10 000 bootstrap samples of the output from 100 national-scale Monte Carlo runs (Metsaranta et al., 2017). Not all sources of uncertainty have been captured. Above all, the analysis did not consider the impact of processes that are currently not simulated (Kurz et al., 2013); hence, the results should not be used to assess potential bias (or accuracy) of estimates. The following paragraphs provide details on the characterization of uncertainty sources.

The forest inventory data used in model simulations are compiled for planning and operational purposes. Methods, standards, definitions and quality differ by jurisdiction, depending on its objectives. Although documentation is usually available on the different inventory techniques and procedures used across the country, it seldom contains any quantitative assessment of uncertainty. While it is currently impossible to quantify uncertainties about, for example, managed forest areas, the influence of this uncertainty source can be indirectly built into the uncertainty associated with the biomass increment simulated by the model. For this assessment, a 50% uncertainty level is associated with biomass increments. It incorporates uncertainties associated with not only managed forest areas, but also the age-class distribution, yield curves and allometric equations that are used in estimation.

The areas of managed forests affected annually by both natural and anthropogenic disturbances greatly influence forest C dynamics. Disturbances affect emissions and removals of C in the short term as well as in the long term, through residual decay and age-class distribution. Uncertainties of 10% and 25% are assumed for the areas of managed forests subject annually to wildfires and insect infestations, respectively. The limited total area of forested peatland that was drained suggests that the impact of the uncertainty associated with this activity is minimal.

The uncertainties surrounding the C removed in harvested material are regionally specific and incorporate error ranges for harvested volume (±1%) and standard deviations for the specific gravity of roundwood and the bark adjustment factor (Table A3.5–7). No error was assumed for the C proportion of biomass. The annual coefficient of variation was multiplied by 2 to use a triangular distribution to approximate a normal distribution.

Table A3.5–7 **Uncertainty Ranges for Harvested Carbon, by Canadian Province and Territory**

Province or Territory	Minimum Multiplier	Maximum Multiplier
Newfoundland and Labrador	0.96	1.04
Prince Edward Island	0.88	1.12
Nova Scotia	0.88	1.12
New Brunswick	0.92	1.08
Quebec	0.86	1.14
Ontario	0.92	1.08
Manitoba	0.86	1.14
Saskatchewan	0.92	1.08
Alberta	0.90	1.10
British Columbia	0.92	1.08
Yukon	0.84	1.16
Northwest Territories	0.74	1.26

Note:
Source: Metsaranta et al. (2014)

The assessment also provides estimates of the uncertainties associated with emissions due to forest conversion that are subsequently used in the Tier 1 uncertainty reporting for the national estimates in conjunction with the 30% uncertainty for areas converted annually, which is also used in this analysis. The section of this annex on forest conversion describes the derivation of this value (see A3.5.2.7).

Soil and DOM pools contain a considerable amount of C. Previous work has shown that, at the beginning of a complete run, the initial DOM C stocks are sensitive to historical disturbance rates. In this assessment, initial C stocks in the soil and DOM pools were allowed to vary by changing the historical (pre-1990) fire return intervals. Even though the rates of soil organic matter decay modelled by the annual processes are very low, they do, by virtue of the pool size and forest areas, strongly influence emissions from annual processes.

For this analysis, 28 model parameters were allowed to vary in the Monte Carlo runs:

- base decay rates for DOM pools (11 parameters)
- proportion of decayed material that is oxidized, versus that which is transferred to another DOM pool (5 parameters)
- turnover rates for biomass pools (12 parameters)

In the absence of evidence to support more complex functions, all input probability distribution functions for biomass increments, activity data on human and natural disturbances and decay parameters are assumed to be triangular distributions. A gamma probability distribution function is used for fire intervals (Metsaranta et al., 2014).

Significant uncertainty in the modelling framework may result from the random selection of forest stands subject to fire and deforestation disturbances (Kurz et al., 2008b), which interacts with the uncertainty associated with forest inventory data. The random effect of stand selection algorithms is included in the analysis by allowing different seed values to initiate the random selection algorithms.

It is important to note the interactions between input data and parameters. For example, the uncertainty associated with the age of a forest stand (or age-class structure of a forest landscape) may affect the simulation of stand (or landscape) productivity, depending on the yield curves and the locations of a given age category along those curves. Emissions due to disturbances—including the conversion of forests to other land categories—are driven not only by the areas affected, but also by the pre-conversion standing C stocks, the parameters of the disturbance matrices that reallocate C among pools or "release" it to the atmosphere, and the post-conversion decay rates. Hence, uncertainties about estimates cannot be obtained from a simple combination of activity data and emission factor uncertainties.

Uncertainty estimates are developed for reported emissions and removals representing anthropogenic drivers, as well as non-reported emissions and removals due to natural disturbances. In years when no substantial changes occur, a comprehensive uncertainty analysis using Monte Carlo simulation is not performed. Instead, confidence intervals for each category in the current submission are statistically extrapolated for both forest and HWP estimates. These extrapolations use the results of the previous submission, in which numerical estimates of uncertainty were derived using Monte Carlo simulations as explained above and as further described in Metsaranta et al. (2017, 2020). Total uncertainty estimates are allocated to the reported and non-reported categories by utilizing the same categorization procedures used to estimate reported and excluded values (see section A3.5.2.3).

Additional considerations may be warranted to identify the direct human-induced effects, and their uncertainties, on forest C dynamics. Improvements are expected to occur in the coming years, due to increased knowledge, refined procedures, improved computer software implementations and access to more computing capacity.

A3.5.2.7. Forest Conversion

To account for the long-term residual effects of forest conversion, annual rates of forest areas converted to other land uses were estimated starting in 1970. The approach to estimating forest areas converted to other land uses before 2010 was based on three main information sources: systematic or representative sampling of remote sensing imagery, records, and expert judgment/opinion. The accuracy of these sources was validated in several pilot projects (Leckie, 2006a), and the methodology was implemented across the country. For years after 2010, the estimation approach has been based on the representative sampling and mapping of large forest conversion events from remotely sensed imagery only.

The core method involves remote sensing mapping of forest conversion based on samples from Landsat images dated circa 1975, 1990, 2000, 2008, 2013, 2018 and 2023. Change enhancements between two dates of imagery are produced to highlight areas of forest cover change and identify possible forest conversion events (i.e., "candidate events"). For any event larger than 1 ha of change, imagery is manually delineated and interpreted to determine whether the land cover of the candidate event was initially forest (at Time 1) and the actual land-use change at Time 2 (Leckie et al., 2002, 2010b).

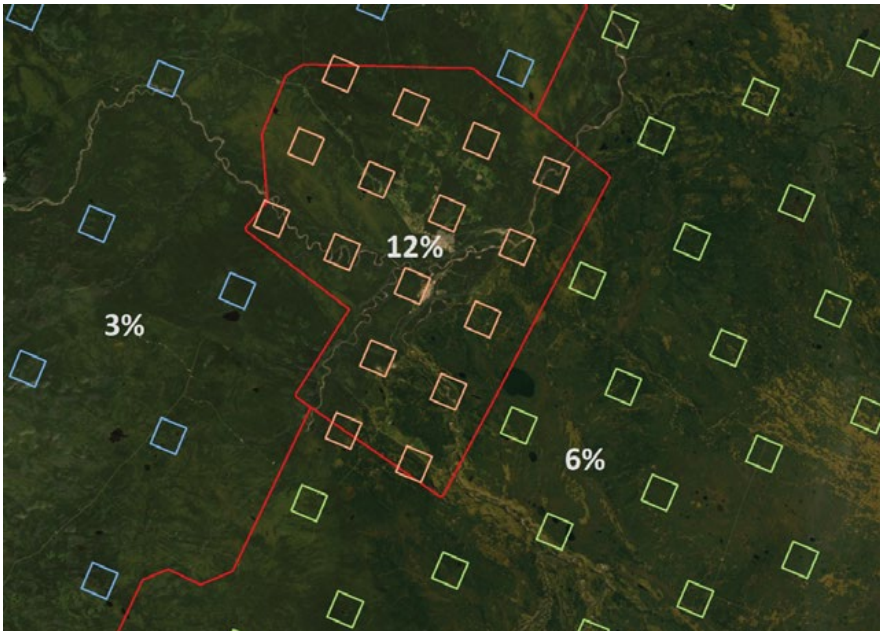
This forest conversion interpretation process is strongly supported by additional spatial data, including: digitized aerial photographs; snow-cover, leaf-off, winter satellite imagery; secondary satellite images from other dates and years; ancillary data, such as maps of road networks, settlements, wetlands, woodland coverage, and mine and gravel pit locations; and specialized databases giving locations of oil and gas pipelines and well pads (Leckie et al., 2006c; Dyk et al., 2015). When readily available, detailed forest inventory information is also used.

Monitoring of forest conversion activity covers all forest areas of Canada and is not limited to the managed forest (Figure A3.5–3). The entire forested area of Canada is broadly stratified into regions of expected forest conversion level and dominant cause, which dictate the target sampling intensity. Depending on the expected spatial patterns and rates of forest conversion, sampling approaches range from complete mapping to systematic sampling over the entire analysis unit of interest to a representative selection of sample cells within a systematic grid. For example, in more heavily populated areas or active deforestation areas, sampling rates up to 12% may be used, with 3.5 km by 3.5 km sample cells at the nodes of a 10 km by 10 km grid (Figure A3.5–5). A lower sampling rate is used in some of the forest activity zones characterized by low population density, where the main economic activities are forestry and other resource extraction. Special cases of known, localized and large forest conversion activities are also identified, such as hydroelectric reservoirs and oil sands development in Alberta. In such cases, the entire areas are handled as single events (“Hot Spot” in Figure A3.5–6), with spatially complete mapping.

In practice, resource constraints limit the size of the remote sensing sample. Wherever possible, a target sampling rate of 12% or 6% was achieved. It is also important to note that different sampling rates may be applied for each time period to track differing activity rates between time periods. The total areas, either fully mapped or sampled, cover a large portion of Canada’s approximately 370 Mha forest land base. This total area was mapped over different time periods, of which over 17 Mha were mapped for 1975 to 1990, 41 Mha were mapped for 1990 to 2000, 22 Mha were mapped for 2000 to 2008, 23 Mha were mapped for 2008 to 2013, 15 Mha were mapped for 2013 to 2018 and 15 Mha were mapped for the period from 2018 to 2023 (Figure A3.5–6). Mapping of sampled areas and larger individual events is updated on a roughly five-year cycle and may be progressively integrated to the monitoring system for the more recent time periods.

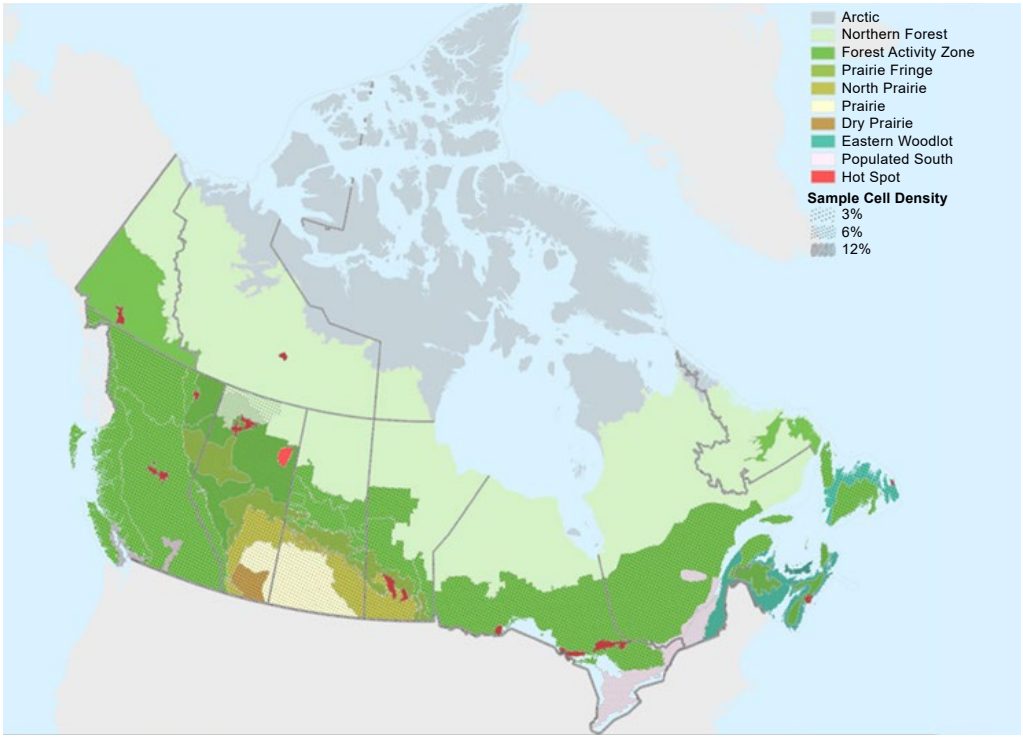
Areas of northern Canada were previously excluded in the National Deforestation Monitoring System estimate due to the anticipated low activity; consequently, zero deforestation had been assumed in this region (Dyk et al., 2015). To verify activity levels in the north, a full-coverage deforestation mapping project in the Northwest Territories’ Taiga Plains ecozone (RU50) was undertaken based on existing anthropogenic disturbance datasets. For the time period from 2013 to 2018, RU50 was processed with full-area mapping which showed that deforestation did occur in this reconciliation unit, though it represents less than 0.2% of Canada’s annual deforestation rate. These results have been reported since the 2022 submission.

Figure A3.5–5 **Three Satellite Imagery Sampling Rates for Forest Conversion Mapping**



Note: Background imagery: Area near Fort Nelson, British Columbia (ESRI World Imagery). The denser grid cells at the centre represent a 12% sampling density; the lighter grid on the right, 6% intensity; and the sparse grid on the left, 3% intensity.

Figure A3.5–6 **Forest Conversion Strata and Areas Sampled in 2018 to 2023**



Records data were also gathered when available, consisting mostly of information on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs (Leckie et al., 2006b). The temporal coverage, availability and applicability of these records are assessed to determine the most appropriate information sources (records or imagery). Records data are sometimes used to aid in the validation of estimates made through image interpretation. In particular, records data were used in the early mapping efforts in British Columbia to provide estimates of conversion activity for power lines and oil and gas operations. The interpretation of remote sensing imagery is used to assess the areas of forest converted as a result of hydroelectric development.

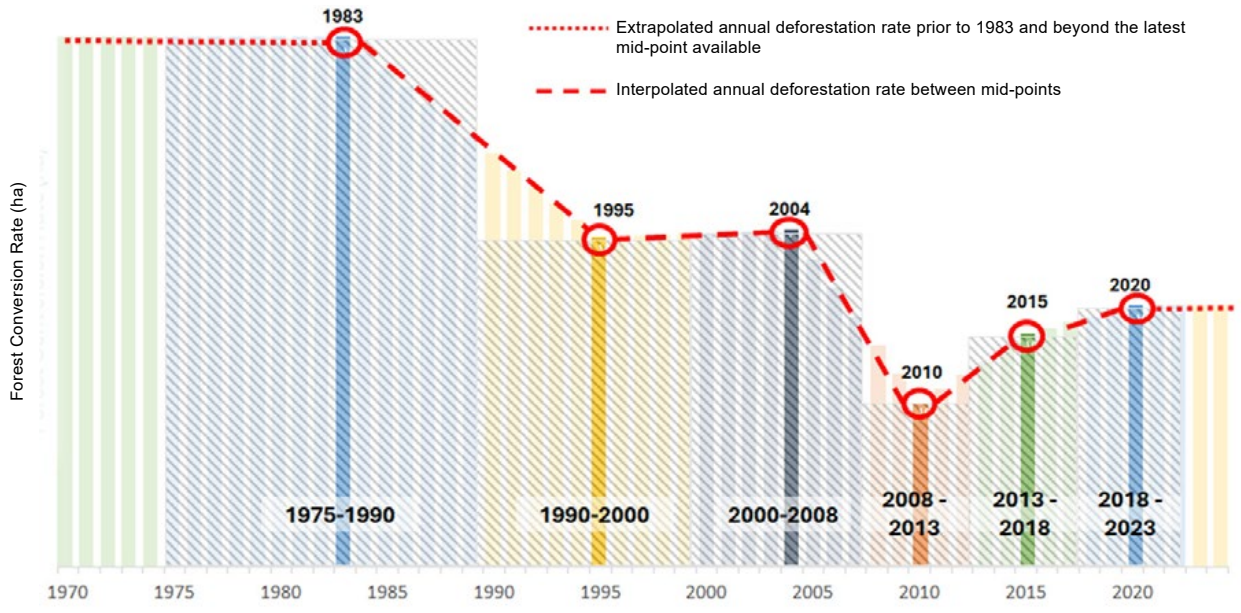
Expert opinion is only called upon when remote sensing-based sampling is insufficient and records data are unavailable or of poor quality. Expert judgment is also used to reconcile differences between records and remote sensing information and to resolve major sequential time periods of mapping (i.e., 1975 to 1990, 1990 to 2000, 2000 to 2008; the most recent time periods are measured on a roughly five-year cycle). In such cases, available expert opinions and data sources are compared, remote sensing and record data are reviewed, and interpretations of forest conversion activities are made (Leckie, 2006b; Leckie et al., 2010a; Dyk et al., 2015). In the case of recent estimates—and certainly those with a significant impact, such as hot spots—estimates are derived directly from remote sensing samples.

Forest conversion activity data are compiled and summarized initially by analysis unit and conversion event in a database. The purpose of this compilation is to summarize events to obtain detailed post-conversion classes for each RU. This compilation process also involves the insertion of records data and expert judgment. During these procedures, a local forest conversion rate (ha $year^{-1}$) is obtained from the compilation of events, based on the time interval between the images. Since the available imagery was not necessarily dated to a specific year, the rates cover different time periods. During the data compilation phase, forest conversion events are assigned to a time period, and the corresponding rate of forest conversion is assigned to that period. For example, a 7.0-ha event encountered on imagery from the period from 1975 to 1989 would yield a 0.5 ha $year^{-1}$ rate (7.0 ha/14 years) and then would be assigned to the period from 1975 to 1990. The total area interpreted in an analysis unit for that time period is then used to determine the relative rate of forest conversion (ha $year^{-1}$ per km^2 interpreted) for all events of the same type. Relative rates are scaled up for each analysis unit. Finally, data are grouped by end land use (e.g., agricultural crop or rural residential) and, in turn, are summarized by broader categories when recompiled by RU.

The remote sensing data were derived from medium-resolution imagery from circa 1975, 1990, 2000, 2008, 2013, 2018 and 2023, and more recent years as new imagery has become available, while the records data are annual or summarized over a given time period. As explained, to date, the core remote sensing method has provided six distinct average rates of forest conversion in the mapped time periods, but no annual estimates of these rates. The preparation of annual forest

conversion rates from 1970 to the current inventory year would require the simultaneous application of two procedures: (i) the extrapolation of annual rates prior to 1983 and beyond the midpoint of the latest mapped time period available; and (ii) linear interpolation between the midpoints of the mapped time periods and recent analyses completed at the time of submission (Figure A3.5–7). Added to the interpolated data are large individual events for which actual disturbance information is known, either from record information or a detailed mapping activity, for example, hydroelectric reservoirs.

Figure A3.5–7 **Procedure for Developing a Consistent Time Series of Forest Conversion Rates**



Quality Assurance / Quality Control of Forest Conversion Data

Great care was taken in analyzing the records data, their suitability and their limitations. Their documentation was examined, personnel involved in managing and implementing data collection and storage were interviewed and, when available, numbers were checked against independent data sources, the high-resolution imagery sampled and expert knowledge.

The interpretation of remote sensing imagery follows defined procedures (Leckie et al., 2010b; Dyk et al., 2015), although it is conducted by a variety of organizations, including provincial government forestry or geomatics groups, remote sensing or mapping companies, research and development organizations and in-house government staff. The basic quality control process for image analysis includes internal checks within the mapping agency or company by a senior person; real-time quality assurance by Canadian Forest Service specialists during interpretation, with feedback provided within days of the interpretation of an area; and the final quality assurance and vetting of the interpretation by the Canadian Forest Service. Field validation is conducted on an ongoing basis as resources permit. Each quality control point and revision is documented in the geographic information system (GIS) database of conversion events (Dyk et al., 2015).

Records of decision as to data used and expert judgment applied, as well as decisions on the resolution of contradictory data, are documented within the overall processing database (Leckie, 2006b) and updated for each new submission (Dyk et al., 2015). Data sources and limitations are recorded, and remote sensing data and interpretations archived.

Uncertainty of Forest Conversion Data

The development of uncertainty ranges for forest conversion data is a complex and difficult task because of the spatial and temporal variability of the data. Compared with earlier deforestation estimates, the current estimates benefit from several years of experience and knowledge gained from the development of previous estimates (Leckie, 2011; Dyk et al., 2015). Specific improvements include:

- expanded datasets with additional Earth observation (EO) data; Landsat, Sentinel 2, Rapid-Eye, SPOT-5 and high-resolution satellite imagery; and aerial photographs;
- expansion of the sampled area in targeted and other areas;

- analysis and validation of record data using high-resolution imagery (for example, co-disturbances from pipelines and access roads);
- extension of temporal coverage to the most recent time period;
- review of the 1970 to 2004 deforestation time series based on more current spatial analysis;
- validation of existing anthropogenic disturbance datasets for northern Canada;
- better knowledge resulting from the increased experience and expertise gained from quality control review and validation activities.

These improvements result in enhanced detection, delineation and determination of event size and cause, as well as a more accurate estimate of the timing of conversion events.

Two approaches to estimating uncertainties were considered: an empirical and an analytical approach. The resulting estimate is based on the consideration of these approaches and provides an estimate of uncertainty associated with activity area estimates. Additional sources of uncertainty related to the forest type being converted, the post-conversion land category and event timing are not considered.

The empirical approach is an attempt to assess the overall uncertainty in the forest conversion area estimate. This approach provides an estimate of uncertainty that considers all the varied components of uncertainty and their potential interactions.

The empirical estimate of uncertainty was developed by estimating the extreme low, low, high and extreme high forest conversion rates for each RU and end-use class, based on expert knowledge of activities and practices at a regional scale. All these estimates were then compiled on a national basis. Comparisons between extreme and non-extreme estimates provided insight into the possible range of conversion activity. Based on this exercise, the estimate of the overall uncertainty associated with forest conversion was determined to be in the range of ±20% to ±30%.

The analytical approach breaks down uncertainty into subcomponents and then combines them through simple error propagation. The components considered are omission, commission, sampling and boundary delineation errors.

Omission and commission errors are influenced by several factors, but in particular by the date and quality of the pre- and post-imagery. Throughout the time series, omitted events tend to be smaller in size, while commission errors usually result from a misinterpretation rather than an oversight, and thus are less size-dependent. Commission and omission errors tend to offset each other. For the post-2000 time periods, commission errors are likely to be greater than omission errors, particularly because of an insufficient time-lapse/period after disturbance to confirm that areas are in fact permanently deforested.

The uncertainty associated with boundary delineation errors involves the errors resulting from the displacement of the event boundary from its actual or true boundary. Both underestimation and overestimation of the area can result. This source of uncertainty is greatly influenced by the quality and resolution of the imagery used in the delineation process; improvements in resolution and image quality reduce this source of uncertainty.

Estimates of sampling uncertainty focus on the sampling process and the scaling of estimates to large regions (strata/RU). The sampling process is a mixture of wall-to-wall mapping and systematic sampling. In some areas, the sample coverage and design were different in each mapping period. The sample error depends on the amount of activity in each region within each time period sampled. In addition, it is dependent on the conversion event size and spatial distribution (Leckie et al., 2015). Uncertainty due to sampling and scaling activity is therefore regionally variable and, because the causes of conversion activities may differ by region, the uncertainty is variable overall.

The results of this analytical approach are consistent with those obtained using the empirical approach. The result was a conservative estimate, which sets the uncertainty at the higher range of ±30%. Further work will help improve the current understanding of the various sources of uncertainty, their interaction and the approaches used to combine these components.

The ±30% range is an overall estimate considering all time periods, regions and forest conversion types. Caution should be exercised in applying this range to the cumulative area of forest land converted to another category over the last 20 years, or 10 years in the case of reservoirs (land areas reported in the CRT tables).

A3.5.3. Harvested Wood Products

The LULUCF sector of the inventory includes an estimate of the biogenic CO_2 fluxes associated with the use and disposal of HWP manufactured from wood resulting from forest harvesting (including bioenergy) and forest conversion activities in Canada and consumed in Canada or abroad. These estimates follow the simple decay approach described in the Annex to Volume 4, Chapter 12, of the 2006 IPCC Guidelines (IPCC, 2006). The simple decay approach is similar to the production approach, excluding HWP imports, including HWP exports, and tracking actual fluxes of carbon associated with HWP to the atmosphere. Wood harvested from the forest is tracked as carbon leaving the forest ecosystem and entering the harvest wood products pool. Biogenic CO_2 fluxes from HWP combustion or disposal are estimated and reported in the LULUCF sector, while CH_4 and N_2O emissions from HWP combustion or domestic disposal and anaerobic decomposition resulting in methane emissions are estimated and reported in the Energy and Waste sectors in accordance with the IPCC Guidelines (IPCC, 2006, 2019).

Although the simple decay approach is used for the underlying estimates, including annual bioenergy emissions in transfers to the HWP pool and emissions from the HWP pool, Canada reports HWP fluxes in the CRT in a manner that is consistent with the production approach as outlined in the 2019 IPCC Refinement (IPCC, 2019).

General Approach and Methods

Canada applies a Tier 3 country-specific flux-data method (Section 12.4.4.1, 2019 Refinement) combined with the simple decay approach (Section 12A.3.2, 2019 Refinement) using a carbon dynamics model (i.e., NFCMARS-HWP, Figure A3.5–8). The National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP) was developed to estimate and report on the fate of C in the wood harvested in Canada's forests and other wooded lands.

Model Inputs and Data Sources

Inputs to the model include the annual mass of C transferred to forest products that result from conventional forest harvesting on Forest Land, forest conversion harvests, and residential firewood harvesting on three different land types (i.e., Forest Land, Cropland, and Settlements). Data on recent harvests, from 1990 onward, were generated by Canada's country-specific forest ecosystem carbon dynamics model CBM-CFS3 (see section A3.5.2.1). These recent data are available spatially by reconciliation units (RU) (see section A3.5.1).

Carbon input from historical harvests was estimated using national-level commodity production data from Statistics Canada for the period from 1941 to 1989. These data were used to develop non-linear equations to backcast commodity production. Domestic and exported quantities were then calculated based on average proportions observed during the five-year period from 1961 to 1965.

Information on residential and industrial bioenergy use was provided by the Energy sector (section A3.1.4.1.4). Industrial bioenergy data were sourced from the annual Report on Energy Supply and Demand in Canada (RESD). Data on domestic residential firewood, wood pellets and manufactured logs were obtained from consumption surveys conducted by Statistics Canada (1997, 2003, 2007, 2015, 2017, 2019, 2021), Canadian Facts (1997), TNS (2006, 2012). Residential firewood data were spatially aggregated to RU (Trégaro, 2020) and converted to carbon using species-specific wood densities (Blondel and Tracey, 2018).

Survey data were spatially aggregated by RU (Trégaro, 2020) and species-specific wood densities were used to estimate carbon content (Blondel and Tracey, 2018). These estimates were then interpolated and extrapolated to other years using the number of heating degree-days in each province, or territory, relative to the survey years. All biomass C inputs to the firewood pool were based on the annual volumes provided by the Energy sector. Specifically, annual residential bioenergy consumption was calculated for each RU across seven (7) allocation categories: (i) softwood harvested from forest land; (ii) hardwood harvested from forest land; (iii) varieties of species harvested from forest land; (iv) woody biomass harvested from cropland; (v) firewood harvested from urban trees in settlements; (vi) domestic residential wood pellets; and (vii) manufactured logs. These categories represent the targets of firewood harvesting to be implemented in the models (Trégaro, 2020; Trégaro and Blondel, 2019; Hafer et al., 2020). Data were sourced from fuelwood and firewood harvest statistics from the National Forestry Database.[5]

Data on wood waste incinerated in controlled industrial incineration facilities were provided by the Waste sector, details on specific data sources and methodologies used are provided in section A3.6.3.

Model Flow and Parameters

The model uses a conceptual flow network describing the movement and transformation of harvested wood (Figure A3.5–8). The simulation is provided with C inputs representative of wood harvested from the forest ecosystem model, categorized by different harvest categories (i.e., industrial roundwood from conventional harvest or deforestation separately, and firewood); a small amount of firewood from non-forest sources (i.e., settlement and croplands) are also included. In annual time steps some of the harvested roundwood is retained domestically and some is exported. Roundwood conversion to commodities is simulated for both domestic and foreign wood. Commodities include sawn wood and other industrial roundwood, wood-based panels, pulp and paper, pellets and manufactured logs used for bioenergy, and residuals referred to as "milling residue". The simulation exports some of the domestic commodities that are produced and keeps track of the additions to and retirements from in-use HWP or combustion for bioenergy.

The simulation begins with inputs representing the volume of harvested roundwood. While some of the roundwood is exported to foreign countries, the majority remains in Canada. In Canada, roundwood is processed into various commodities, including sawnwood, panels, pulp and paper, and other industrial roundwood products. The NFCMARS-HWP simulates these conversion processes both domestically and in foreign regions. Most of the commodities produced in Canada are subsequently exported, while a portion is retained for domestic consumption.

5 National Forestry Database, available online at: http://nfdp.ccfm.org/en/data/harvest.php.

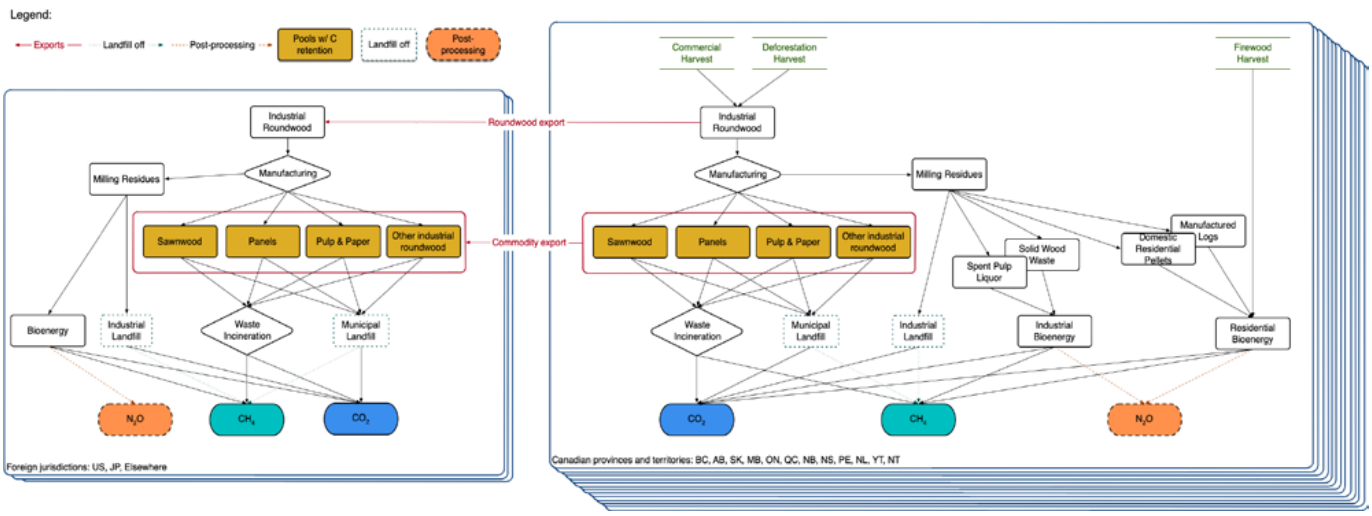
Two FAO databases, Forestry Production and Trade[6] and Forestry Trade Flows,[7] are used to determine the proportion of Canadian roundwood and commodities exported to foreign jurisdictions, and the proportion of roundwood converted into commodities. These proportions are referred to as allocation parameters in NFCMARS-HWP. These proportions are generated annually using a mass-balance approach. The data for recent years (usually the most recent two years) may be incomplete, and subject to revision by FAOSTAT resulting in recalculations as data becomes available. Because FAOSTAT reports roundwood volume excluding bark, the IPCC default bark expansion factors are used to reincorporate the bark content (Table A6.5–1). Country-specific conversion factors are used where available. Otherwise, the IPCC default conversion factors are used (Table A6.5–2).

The model simulates the decay and retention of carbon within domestic and foreign commodity pools. The flux of carbon leaving sawnwood, panels, pulp and paper and other industrial roundwood are estimated by applying first order decay functions (Equation 12.2 of the 2019 Refinement) and a mix of country-specific and IPCC default half-lives (Table A6.5–3). Commodities that are retired to solid waste disposal sites are treated as being instantaneously oxidized, a conservative assumption given that they are likely stored for a period of time.

Woody biomass used for bioenergy is assumed to be combusted in the year of harvest. Emissions from the industrial use of wood-based energy (treated as milling residue in the model) are assumed to result from the combustion of wood wastes (i.e., hog fuel) and spent pulping liquors by the pulp and paper manufacturing sector. As with residential bioenergy use, emissions from industrial biomass energy use are derived by multiplying the amount of fuel consumed by the emission factor for that fuel type. The emission factors for both industrial wood waste and spent pulp liquors are also given in Table A6.6–1. Note that these emission factors are expressed in grams of gas emitted per kg of fuel consumed, with the fuel assumed to have a moisture content of 0%.

Residential firewood combustion emissions consist of CO_2, and some remaining unaccounted-for C likely found in volatile organic compounds, unburned hydrocarbons and charcoal that are assumed to be instantly oxidized. Emissions are derived by multiplying the amount of wood burned in each appliance type by the emission factor for that appliance type. The relevant emission factors are given in Table A6.6–1, expressed in grams of gas emitted per kilogram of fuel combusted, which for the purposes of the model have been converted to tonnes of C emitted as gas per tonne C in fuel.

Figure A3.5–8 **A Simplified Schematic of Carbon Flows in Harvested Wood Products, NFCMARS-HWP**



Note:
a. OIR = Other Industrial Roundwood

6 FAOSTAT Forestry Production and Trade, available online at: http://www.fao.org/faostat/en/#data/FO.

7 FAOSTAT Forestry Trade Flows, available online at: http://www.fao.org/faostat/en/#data/FT.

Uncertainty

The uncertainty analysis (Metsaranta et al., 2020) for this category divides the uncertainty into three categories: (i) uncertainties in assumptions (e.g., the assumption that HWP disposal follows the exponential decay pattern); (ii) uncertainties in factors or parameters that are not derived from activity data (e.g., half-lives of commodity-in-use pools); and (iii) uncertainties in harvest inputs and allocation parameters.

A sensitivity analysis was used to first filter out parameters in which variations are unlikely to cause significant changes to the emission results. Uncertainty distributions and ranges of the remaining parameters were developed based on published literature and, where no distributions were available, on expert judgment.

Harvest carbon inputs consisted of historical (pre-1990) inputs and contemporary (post-1990) inputs, which are based on estimates of harvest and forest conversion in the forest ecosystem model, the volume of residential firewood provided by the Energy sector, and statistics available on pre-1990 commodity production. Historical inputs were assigned a uniform distribution and a range of baseline value ±25%. Contemporary inputs are obtained from the uncertainty analysis of the forest ecosystem model (CBM-CFS3, section A3.5.2).

The uncertainty distributions of model parameters and harvest inputs were used to run the Monte Carlo analysis with a sample size (n) of 100.

As is the case with Forest Land uncertainty analysis, in years with no substantial changes, a comprehensive uncertainty analysis is not performed and, instead, confidence intervals for each category in the current submission year are statistically extrapolated using the results of the previous submission.

A3.5.4. Cropland

The methodologies described in this section apply to C stock changes in mineral soils subject to cropland management and to the conversion of land in the Forest Land and Grassland categories to the Cropland category, CO_2 emissions from the cultivation of histosols, changes in the biomass of woody perennial crops, and N_2O emissions from soil disturbance resulting from conversion to cropland. The estimation methodologies for C stock changes and GHG emissions from the biomass and DOM pools resulting from conversion of forest land to cropland are provided in section A3.5.2.7.

A3.5.4.1. Cropland Remaining Cropland

A detailed description of the methodologies used for estimating C changes associated with tillage practices, perennial/annual crop conversion, and forest land and grassland conversion to cropland can be found in McConkey et al. (2007a).

Change in Carbon Stocks in Mineral Soils

Changing Management Practices

The amount of organic C retained in soil represents the balance between the rates of input from crop residues and losses through soil organic carbon (SOC) decomposition. The amount of SOC stored in a soil increases or decreases is determined by soil management practices. The development of the CO_2 estimation methodology is based on the premise that, on long-existing cropland, changes in soil C stocks over time occur following changes in soil management that influence the rates of either C additions to, or C losses from, the soil. If no change in management practices occurs, the C stocks are assumed to be at equilibrium, and hence the change in C stocks is deemed to be zero.

Some management practices are generally known to increase SOC in cultivated cropland, such as reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting practices and re-establishment of perennial vegetation (Janzen et al., 1997; Bruce et al., 1999). Adoption of reduced tillage (RT) or no-till (NT) can result in significant accumulation of SOC compared with intensive tillage (IT) (Campbell et al., 1995, 1996a, 1996b; Janzen et al., 1998; McConkey et al., 2003). Many cropping systems can be intensified by increasing the duration of photosynthetic activity through the greater use of perennial forage (Biederbeck et al.,1984; Bremer et al.,1994; Campbell et al.,1998). Switching from conservative to conventional tillage or from intensive to extensive cropping systems will generally reduce C input and increase organic matter decomposition, thereby reducing SOC.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management practices on SOC. More recent analyses (Fan et al., 2017; Liang et al., 2020a, 2020b; Liang et al., 2021; Thiagarajan et al. 2022) have prompted new methodological developments. The original compendium of data by VandenBygaart et al. (2003) and these new studies, as well as activity data available from the *Census of Agriculture*

(COA), provide the basis for identifying key management practices and management changes used to estimate changes in soil C stocks. Emissions and removals of CO_2 from mineral soils are estimated for the following land management changes (LMCs):

1. Change in mixture of crop types
    a) Increase in perennial crops
    b) Increase in annual crops
2. Change in tillage practices
    a) IT to RT
    b) IT to NT
    c) RT to IT
    d) RT to NT
    e) NT to IT
    f) NT to RT
3. Change in crop productivity / crop residue C input
4. Manure application

Where nutrients are strongly limiting, proper fertilization can increase SOC and, in such conditions, fertilizer or other nutrient-enhancing practices are generally applied. Irrigation in semi-arid areas can affect SOC, but the impact is unclear and the area of irrigated land has been relatively constant in Canada. Therefore, it is assumed that these selected LMCs represent the most important and consistent influences on SOC in mineral soils.

Area-Based Carbon Stock Change Factor

To estimate C emissions or removals, a SOC stock change factor specific to each combination of SLC polygon and land management is multiplied by the area of change (Equation A3.5–1). The stock change factor is the average rate of SOC change per year and per unit of area of LMC.

Equation A3.5–1

$$\Delta C = F \times A$$

ΔC = change in SOC stock for inventory year, Mg C
F = average annual change in SOC subject to LMC, or C factor, Mg C ha^{-1} yr^{-1}
A = LMC area, ha

The areas affected by LMCs, such as changes in tillage and crop type, are obtained from the COA. Census data provide information on the net change in area over five-year census periods. In practice, land probably both enters and leaves a land management practice, and combinations of management changes occur. However, because only net change data are available, two assumptions are made: the additivity and reversibility of SOC factors. Reversibility assumes that the factor associated with an LMC from A to B is the opposite of that associated with the LMC from B to A. Additivity assumes that C changes from each individual LMC occurring on the same piece of land are independent and therefore cumulative. While the approach is additive, the SOC factors decline over time and implementation of different factors do not occur simultaneously. As a result, this country-specific approach is more temporally accurate than the simple factorial approach outlined in the IPCC Guidelines. This approach is supported by the findings of McConkey et al. (2003), who reported that the impact of tillage and crop rotations on SOC is additive.

A relatively large set of Canadian observations is available on long-term changes in SOC resulting from LMCs such as the adoption of NT (VandenBygaart et al., 2003; Campbell et al., 2005; Liang et al., 2020a). However, even this extensive data set does not cover the full geographical extent of Canadian agriculture. In addition, difficulties arise in comparing measurements among research sites, determining the duration of an effect, estimating full uncertainty from a range of initial soil conditions, and determining the variability of soil C stocks without an LMC.

Because of these limitations, a well-calibrated and validated model of SOC dynamics, the Century model (Parton et al., 1987, 1988), was used to derive the individual SOC factors for changes between NT and IT, RT and IT, RT and NT, and annual and perennial crops. The Century model has been widely used to simulate SOC changes under Canadian conditions (Liang et al., 1996; Monreal et al., 1997; Campbell et al., 2000, 2005; Pennock and Frick, 2001; Carter et al., 2003; Bolinder, 2004).

Smith et al. (1997, 2000, 2001) developed an approach using the Century model to estimate SOC changes on agricultural land in Canada. Estimating C changes required the development of a generalized description of land use and management on cropland from 1910 onward for a sample of soil types and climates across Canada. These scenarios were generated from a mixture of expert knowledge and agricultural statistics on land management, including crop types, fallow practices and fertilizer application (Smith et al., 1997; Smith et al., 2000). They were used for the first comprehensive assessment of SOC changes on agricultural land within a broader assessment of soil health (McCrae et al., 2000).

The SOC values in the SLC polygon attribute database (Canadian Soil Information Service, or CanSIS) served as the starting point for developing C factors for tillage and crop mixtures (Figure A3.5–9 and Figure A3.5–10). These SOC values were derived from measurements from soil surveys and land resource studies (Tarnocai, 1997) and are assumed to represent average SOC values on cropland in 1985. The initial SOC in 1910 was 1.25 times the SOC in the corresponding SLC polygon today Changes in SOC factors were estimated using the difference in SOC stocks over time based on the simulation of a generalized land-use and land management scenario with and without the LMC of interest (Smith et al., 2001).

To develop area-based factors, a 10-year crop-and-tillage system (CTS) was developed for each analysis unit and census year, using data from the COA. The CTS focused on seven crops or crop types (grain, oilseeds, pulses, alfalfa, root crops and perennial crops) and three tillage practices (IT, RT and NT). Essentially, each CTS represents a mix of crops and tillage practices in space as a mix of crops and tillage practices in time. Under this scheme, a polygon with 20% of cropland area in grain and 20% of cropland area in NT, for example, has 2 of 10 years in grain and 2 of 10 years in NT. Temporal sequences of crop and tillage practices are developed from expert-defined rulesets, such as “summerfallow never follows summerfallow” and “corn typically follows soybeans.” The construction allows a base CTS and substitutions of LMCs in the CTS to be readily input in the Century model.

The SOC change factor is determined as factor = (C for CTS with LMC – C for base CTS) / [(fraction of CTS substituted with the LMC) × (duration considered)]. If a land management system is defined as a particular mix of crops and tillage practices on a specified land area, a change in SOC due to an LMC (ΔC_{LMC}) can be estimated as the difference in SOC stock between two land management systems divided by the proportion of the land area subject to an LMC.

Equation A3.5–2

$$\Delta C_{LMC}(t) = \frac{\Delta C}{P_{LMC}}$$

$\Delta C_{LMC}(t)$ = change in SOC between land management systems in year t (Mg C ha^{-1})
ΔC = change in SOC due to LMC (Mg C)
P_{LMC} = proportion of the land area under a given land management system subject to the LMC, ha

This proportion (P_{LMC}) can be derived as the proportion of the land management system in the base system less the area under new land management system.

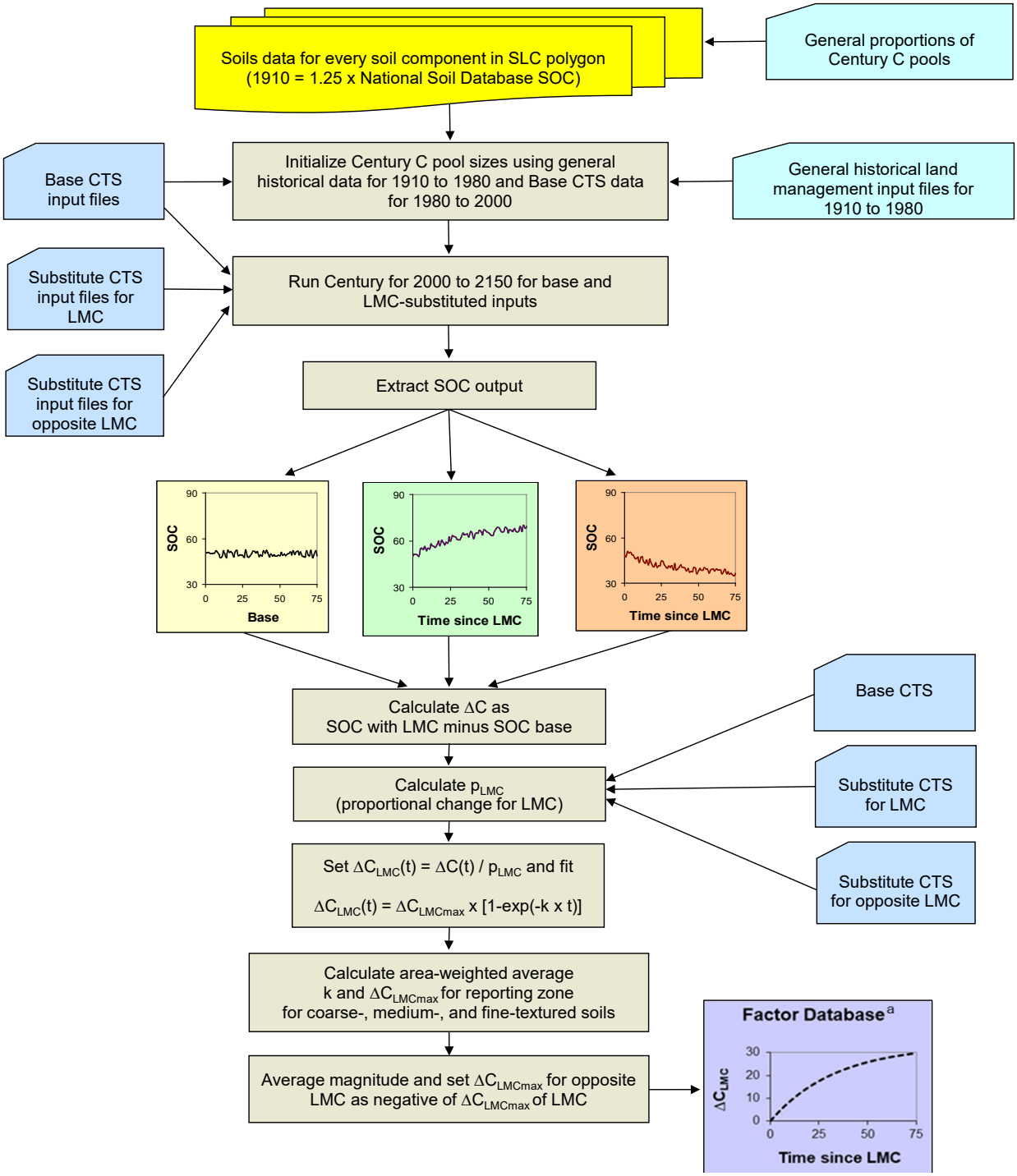
Equation A3.5–3

$$P_{LMC} = P_{LMbase} - P_{LMnew}$$

P_{LMC} = proportion of the land area under a given land management system subject to the LMC
P_{LMbase} = fraction of land management system of interest in the base land management system
P_{LMnew} = fraction of land management system of interest in the new land management system

Figure A3.5–10 provides an example of Century runs for a Lethbridge loam (Orthic Dark Brown Chernozem) in the Semi-arid Prairies reporting zone. A base model run was performed using a 10-year base mix of crops based on the 1996 COA and weather data covering the 1951 to 2000 period. Century simulations of SOC were run by substituting perennial crops for the seven annual crops out of 10 in the base mixture. As a separate exercise, NT was substituted for IT for four years out of 10 in the base mixture (Figure A3.5–10). The next step was to calculate the $\Delta C_{LMC}(t)$ function by subtracting the simulated SOC values for the base mixture values from those imposed by the LMC of interest (Equation A3.5–2). Finally, the $\Delta C_{LMC}(t)$ was calculated as the proportion of the area of farming system divided by the P_{LMC} (Equation A3.5–3). In the case of the time series of ΔC_{LMC}, the respective values of P_{LMC} for the IT to NT reduction and for the addition of perennial crops were 4/10 and 7/10 (Figure A3.5–11).

Figure A3.5–9 **Method for Deriving Area-Based Carbon Factors for a Land Management Change of Interest**



Notes:
a. Cumulative C gain over time
CTS = crop and tillage system

Figure A3.5–10 **Soil Organic Carbon (SOC) for a Base Crop Mix, for a Perennial (Alfalfa) Crop Substituted for an Annual Crop (Wheat) and for No-Till (NT) Substituted for Intensive Till (IT), in a Lethbridge Loam, Based on Century Runs**

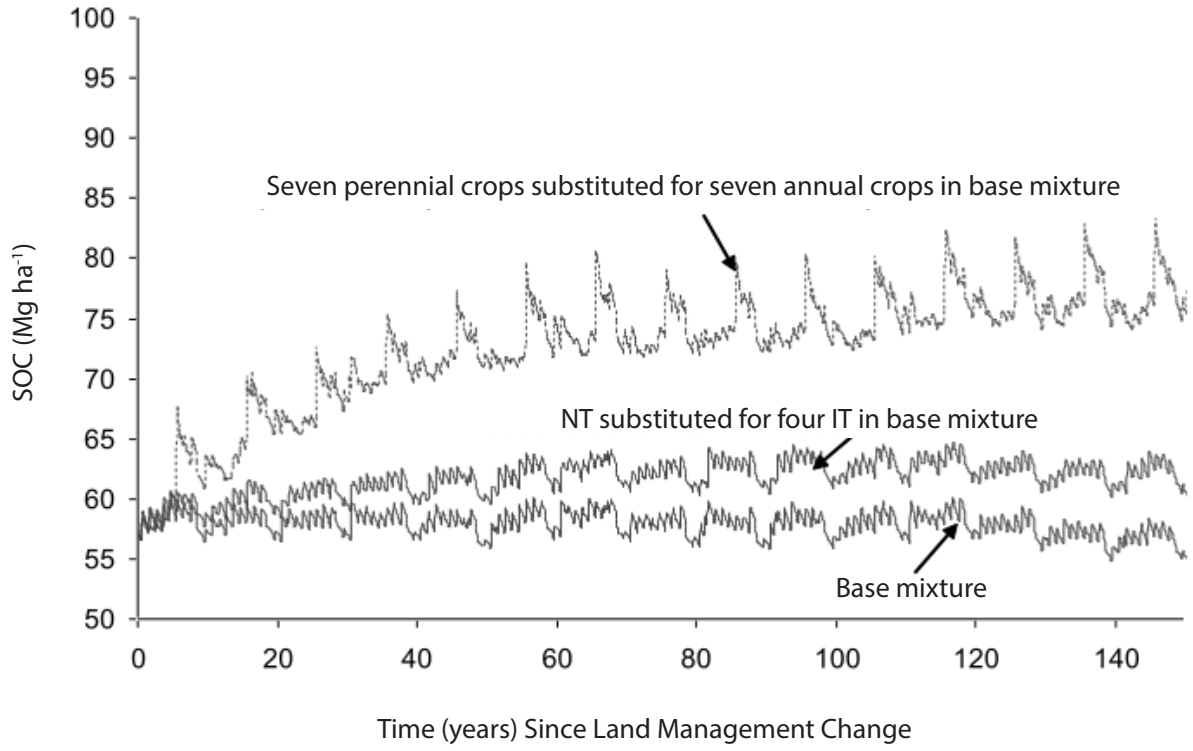
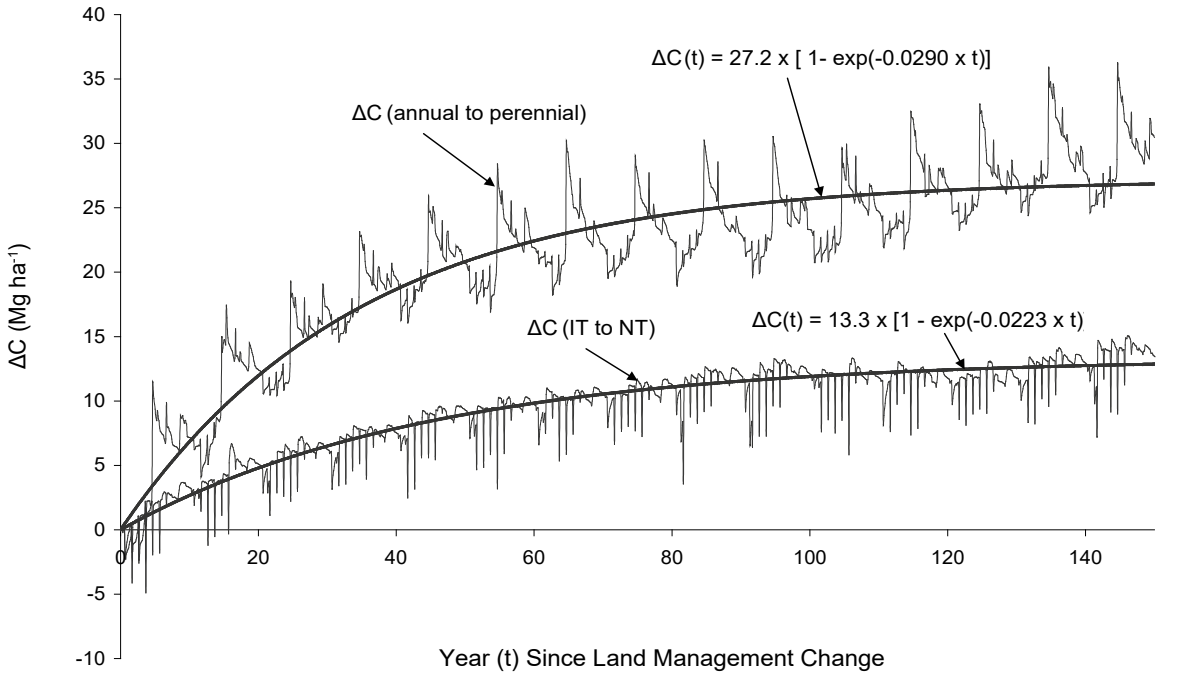


Figure A3.5–11 **Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix**



SOC dynamics are believed to be governed by first-order kinetics, and thus the C change can be expressed as:

Equation A3.5–4

$$\Delta C_{LMC}(t) = \Delta C_{LMCmax} \times [1 - exp(-k \times t)]$$

$\Delta C_{LMC}(t)$ = change in SOC due to LMC at time t (Mg C ha^{-1})
ΔC_{LMCmax} = maximum SOC change induced by LMC (Mg C ha^{-1})
k = rate constant, yr^{-1}
t = number of years after LMC

In practice, the exponential equations are fit statistically using a least squares method. The rates of change over time in Mg C ha^{-1} y^{-1} were established using a natural log transformation. These rates represent the instantaneous factor values for the LMC. Since the estimation is based on annual changes, the equation used for estimating the factor for annual change from the previous year (i.e., from year t−1 to year t) is:

Equation A3.5–5

$$F_{LMC}(t) = \Delta C_{LMCmax} \times [exp\{-k \times (t-1)\} - exp(-k \times t)]$$

$F_{LMC}(t)$ = instantaneous C factor value due to LMC at time t, Mg C ha^{-1} yr^{-1}
ΔC_{LMCmax} = maximum SOC change induced by LMC (Mg C ha^{-1})
k = rate constant, yr^{-1}
t = number of years after LMC

Since perfect steady-state conditions are never reached, the exponential equation should theoretically apply forever. In practice, however, the exponential equation was truncated when the $F_{LMC}(t)$ dropped to 25 kg C ha^{-1} yr^{-1}. This rate was below the practical measurement limit (Figure A3.5–12).

Estimating Mean k and ΔC_{LMCmax} for Practical Factor Calculations

The ΔC_{LMCmax} and k parameters were determined for all 11 602 soil components in the CanSIS database and two LMCs (changes in tillage practices and annual-perennial crop mix). These soil components represent a wide range of initial SOC states and combinations of base crop mixtures and substitution amounts. The parameter values were estimated for each reporting zone as the mean of these soil components, weighted by the area of cropland on each component. The geometric mean was used for k, since its distribution was positively skewed. These means were calculated for three general soil textural classes (sandy, loamy and clayey) and applied to each soil component based on its textural class. Occasionally, k values of less than 0 resulted from the fit to ΔC_{LMC}; the k and ΔC_{LMCmax} from these fits were excluded from the reporting zone means.

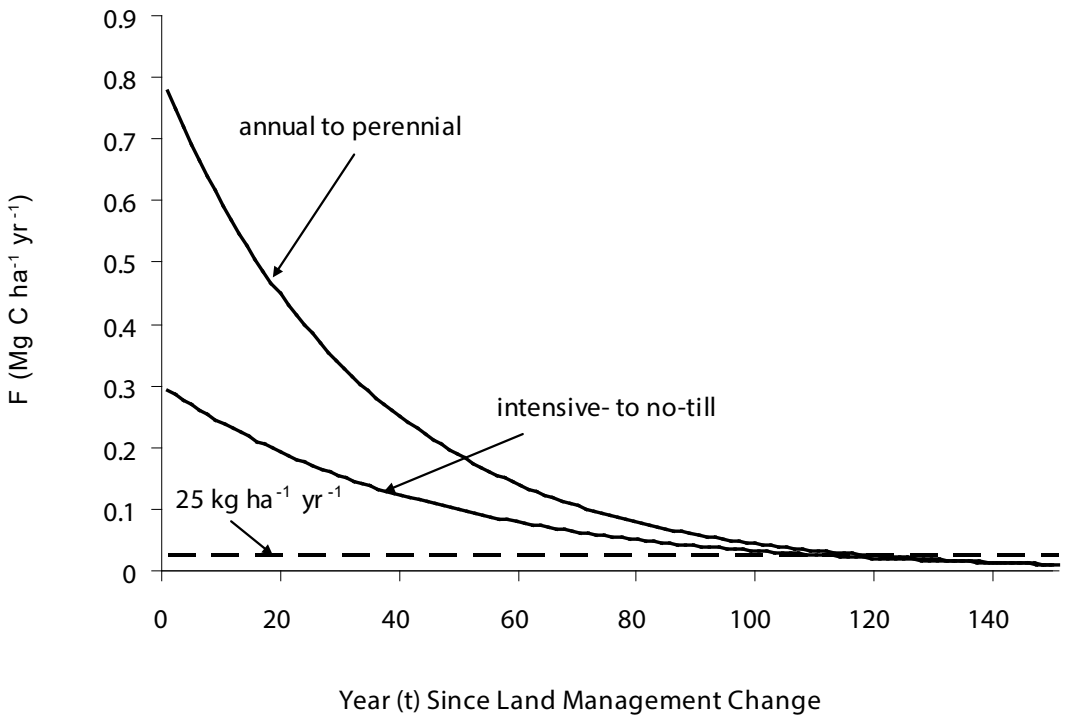
Generally, the rates of SOC losses following an LMC are expected to be greater than the rates of SOC gains following the reverse LMC. However, this effect is highly dependent on the relative SOC amount at the time of the LMC. Documenting the SOC at the time of all LMCs is currently impossible. Consequently, to ensure transparency and simplicity, the reversibility assumption was imposed, whereby the SOC effect of an LMC in one direction is exactly the negative of the SOC effect of the same practice in the opposite direction.

Area-Based Soil Carbon Factor Validation – Tillage and Crop Mixtures

SOC change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). This showed that the empirical data comparing the SOC change between IT and NT were highly variable, particularly for Eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. The mean IT-NT factor derived from experiments in the Sub-humid Prairies reporting zone was over four times the value for the Semi-arid Prairies reporting zone. The mean Century model-derived factor for the Semi-arid Prairies reporting zone was similar to the factor derived from the field experiments. However, the Century-derived IT-NT factor for the Subhumid Prairies reporting zone was about 30% lower than the factor derived from the field experiments.

The mean empirical factor for the switch from annual to perennial cropping was 0.59 Mg C ha^{-1} per year, which compares favourably with the range of 0.46–0.56 Mg C ha^{-1} per year in the modelled factors for the Parkland, Semi-arid Prairies and West zones (Table A6.5–4). In Eastern Canada, only two empirical change factors were available for the East Central zone, but they appeared to be in line with the modelled values (0.60–1.07 Mg C ha^{-1} per year empirical versus 0.74–0.77 Mg C ha^{-1} per year modelled).

Figure A3.5–12 **Carbon Factors as a Function of Time**



Crop Productivity / Crop Residue C Inputs

Grain yields of major field crops in Canada have increased steadily since 1970 (Figure A3.5–13). The accurate estimation of crop productivity and quantification of crop residue C input on SOC storage at a regional or national scale over time relies on the use of spatiotemporal C input data. Estimating crop productivity / crop residue C input requires information on net primary productivity (NPP) and the proportion of NPP returned to the soil (Bolinder et al., 2007). NPP, measured as aboveground and belowground plant biomass, is calculated using crop yield information. Fan et al. (2017) analyzed the harvest index and crop yield for 11 major crops from published field studies in temperate regions and found significant linear relationships between harvest index and crop yield for wheat, maize, oats, barley, peas, chickpeas, lentils, soybeans, canola, and flax (r^2 = 0.19–0.65). These relationships between harvest index and crop yield were then used to develop estimates of crop residue inputs. For other crops, crop residue C is estimated using allocation ratios for grain, straw and roots from Janzen et al. (2003) and Thiagarajan et al. (2018). All of the C from both shoots and roots, on a dry matter basis is considered as a C input to the soil.

Crop residue C input is estimated using annual crop yield, considering the removal of crop residues by field burning and baling for each field crop as follows:

Equation A3.5–6

$$CRC_i = \sum (CRC_AGR_{TC,i} + CRC_BGR_{TC,i}) \,/\, T_AREA_i$$

where:

CRC_i = crop residue C input estimated for all annual crops in ecodistrict i, Mg C ha^{-1} yr^{-1}

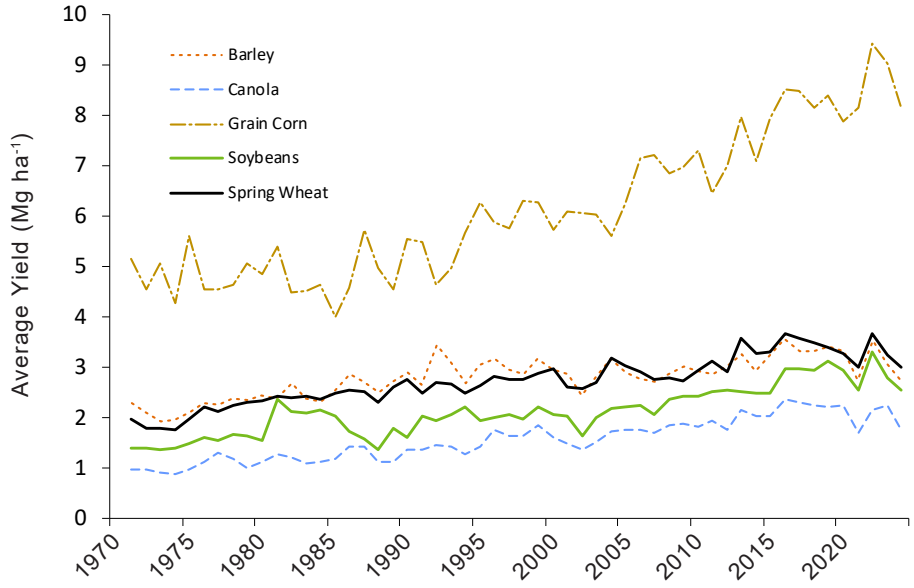
$CRC_AGR_{TC,i}$ = total above-ground (AGR) crop residue C from crop type (TC) in ecodistrict i, Mg C

$CRC_BGR_{TC,i}$ = total below-ground (BGR) crop residue C from TC in ecodistrict i, Mg C

T_AREA_i = total area of annual crops, including summerfallow, in ecodistrict i, ha

For major field crops, the harvest index is estimated by using a linear relationship with grain yield as reported by Fan et al. (2017).

Figure A3.5–13 **Average Yields of Major Field Crops Grown in Canada from 1970 to 2024**



Note:
Data source: Statistics Canada, 2023, Table 32-10-0359-01: Estimated areas, yield, production, average farm price and total farm value of principal field crops.

Equation A3.5–7

$$HI_{TC} = YIELD_{TC,i} \times \left(1 - \frac{MC_{TC}}{100}\right) \times SLOPE_{TC} + INTERCEPT_{TC}$$

HI_{TC} = harvest index for crop type (TC), %
$YIELD_{TC,i}$ = grain yield for TC in ecodistrict i, Mg ha^{-1}
MC_{TC} = moisture content of grain yield for TC, %
$SLOPE_{TC}$ = linear regression coefficient for TC as specified in Fan et al. (2017)
$INTERCEPT_{TC}$ = intercept for TC as specified in Fan et al. (2017)

The dry matter portions of the above-ground residues and roots of major field crops are estimated using the harvest index and root-shoot ratio (Fan et al., 2017). For minor field crops, the dry matter portions of grain, above-ground residue and roots are calculated using the method proposed by Janzen et al. (2003).

Equation A3.5–8

$$CRC_AGR_{TC,i} = \left[\left\{\sum PROD_{TC,i} \times \frac{PROD_{p,TC}}{\sum_{TC}(YIELD_{TC,i} \times AREA_{TC,i})}\right\} \times \left(1 - \frac{MC_{TC}}{100}\right) \times \frac{100}{HI_{TC,i}} \times \{1 - (BALE_{TC} \times 0.5 + BURN_{TC})\}\right] \times 0.45$$

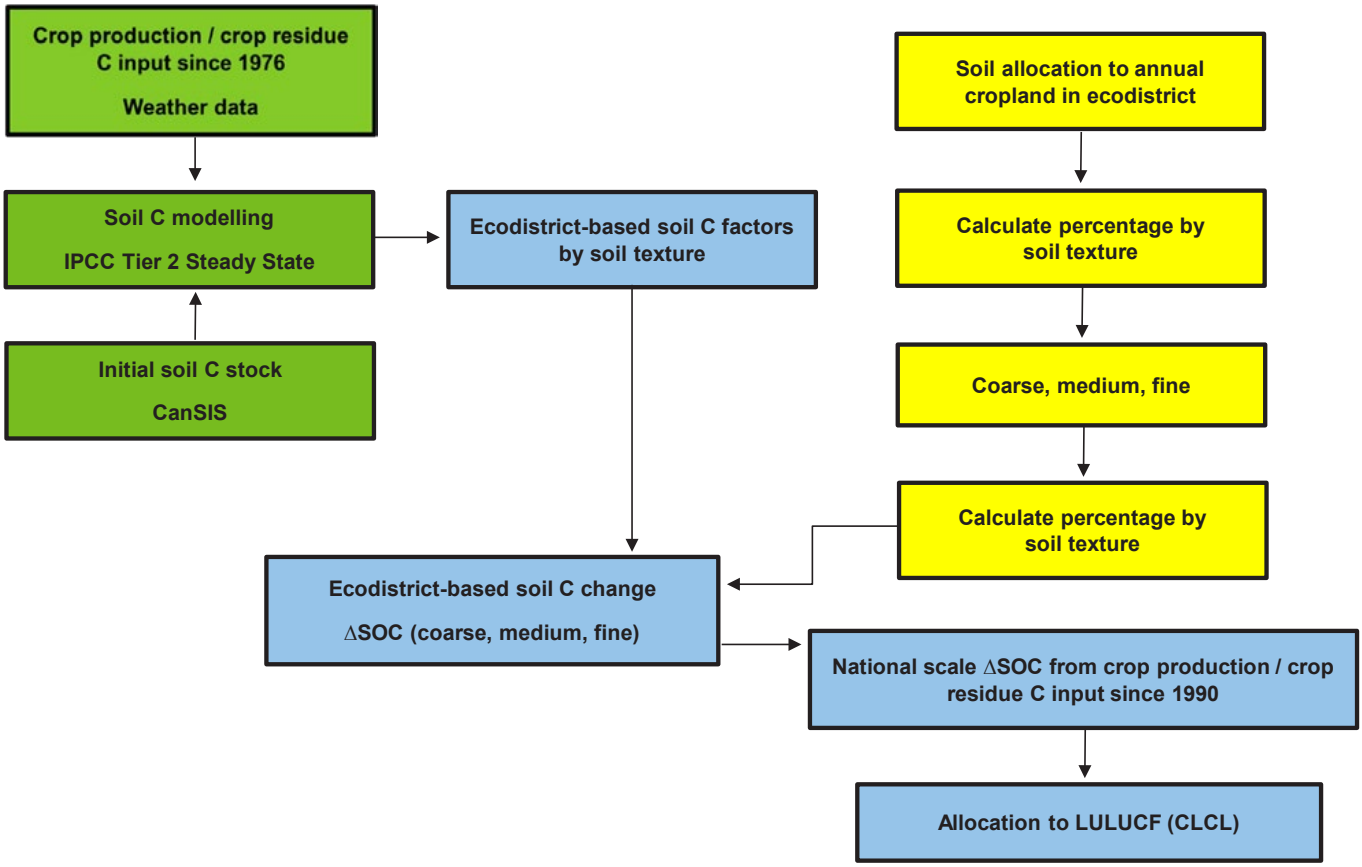
$$CRC_BGR_{TC,i} = \left[\left\{\sum PROD_{TC,i} \times \frac{PROD_{p,TC}}{\sum_{TC}(YIELD_{TC,i} \times AREA_{TC,i})}\right\} \times \left(1 - \frac{MC_{TC}}{100}\right) \times \frac{100}{HI_{TC,i}} \times RSR_{TC}\right] \times 0.45$$

$CRC_AGR_{TC,i}$ = above-ground crop residue C for crop type (TC) in ecodistrict i, Mg C
$CRC_BGR_{TC,i}$ = total below-ground (BGR) crop residue C from TC in ecodistrict i, Mg C
$PROD_{TC,i}$ = total grain production for TC in ecodistrict i, Mg
$PROD_{p,TC}$ = total grain production for TC in province p, Mg
$\sum_{TC}(YIELD_{TC,i} \times AREA_{TC,i})$ = estimated grain production using average yield and seeded area for TC in ecodistrict i, Mg
MC_{TC} = moisture content of grain for TC, %
$HI_{TC,i}$ = harvest index for TC in ecodistrict i, %
$BALE_{TC}$ = baling of crop residues for TC, assuming 50% baling efficiency, fraction
$BURN_{TC}$ = field burning of crop residue for TC, fraction
RSR_{TC} = root to above-ground crop residue ratio for TC, fraction (Thiagarajan et al., 2018)
0.45 = fraction of C in crop residue

SOC Change Factors

The 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019) provides a Tier 2 Steady State approach for estimating the change in SOC as impacted by crop productivity on land in the Cropland Remaining Cropland subcategory (IPCC, 2019). This approach considers three conceptual C pools (active, slow, and passive) in the top 30 cm soil. Decomposition is driven by decay rates that depend on temperature and soil moisture. Soil texture and tillage practices alter the decomposition of the active and slow C pools. Ogle et al. (2012) provide a more detailed discussion of this model. The approach used in the IPCC Tier 2 steady state method requires the lignin and N content of the C inputs (IPCC, 2019). The model is initialized using the first 10-year C inputs as recommended in the IPCC guidelines (IPCC, 2019). The initial average soil C stocks for model initialization were extracted from the National Soil Database[8] (NSDB, Version 3.2) for the dominant soil series in each textural class by ecodistrict. Figure A3.5–14 provides a schematic representation of the procedures for estimating soil C changes as impacted by crop productivity / crop residue C input. Previously, a quality control procedure replaced carbon inputs above the 80th percentile with annual mean values. This procedure has now been removed to fully conserve the C inputs and enhance the accuracy of the SOC emission and removal estimates.

Figure A3.5–14 **Schematic Representation of Procedures for Estimating Soil Organic Carbon Changes as Impacted by Crop Productivity / Crop Residue Carbon Input**



Notes:
CLCL = Cropland Remaining Cropland
SOC = soil organic carbon

8 Available online at: https://sis.agr.gc.ca/cansis/nsdb/index.html.

The IPCC Tier 2 Steady State approach was applied to Canadian soils to calculate a factor used to estimate the change in soil C associated with crop productivity. The change in SOC is calculated by applying a ΔSOC factor weighted by the proportions of textural classes in each ecodistrict to the total area in the ecodistrict for each consecutive year from 1976 to current inventory year. The total C change in an ecodistrict is then generated by summing SOC change values across all the textural classes present in the ecodistrict (Equation A3.5–9).

Equation A3.5–9

$$\Delta SOC_{t,i} = \sum\{(SOC_{t,TX,i} - SOC_{t-1,TX,i}) \times TF_{t,i,TX}\} \times T_AREA_{t,i}$$

$\Delta SOC_{t,i}$ = change in soil organic carbon (SOC) in ecodistrict i, and year t, Mg C

$SOC_{t,TX,i}$ = SOC stock associated with soil texture class (TX) in year t and ecodistrict i, Mg C ha^{-1}

$SOC_{t-1,TX,i}$ = SOC stock associated with soil TX in year t-1 and ecodistrict i, Mg C ha^{-1}

$TF_{t,TX,i}$ = soil texture fraction in coarse, medium and fine, TX in ecodistrict i and year t, fraction

$T_AREA_{t,i}$ = total area of annual crops, including summerfallow, in ecodistrict i and year t, ha

Owing to the lack of certainty surrounding the actual C stocks and to maintain consistency with the other C factors, the method only reports the change in fluxes of C since 1990, consistent with the area-based factor approach. The period from 1976 to 1989 is considered the baseline reference, and the mean change in C stocks resulting from the change in crop productivity (ΔC_{CP}) values relative to the reference period are then added to the ΔC_{LMC} values.

Manure Application

The application of animal manure on agricultural soils can increase SOC storage, particularly soils used for annual crop production. The manure-induced C retention (MCR) factor represents the average fraction of C input from various manures that is retained in the soil. This factor was established based on the measurements taken in multiple long-term studies. A country-specific method using MCR values is proposed to estimate the change in the soil C sink resulting from the application of manure to cropland soils in Canada. Eight field studies using various types and rates of manure application on different crop rotations, with durations varying from 10 to 74 years, were used to quantify MCR values under different climatic conditions in Canada. Solid cattle and swine manure had an MCR value of 26%, whereas the MCR value for liquid manure, including that from swine and cattle, was much lower, at only 5%. Compared with stockpiled manures, composted manure had a higher MCR (36%) due to the additional stabilization of C during the composting process (Liang et al., 2021). The use of individual MCR values for different manure types (Table A6.5–6) provides a sound approach to quantifying changes in soil C storage resulting from manure applications at a regional or national scale. According to the study by Liang et al. (2021), this approach is more accurate for Canadian conditions than the IPCC default ratio factors, which use a qualitative measure of manure input (IPCC, 2006).

Other variables required for estimating soil C storage from manure application include livestock populations, manure N excretion, and manure N losses during storage and handling (ammonia volatilization and N leaching). These data are consistent with those used in the estimation of emissions reported in the Enteric Fermentation and Manure Management categories in the Agriculture sector (see Annex 3.4). The amount of C in the manure was estimated using C:N ratios compiled in the literature review (Table A6.5–5).

Equation A3.5–10

$$\Delta C_{ManureC} = \sum(ManureN_{T,AWMS,i} \times CN_{T,AWMS}) \times MCR_{T,AWMS}$$

$\Delta C_{ManureC}$ = amount of soil C gain from manure application, kg C ha^{-1} yr^{-1}

$ManureN_{T,AWMS,i}$ = amount of manure N applied in ecodistrict i, for livestock type (T) and animal waste management system (AWMS) on annual crop, kg N ha^{-1} yr^{-1}

$CN_{T,AWMS,i}$ = C:N ratio of applied manure for T and AWMS, unitless, as specified in Table A6.5–5

$MCR_{T,AWMS}$ = manure-induced C retention for T and AWMS, fraction, as specified in Liang et al. (2021)

Estimates of Change in Soil Carbon Stocks

SOC changes as a result of LMC were reported for all inventory years since 1990. Because the effect of an LMC declines over time, the time period when the change was deemed to have occurred is maintained for each LMC. The C change factor was multiplied by the area of the LMC or management activity and summed across the soil components to produce the estimated SOC change for the SLC polygon. The SLC polygon is the smallest georeferenced unit of SOC stocks and SOC stock changes calculated using a country-specific approach:

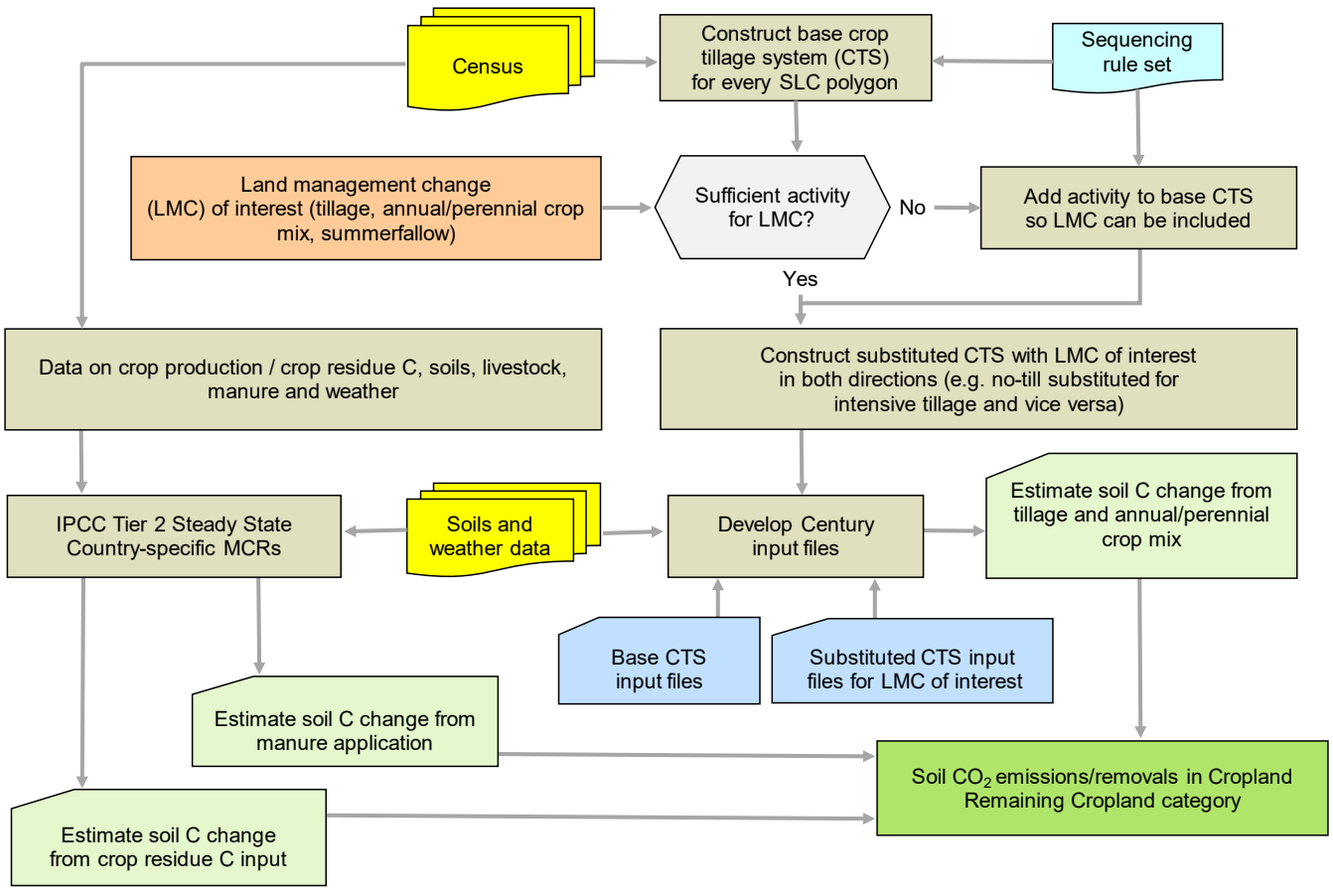
Equation A3.5–11

$$\Delta C_{LMC} = \sum_{1990-n} \sum_{ALLSLC} (\Delta C_{TILL} + \Delta C_{CP} + \Delta C_{CROPPING} + \Delta C_{ManureC})$$

ΔC_{LMC} = change in SOC stocks due to LMC for a specific year after 1990 until year n (latest inventory year)
$ALLSLC$ = all SLCs that contain land under cropland management practices
ΔC_{TILL} = change in SOC stocks due to change in tillage practices in each SLC since each particular tillage change
ΔC_{CP} = change in SOC stocks due to the change in crop productivity / crop residue C in each SLC
$\Delta C_{CROPPING}$ = change in soil C stocks due to the change in annual and perennial crops in each SLC
$\Delta C_{ManureC}$ = change in soil C stocks due to the change in manure application in each SLC

Figure A3.5–15 provides a schematic diagram of C change estimation methods.

Figure A3.5–15 **Method of Using Area-Based and Input-Based Factors for Land Management Change to Estimate Carbon Change in Canada**



Note:
MCR = manure-induced C retention

Data Sources

Carbon stock change estimates rely on C factors and a time series of land management data in the COA. Two types of data are used in deriving C factors (modelling) or calculating actual soil C stock change estimates. The main data used for modelling C factors include information from the SLC database, data on crop-tillage systems derived from the COA, crop yields, climatic data and activity data from other surveys and databases. Data on land management practices from the COA are the main inputs used in estimating annual soil C stock changes.

Land Information and Activity

The SLC is a national-scale spatial database describing the types of soils associated with landforms, displayed as polygons at a representation scale of 1:1 million.[9] The SLC was chosen for the LULUCF inventory because of its national scope and standardized structure, which ensures that all areas of the country are treated consistently regarding inventory assessment procedures. The current version of the SLC in the NSDB data holdings is version 3.2; in this version, the coverage of soil attributes information is restricted primarily to the agricultural areas of Canada. In instances where agricultural land was mapped outside the coverage of SLC v3.2, soil attributes information was extracted from SLC version 2.2, which is older but covers all soils in Canada. All SLC polygons are nested within the 1995 National Ecological Framework, making it possible to scale up or scale down data and estimates, as required.

In all provinces within the Canada's agricultural ecumene, detailed soil survey information at map scales greater than 1:1 million was used to delineate the SLC polygons and compile the associated database files. The SLC Component Soil Names Tables and Soil Layer Tables provided specific input data, including soil C content, soil texture, pH, bulk density and soil hydraulic properties for modelling C factors with Century. The SLC polygon provides a spatial basis for allocating land management practices. COA provides information on tillage practices and cropping systems and is used for estimating the land area associated to cropland converted from forest and grassland—to modelled C factors. The estimated areas of cropland and other land-use practices in each SLC polygon were derived from EO-based maps for 1990, 2000, 2005, 2010, 2015 and 2020.

Analysis Units

There are 3475 SLC polygons in which agricultural activities occur. Since the SLC polygons have several soil landscape components, the finest spatial resolution for the analysis of agricultural activities in SLC polygons results in 13 771 unique combinations of soils, landforms and slope positions. These unique combinations represent the basic analysis units. The locations of land management types and soil components are not spatially explicit but instead are spatially referenced to SLC polygons.

A procedure was developed to assign agricultural activities to the SLC polygons based on the suitability of each component of a soil polygon. The soil components have different inherent properties that make them more or less likely to be used for specific types of agricultural activities. Each soil component in the SLC attribute file has a suitability rating of high, moderate or low in terms of its likelihood of being under annual crop production. In this way, annual crop production is linked to those soils with a high rating. If the area with a high likelihood of being under annual cropland is insufficient to be linked to annual crop production, the remaining annual crop production will be assigned to components with a moderate likelihood of being under annual crop production and, if required, to low-ranked components. After the annual crop production area was assigned, perennial forages and seeded pasture area were linked to the remaining components in the same manner, starting with components with the highest likelihood of being under annual crop production and ending with components with the lowest likelihood of being under annual crop production.

Crop Yields

Crop yields at the ecodistrict level were developed from annual surveys conducted by Statistics Canada. Involving as many as 31 000 farmers, these surveys are stratified by region, and are used to compile estimates of the area, yield, production and stocks of the principal field crops grown in Canada. Several publications are released at strategic points in the crop year. Yields and levels of production by province are estimated twice, the first time in July based on expectations to the end of harvest and the second time, in November, after the harvest. The data are released at the small area data (SAD) region level, providing crop yields for approximately 70 spatial units in the country. SAD region boundaries were overlaid on SLC boundaries in a GIS, and a yield value for each crop in each soil polygon was assigned based on a majority rule. Data used to calibrate the Century crop growth sub-model for arriving at area-based factors included 1975 to 2004 yield data for wheat, barley, oats, corn, soybeans, potatoes and canola. Data used for crop C input modelling included all crop yield data since 1976. When crop yields were not available at the SAD region level, provincial yield statistics were used instead. Statistics Canada SAD yields for seven major crops; barley, canola, corn, flaxseed, soybeans and wheat were refined using vegetation indices to account for different growing conditions within SLC polygons using linear relationships between indices and SAD crop yields (Liu et al., 2020; Mkhabela et al., 2011).

9 Available online at http://sis.agr.gc.ca/cansis.

An improved crop-yield workflow is implemented, integrating three supplementary data sources into a single harmonized yield dataset: (i) Enhanced Vegetation Index 2 (EVI2) adjusted Earth Observation (EO) yields, which provide spatially explicit corrections for regional yield anomalies beginning in 1985 and refined through progressively improved Moderate Resolution Imaging Spectroradiometer (MODIS) and Google Earth Engine (GEE) routines; (ii) Environmental Policy Integrated Climate (EPIC) model yields for alfalfa, improved and unimproved pasture (Williams et al., 1989), produced from spatially explicit crop growth simulations across SLC polygons, enhanced through updated weather files; and (iii) provincial crop insurance yields, providing field-validated estimates for a subset of Prairie crops and harmonized to SLC boundaries through a series of quality checks. These three data sources are merged with Statistics Canada provincial yields aligned to Census production totals.

The amount of crop residue C that is returned to the soil at an ecodistrict scale since 1976 was quantified annually based on crop production data (Statistics Canada, 2020). Information on the baling of residues from various field crops is collected by Statistics Canada, through its Farm Environmental Management Survey (FEMS). Data on the field burning of crop residues are also available (see section A3.4.7).

Climatic Data

The database maintained by Agriculture and Agri-Food Canada (AAFC) contains 958 weather stations (2021). Long-term normals for monthly maximum and minimum temperatures (T, ºC) and precipitation (mm) from 1951 to 2000 for all ecodistricts were used for the area-based modelling of C factors. For input-based models, the Environment and Climate Change Canada (ECCC) weather database (1981 to 2010) was used to ensure consistency with the climate parameters in the N estimation methodology. Application of the IPCC Tier 2 methodology also required T_{max}, T_{min}, T_{avg}, precipitation and potential evapotranspiration (PET) data. AAFC-archived weather data were provided by ECCC's Meteorological Service of Canada.

Earth Observation and the *Census of Agriculture* (COA)

Activity data for C stock estimation in the Cropland Remaining Cropland category rely mainly on a combination of data from the COA and area estimates based on EO analyses. The COA is conducted every five years to develop a statistical portrait of Canada's farms and agricultural operators. For confidentiality reasons, the smallest area for which Statistics Canada externally releases data from the COA is the dissemination/enumeration area level (of which there are approximately 52 000 in Canada). To provide a biophysical basis for modelling, data at this level were attributed to the SLC polygons (McConkey et al., 2007a).

EO-based mapping data were used to provide area estimates of all land-use practices within each of the agricultural SLC polygons in Canada. Land-use maps based on EO information were generated for 1990, 2000, 2005, 2010, 2015 and 2020 (Huffman et al., 2015a; AAFC, 2021). SLC polygons were used as the level of spatial stratification and data were compiled in seven primary land cover classifications: cropland, grassland, forest, settlements, wetlands, water, and other land cover. From 1990 to the latest inventory year, annual estimates of land-use areas were generated by interpolating between EO years and extrapolating beyond the last year of coverage. Agricultural land-use estimates prior to 1990 were obtained using COA data and relative changes in cropland and grassland areas between census periods. Land-use estimates for 1981 were calculated by determining the relative change in agricultural land use from 1991 and 1981 census data and applying this change to the 1990 EO data. Then, moving progressively back through the periods between census years, the relative changes were used to generate agricultural land-use estimates back to 1951. To minimize the spatial variability associated with known issues involving the reporting of land-use areas based on farm headquarters, the relative change in land-use estimates was calculated at the ecodistrict scale and applied to all nested SLC polygons.

The EO-based cropland attributes were estimated using ratios of cropland area attributes to total cropland area from the COA. To reduce the differences between the EO-based and census-based estimates of provincial crop areas, EO cropland categories (i.e., cropland, pasture, orchards and vineyards) were reconciled using provincial scaling factors. Reconciliations were constrained by the total area of agricultural land within SLC polygons, as interpreted through EO analysis. Data on tillage management practices were taken from the COA in the following categories: IT (tillage that incorporates most of the crop residue in the soil); RT (tillage that retains most of the crop residue on the surface); and NT (no-till seeding or zero-till seeding). For summerfallow, the following tillage categories were used: NT (the area on which chemicals were exclusively used for weed control); IT (the area on which tillage only was used); and RT (the area on which a combination of tillage and chemicals were used). More details on the methodological approach used to create EO-based agricultural activity data are provided in Cerkowniak (2019).

Uncertainty

The derivation of uncertainties associated with estimates of CO_2 emissions and removals requires estimates of uncertainties for LMC areas and the C factors associated with changes in tillage and annual/perennial crops (McConkey et al., 2007b). The uncertainty described in this report is based on the 2014 submission methodology and has not yet been updated for the new EO methodology.

The uncertainty surrounding the area of change was determined for ecodistricts. The average area of agricultural land within an ecodistrict is about 140 kha, i.e., large enough that the areas of different management practices were considered independent of those in others, including adjacent ecodistricts. Errors in the areas of management practices in each ecodistrict were assumed to represent inherent uncertainty that was unaffected by the uncertainty of those in other ecodistricts. Furthermore, the ecodistrict area is large enough that a null report for an activity can be assumed to mean that the activity is not occurring within the ecodistrict. Therefore, the uncertainty over area can be more for an ecodistrict than for an SLC polygon when considered in relative terms.

The uncertainty surrounding the area of a management practice in an average ecodistrict at a given time was based on the relative proportion of the area of that management practice in the ecodistrict. The relative uncertainty of the area of a management practice expressed as the standard deviation of an assumed normal population decreased from 10% of the area to 1.25% of the area as the relative area of that practice increased (McConkey et al., 2007b).

The uncertainties associated with C change factors for fallow, tillage and annual/perennial crops were assumed to arise from two main sources: (1) the process uncertainty associated with C change due to inaccuracies in predicting C change even if the situation of the management practice was defined perfectly; and (2) the situational uncertainty associated with C change due to variation in the situation of the management practice.

Process uncertainty includes the effect of uncertainty in the model. This includes the uncertainty in the model predictions due to uncertain model parameters and the inaccurate and/or incomplete representation of all relevant processes by the model. When empirical data are used, process uncertainty includes inadequacies in measurement techniques, analysis error, poor representativeness of measurements, and failure to measure components of C change. To estimate the process error, the variation from measured C change values in controlled experiments was used. It was assumed that this represents the inherent uncertainty even when the situation is accurately described. Process uncertainty scaling coefficients for tillage and fallow were derived for Canada from VandenBygaart et al. (2003).

Situational uncertainty derives from the inability to accurately describe each situation. This includes the effect of interactions with past or concurrent changes to land use or land management and variability in the weather, soil properties, crop management and LMC continuity. The situational uncertainty scaling coefficients for fallow change, tillage change and annual perennial crop change were estimated based on the observed variability of Century-simulated C change for all soil component–management–climate combinations within the RU. C change was calculated for many management combinations. In addition, a range of historical ecodistrict weather data was included in the Century simulations. The situational uncertainty also includes the additional variability of the regional factors introduced by the imposition of C change reversibility. Average situational uncertainty scaling coefficients were derived for Canada (McConkey et al., 2007b).

Although process and situational uncertainty are expected to interact, describing their relationship is not feasible given the complexity resulting from the large number of possible interactions between deviations due to process uncertainty and to situational uncertainty. Hence, it was assumed that the total deviation in total C change was the sum of the deviations resulting from process and situational uncertainty. Details of uncertainty estimate development are provided in McConkey et al. (2007b). The results of this analysis are outlined in section 6.5.1.

A formal uncertainty analysis has not yet been carried out for the estimates of cropland C change associated with changes in crop yield. However other soil C models of varying complexity (i.e., Rothamsted carbon model [RothC], Introductory Carbon Balance Model [ICBM)] and Campbell model) that can use measured yields as C inputs in simulations were tested in the national C assessment analysis. These models were also used for simulations of SOC, with a varying degree of success relative to field observations (Thiagarajan et al., 2022). Estimates of national C change varied from a loss of 5.4 Mt C in 1990 to a gain of 4.4 Mt C in 2020 with the Campbell model, and gains of 9.9 Mt C and 38.5 Mt C in 1990 and 2020, respectively, with the ICBM model. To provide comparability among Annex 1 Parties, the IPCC Tier 2 approach is used for estimating the change in SOC as impacted by crop productivity / crop residue C input at the ecodistrict, RU and Canada-wide spatial scales. The results of this approach were observed to be roughly equivalent to the mean of the other models, suggesting that it provides estimates within the bounds of what has been typically observed in other studies, as represented by the default parameters in existing soil C models.

Similarly, a formal uncertainty analysis has not been conducted on the estimation of cropland C change resulting from manure application, although uncertainty estimates associated with field measurements of MCRs are available: ±30% for solid swine and cattle manure, ±13% for swine manure compost, and ±330% for liquid swine and cattle manure. Discussions of the uncertainties associated with livestock types, populations, and manure excretion as well as the C:N ratio in various types of manures can be found in sections A3.4.1, A3.4.3 and Table A6.5–5 respectively.

CO_2 Emissions and Removals from Woody Biomass

Estimates of emissions and removals from woody biomass on croplands include those originating from trees and shrubs on agricultural land as well as in vineyards, fruit orchards and Christmas tree plantations. A remote sensing-based sampling approach was used to determine areas of trees and shrubs during the reporting period, while the COA provided estimated areas of vineyards, fruit orchards and Christmas tree farms.

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yields. Vineyards are pruned each year, leaving only the trunk and one-year-old stems. Similarly, fruit trees are pruned annually to maintain the desired canopy shape and size. Old plants are replaced on a rotating basis for disease prevention, stock improvement or introduction of new varieties. Typically, Christmas trees are harvested at about 10 years of age. For all three crops, it was assumed that, because of these rotational practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass C in existing farms, since the C lost from harvest or replacement would be balanced by gains due to new plant growth. The approach was therefore limited to detecting changes in areas under vineyards, fruit orchards and Christmas tree plantations and estimating the corresponding C stock changes in total biomass.

There are no Canadian studies on above-ground or belowground C dynamics in vineyards or fruit orchards. However, results from other studies are considered valid, since the varieties, field production techniques and even root stocks are often the same. Canadian literature on Christmas tree plantations is used whenever suitable.

On average, vines are replaced at 28 years of age; the average vine is therefore 14 years old (Mailvaganam, 2002). Because of intensive pruning, linear rates of aboveground and belowground biomass accumulation in trunks and roots were established at 0.4 and 0.3 Mg ha^{-1} yr^{-1}, respectively (Nendel and Kersebaum, 2004). These were converted to C values using a 50% C content in biomass. Upon a decrease in vineyard areas, an instantaneous loss of 4.9 Mg C ha^{-1} is assumed, equal to the average standing biomass for 14-year-old vines (McConkey et al., 2007a).

Because of different standard planting densities, the range of standing biomass per area for apple and peach orchards varied narrowly between 36 and 40 Mg ha^{-1} (McConkey et al., 2007a). This similarity is expected since, regardless of tree size and planting density, the tree shapes and canopies are manipulated to maximize net photosynthesis per area. The annual rate of C sequestration was calculated over a 10-year growth period at 1.6 Mg C ha^{-1} yr^{-1}. The same rate, multiplied by a root-to-shoot ratio of 0.4 (Bartelink, 1998), was used to estimate C sequestration in belowground biomass. Instantaneous C loss upon a decrease in orchards was equal to 50% of the total biomass of a 10-year-old tree (22.4 Mg C ha^{-1}).

Christmas trees are marketed at about 10 years of age (McConkey et al., 2007a). With a root-to-shoot ratio of 0.3 (Bartelink, 1998; Litton et al., 2003; Xiao and Ceulemans, 2004), the total C biomass of a marketable tree plantation is estimated at 11.1 Mg C ha^{-1}. Carbon sequestration in the biomass of new Christmas tree plantations is calculated at five years at rates of 0.85 and 0.26 Mg C ha^{-1} for above-ground and below-ground biomass, respectively. A decrease of plantation area would result in the immediate loss of 5.6 Mg C ha^{-1}.

Trees and shrubs on agricultural land include perennial woody cover types in farmyards, shelterbelts and hedgerows. Carbon storage in woody biomass in the landscape changes over time as trees and shrubs grow and die; areas of land with woody biomass change due to planting or colonization of cropland areas; or tree clearing takes place.

The EO-based sampling approach used to quantify changes in woody biomass on Canadian croplands was developed by Huffman et al. (2015b). Briefly, the National Ecological Framework (Marshall et al., 1999) was used to develop a spatially stratified, random sampling approach, with 30 sample sites per ecozone targeted as the objective. High-resolution historical aerial photos from the National Air Photo Library of Natural Resources Canada and from provincial databases were selected to digitize the land cover of tree and shrub in 1 km^2 or 4 km^2 plots at circa 1990, circa 2000 and circa 2010 at a 1:10000 scale. The “trees” land cover class was defined as having less than 25% crown closure and occupying less than 1 ha. The “shrubs” land cover class represents non-agricultural woody plants that would not be expected to meet the forest or “trees” definition when mature. Wood volume yield estimates for each ecozone were derived based on published literature and consultations with provincial forestry and agriculture specialists, conservation associations and researchers in academia. Overall, estimates of above-ground wood volume ranged between 99.3 and 181.7 m^3 ha^{-1} across ecozones and estimates of mean annual increments, between 1.2 and 3.8 m^3 ha^{-1} yr^{-1}. With the addition of a new data set in 2020, the growth, loss and gain in the biomass of trees and shrubs (in tonnes of C) were calculated for two time periods: 1990-2000 and 2000-2010 in croplands. An interpolation splicing technique from the 2006 IPCC Guidelines is applied to the transition between the two time periods to improve smoothness of the time series. The analysis, coefficients and parameters used to estimate C stock changes were based on the methodology described by Huffman et al. (2015b) for both time periods.

An analysis of firewood production suggested that agricultural lands serve as an important source of fuel for residential bioenergy production in Canada (Doyon et al., 2019). A portion of the tree biomass lost from cropland was therefore transferred to the HWP pool as firewood input to meet regional residential bioenergy requirements (see section A3.5.3) at the RU level. Furthermore, in RUs where there is a shortage of HWP for use as firewood, the missing tree biomass is assumed to be supplied from neighboring RUs. The C transferred from woody biomass is reported in the Cropland Remaining Cropland category as a flux to HWP.

Uncertainty

Orchards and vineyards with poor growth are regularly removed and replaced, and fruit trees and vineyards are often irrigated to maintain desired growth during dry periods. Consequently, the variability in C stock changes should be less than that for other agricultural activities.

In the case of loss of area, all C in woody biomass is assumed to be immediately released. There are no Canadian-specific data on the uncertainty surrounding vineyards, orchards and Christmas tree plantations. Therefore, the default uncertainty from the 2006 IPCC Guidelines of ±75% for woody biomass on cropland was used for these land cover types. The error propagation approach described in Huffman et al. (2015b) was applied to trees and shrubs. Although the loss in area of fruit trees, vineyards or Christmas tree farms is estimated to have been replaced by annual crops, a perennial-to-annual crop conversion is also deemed to occur, with an associated C change uncertainty that contributes to the overall C change uncertainty for a reporting zone.

Cultivation of Organic Soils

The cultivation of histosols for annual crops and perennial forage production usually involves drainage, tillage and fertilization. All these practices increase SOC decomposition and thus the release of CO_2 to the atmosphere.

Methodology

The IPCC Tier 1 methodology is based on the rate of C released per unit land area:

Equation A3.5–12

$$C = \sum (A_p \times EF)$$

C = C emissions from cultivation of organic soils (Mg C yr^{-1})

A_p = area of organic soils that is cultivated for annual crop and perennial forage production in province p, ha

EF = C emission factor, Mg C loss ha^{-1} yr^{-1}—the default emission factor of 7.9 and 5.7 Mg C ha^{-1} yr^{-1} was used for annual crop and perennial forage crops, respectively (IPCC, 2014)

Data Sources

The COA does not provide information on areas of cultivated histosols by province. In the absence of these data, consultations were undertaken with numerous soil and crop specialists across Canada. Based on these consultations, the total area of cultivated organic soils in Canada was estimated to be 50 kha (Liang et al., 2004) with 16 kha used for annual crop production and 34 kha for perennial forage crops.

Uncertainty

The uncertainty associated with emissions from this source is due to the uncertainties surrounding the emission factor and the area estimates for cultivated histosols. A ±50% uncertainty level has been assigned to the 95% confidence limits associated with the area estimate of cultivated histosols, while a ±90% uncertainty level has been assigned to the 95% confidence limits for the emission factor provided in the 2006 IPCC Guidelines (IPCC, 2006). The results of the 2004 consultation identified known areas of organic soils in Canada that were drained and are actively farmed. Recent analyses have suggested that there is significant overlap of regions with organic soils and agricultural activity (Carlson et al., 2017; Rochefort et al., 2022). Further explorations of these analyses are underway, however, there is not a clear link that has been established between the presence of organic soils and active agricultural drainage and exploitation of these soils. It is probable that these soils may be indirectly impacted by agricultural production and drainage, but it is unlikely that the emission factors that are developed in the current guidelines are appropriate for indirect impacts.

A3.5.4.2. Grassland Converted to Cropland

The conversion of native grassland to cropland results in losses of SOC and soil organic nitrogen (SON) and in turn leads to emissions of CO_2 and N_2O to the atmosphere.

Several studies on changes in SOC and SON in grassland converted to cropland have been carried out in the Brown, Dark Brown and Black soil zones of the Canadian Prairies, and their results are summarized by McConkey et al. (2007a).

C stock Change from Biomass

Converting grassland to cropland results in biomass loss from grasslands and biomass gain in croplands during the conversion year. A 100% loss in biomass from grasslands is considered in this conversion. Due to variability in Canadian grassland biomass, a default value of 6.5 t dm ha^{-1} was used as recommended in Chapter 4, Table 6.4 of the IPCC guidelines (2006) and a carbon content value of 0.47 was used according to IPCC Guidelines (2006). For croplands, biomass values were estimated based on grain yields, harvest index, and root-shoot ratios (Fan et al., 2017; Jansen et al., 2003; Thiagarajan et al., 2018). The change in carbon stocks was calculated as the difference between the biomass losses and gains at the spatial scale of the RU.

Losses of Soil Organic Carbon

The average loss of SOC based on field observations was 22% (McConkey et al., 2007a). Many of the studies involved comparisons within 30 years of breaking of the native grassland, whereas others were 70 or more years from breaking. Since many of these studies did not specify the period since breaking, it is assumed that the 22% SOC loss would refer to about 50–60 years after the land was broken.

The SOC dynamics from conversion of grassland to cropland on Brown and Dark Brown Chernozemic soils (Figure A3.5–16) can be estimated with the Century model (Version 4.0). Shortly after breaking, there is an increase in soil organic matter, as the belowground biomass of the grass becomes part of the SOC. After a few years, the SOC declines to less than the amount of SOC that existed under grassland. The rate of SOC decline gradually decreases with time. When the initial SOC increase due to the added C from roots is excluded, the simulated SOC dynamics can be described by the following equation:

Equation A3.5–13

$$\Delta C(t) = \Delta C_{Bmax} \times [1 - exp\{-k \times (t - t_{lag})\}]$$

$\Delta C(t)$	=	change in SOC for the t^{th} year after conversion, Mg C ha^{-1}
ΔC_{Bmax}	=	ultimate change in SOC from grassland to cropland, Mg C ha^{-1}
k	=	rate constant for describing decomposition, yr^{-1}
t	=	time since breaking of grassland, years
t_{lag}	=	time lag before ΔC becomes negative, years

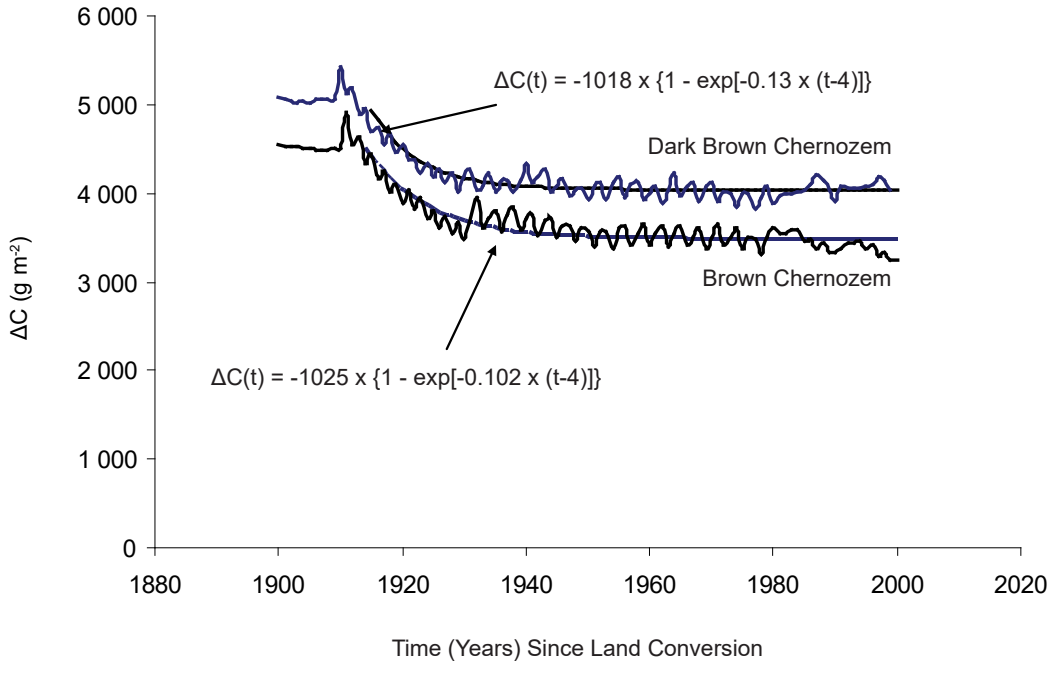
Assuming that the 22% loss at about 50–60 years after initial breaking is the total loss, the ΔC_{Bmax} is 0.22/(1−0.22), or 28% of the stabilized SOC under agricultural land use. Given the uncertainty associated with the actual dynamics, no time lag was assumed to occur in SOC loss from breaking grassland, so that SOC starts to decline immediately upon breaking. With these assumptions, the general equation for predicting SOC loss from breaking grassland becomes:

Equation A3.5–14

$$\Delta C(t) = 0.28 \times SOC_{agric} \times [1 - exp(-0.12 \times t)]$$

$\Delta C(t)$	=	change in SOC for the t^{th} year after conversion, Mg C ha^{-1}
t	=	time since breaking, years
SOC_{agric}	=	0 to 30 cm SOC from the National Soil Database within CanSIS under an agricultural land use (Cropland category), Mg C ha^{-1}

Figure A3.5–16 **SOC Dynamics after the Breaking of Grassland to Cropland on Brown and Dark Brown Chernozemic Soils, Simulated with the Century Model**



Thus, the total losses of SOC in grassland converted to cropland were calculated using an IPCC Tier 2 approach:

Equation A3.5–15

$$\Delta C_{GLCL} = \sum_{1951-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{GLCL})$$

ΔC_{GLCL}	=	losses of SOC in the inventory year n due to conversion of grassland to cropland since 1951 until year n, Mg C
$ALLSLC$	=	all soil polygons that contain grassland conversion to cropland
t	=	time after grassland conversion, years
ΔC_t	=	change in SOC for the t^{th} year after conversion, Mg C ha^{-1}
$AREA_{GLCL}$	=	area of grassland converted to cropland annually since 1951, ha

Losses of Soil Organic N and N_2O Emissions

The change in SON is estimated as a fixed proportion of C losses. Where changes in both SON and SOC were determined, the average change in SON was 0.06 kg N lost/kg C lost (McConkey et al., 2007a). Consequently, N_2O emissions from the conversion of grassland to cropland were calculated using an IPCC Tier 2 approach:

Equation A3.5–16

$$N_2O_{GLCL} = \sum_{1951-n} \sum_{ALLSLC} \sum_{t} (\Delta C_{GLCL} \times AREA_{GLCL}) \times 0.06 \times EF_Base \times RF_SN \times RF_TX \times RF_NSE \times \frac{44}{28}$$

N_2O_{GLCL}	=	emissions of N_2O in year n due to the conversion of grassland to cropland from 1951 to year n, kt
$ALLSLC$	=	all soil polygons containing grassland conversion to cropland
t	=	time after grassland conversion, years
ΔC_{GLCL}	=	change in SOC for the t^{th} year after grassland conversion, Mg C ha^{-1}
$AREA_{GLCL}$	=	area of grassland converted to cropland annually since 1951, ha
EF_Base	=	N_2O emission factor, defined as a function of long-term climate normals (growing season precipitation from May to October at the ecodistrict level) (see section A3.4.5)
RF_SN	=	ratio factor for adjusting the effect of source of N in soil N_2O emissions (see section A3.4.5)
RF_TX	=	ratio factor for adjusting soil texture (TX) effect on soil N_2O emissions (see section A3.4.5)
RF_NSE	=	ratio factor for correcting non-growing season soil N_2O emissions (see section A3.4.5)
0.06	=	ratio of SON to SOC losses
$44/28$	=	coefficient converting N_2O-N to N_2O

Data Sources

The area of grassland reported in the Grassland Remaining Grassland category was estimated using a combination of COA and EO data. Area estimates reported in the Grassland Converted to Cropland category were based on the reconciliation of changes in land area between Grassland Remaining Grassland and land under cropland management. To avoid issues associated with farm headquarters reporting, data were aggregated to the ecodistrict level prior to the land reconciliation process. Estimates of areas of grassland converted to cropland at the ecodistrict level were then apportioned back to SLC polygons.

Within each SLC polygon, areas under Grassland Remaining Grassland were allocated to soil components identified as having a “low” likelihood of being cropped. Soil C data from the National Soil Database were used to calculate an average SOC content for soils in each SLC polygon.

Uncertainty

The conversion of agricultural grassland to cropland occurs, but the reverse does not. The uncertainty associated with the converted area in a given ecodistrict cannot be greater than the uncertainty associated with the final area of cropland or the initial area of grassland. Therefore, the uncertainty associated with the conversion area was assumed to be equal to the uncertainty over the area of land in the Cropland or Grassland category, whichever was lower. The factor scaling coefficient was assumed to be the same as for annual-perennial crop conversions (McConkey et al., 2007b).

A3.5.4.3. Forest Land Converted to Cropland

Emissions of CO_2 and N_2O from Soils

The clearing of forest to increase the area of agricultural land is a declining but still significant practice in Canada. This section describes the methodology for estimating CO_2 and N_2O emissions associated with soil disturbance, while the methodology for estimating emissions from biomass after conversion is presented in sections A3.5.2.1 and A3.5.2.7. For SOC changes, it is necessary to differentiate between Eastern and Western Canada.

Eastern Canada

Many studies have compared SOC values for forested land with SOC values for adjacent land under agriculture in Eastern Canada. The mean C loss was 20.3% for an approximately 0-30 cm depth (McConkey et al., 2007a). This value is comparable to that found in the CanSIS soil database (Table A6.5–12), indicating that, on average, SOC in the uppermost 30 cm of soil under agriculture was 20.5% less than that in soil under forest.

Although SOC values for forested land include the C in the litter layer above the mineral soil, in practice, uncertainty is always involved in quantifying this source of C, as well as the organic C in soil debris (Paul et al., 2002). Soil erosion, which is generally assumed to increase under agriculture, also reduces measured SOC values on agricultural land.

The Century model (version 4.0) was used to estimate the SOC dynamics from forest conversion (Figure A3.5–17). In the first years after conversion, soil organic matter increases as litter and above-ground and below-ground DOM become part of SOC. After a few years, SOC falls below the pre-conversion value that existed before forest conversion. The rate of SOC decline gradually decreases with time.

The following equation was fit to the Century results in Figure A3.5–16, excluding the initial SOC increase:

Equation A3.5–17

$$\Delta C_{(t)} = \Delta C_{Dmax} \times [1 - exp\{-k \times (t - t_{lag})\}]$$

where

$\Delta C_{(t)}$ = change in SOC for the t^{th} year after conversion, Mg C ha^{-1}

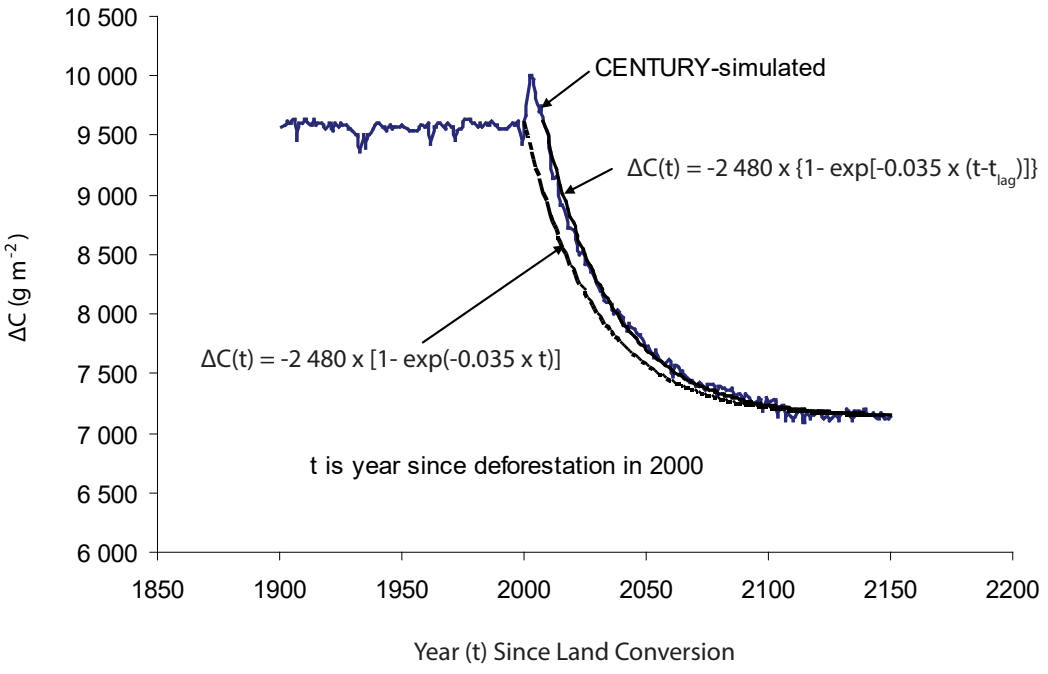
ΔC_{Dmax} = maximum change in SOC from forest conversion to agriculture, Mg C ha^{-1}

k = rate constant describing decomposition, yr^{-1}

t = time since conversion of forest land, years

t_{lag} = time lag before ΔC becomes negative, years

Figure A3.5–17 **Soil Organic Carbon Following Conversion of Deciduous Forest to Cropland, as Simulated by the Century Model**



In simulations of SOC after the conversion of deciduous forest to cropland (Figure A3.5–17), 25% of C losses occur within 20 years of forest conversion and 90%, within 100 years. Given the uncertainty in the actual dynamics, it was assumed that there is no time lag in SOC loss from forest conversion, so that SOC starts to decline immediately upon conversion, i.e. the fitted SOC loss (Figure A3.5–17) is used to estimate SOC loss with the time lag set to 0 after fitting.

The mean SOC loss of 20.5% resulting from forest conversion to cropland in Eastern Canada, based on CanSIS information, was assumed to correspond to the value approximately 100 years after forest conversion. The ΔC_{Dmax} is therefore corrected by a factor of 1/0.927, which assumes that only 92.7% of the C has been lost after 100 years, based on the integration of Equation A3.5–18, resulting in a ΔC_{Dmax} value of 22.1% of SOC under long-term forest. Since the CanSIS soil database has more data on SOC under long-term cropland conditions than on SOC under long-term forest conditions in areas where cropland exists, the maximal SOC losses were calculated relative to stabilized cropland SOC (i.e., loss = 0.221/(1−0.221) × SOC or loss = 0.284 × SOC under agriculture). Therefore, the final equation for estimating SOC loss from forest conversion to cropland in Eastern Canada is:

Equation A3.5–18

$$\Delta C(t) = 0.284 \times SOC_{agric} \times [1 - exp(-0.0262 \times t)]$$

$\Delta C(t)$	=	change in SOC for the tth year after conversion, Mg C ha^{-1}
SOC_{agric}	=	0- to 30 cm SOC for a cropland soil, Mg C ha^{-1}, according to CanSIS
-0.0262	=	rate constant for describing decomposition, yr^{-1}
t	=	time since conversion, years

Thus, the total amount of SOC lost from forest land converted to cropland can be estimated using the following equation:

Equation A3.5–19

$$\Delta C_{FLCL} = \sum_{1970-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL})$$

ΔC_{FLCL}	=	total SOC loss in year n from the conversion of forest land to cropland from 1970 to year n, Mg C ha^{-1}
t	=	time after conversion, year
$ALLSLC$	=	all soil polygons that contain forest land converted to cropland
ΔC_t	=	change in SOC for the tth year after conversion, Mg C ha^{-1} (see Equation A3.5–18)
$AREA_{FLCL}$	=	area of forest land converted to cropland annually since 1970, ha

Note that the SOC loss predicted by Equation A3.5–19 is in addition to C stock changes in the tree biomass and woody DOM present in the forest at the time of forest conversion.

According to field observations, the average N change in Eastern Canada was -5.2%, representing 0.4 Mg N ha^{-1} (McConkey et al., 2007a). For those comparisons where both N and C losses were determined, the corresponding C loss was 19.9 Mg C ha^{-1}, and the C loss was 50 times the N loss. For simplicity, it was assumed that the N loss was a constant 2% of the C loss. Thus, N_2O emissions from the conversion of forest land to cropland are estimated using the following equation:

Equation A3.5–20

$$N_2O_{FLCL} = \sum_{1970-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL}) \times 0.02 \times EF_Base \times RF_SN \times RF_TX \times RF_NSE \times \frac{44}{28} \times 1000^{-1}$$

N_2O_{FLCL}	=	emissions of N_2O resulting from conversion of forest to cropland from 1970 to year n (latest inventory year), kt
$ALLSLC$	=	all soil polygons where forest land conversion occurs
ΔC_t	=	change in SOC for the tth year after conversion, Mg C ha^{-1} yr^{-1}
$AREA_{FLCL}$	=	area of forest land converted to cropland annually since 1970, ha
0.02	=	conversion of C to N
EF_Base	=	base emission factor, defined as a function of long-term climate normals (growing season precipitation from May to October at the ecodistrict level) (see section A3.4.5)
RF_SN	=	ratio factor for adjusting the effect of source of N on soil N_2O emissions (see section A3.4.5)
RF_TX	=	ratio factor for adjusting soil texture (TX) effect on soil N_2O emissions (see section A3.4.5)
RF_NSE	=	ratio factor for correcting non-growing season soil N_2O emissions (see section A3.4.5)
t	=	time after conversion, year
$44/28$	=	coefficient converting N_2O-N to N_2O
1000^{-1}	=	converting from Mg to kt

Western Canada

Much of the current agricultural soil in Western Canada was grassland prior to cultivation. Therefore, the conversion of forest to cropland has primarily involved forest that adjoins grassland areas. There is also limited conversion of secondary forest that has grown on former grassland since the suppression of wildfires with agricultural development. Historically, forest conversion has been less prevalent in Western Canada than in Eastern Canada, and fewer comparisons of SOC under forest and agriculture are available in the literature for this region. Ellert and Bettany (1995) reported no difference in SOC values for native aspen forest and for long-term pasture that had remained uncultivated since it was cleared, on an Orthic Gray Luvisol near Star City, Saskatchewan.

CanSIS data provide numerous comparisons of SOC in forest and cropland soils (Table A6.5–12). On average, these data indicate no loss of SOC from forest conversion. This suggests that, in the long term, the balance between C input and SOC mineralization remains similar under agriculture to what it was under forest. It is important to recognize that the northern fringe of western Canadian agricultural areas, where most forest conversion is now occurring, contains marginal land for annual crops, and pasture and forage crops are the primary agricultural uses after clearing. In general, C loss from forest conversion to agriculture is the lowest where agricultural land contains forages and pastures.

In Western Canada, no loss of SOC over the long term was assumed from the conversion of forest to pasture and forage crops. Therefore, C losses from land conversion in Western Canada would be from losses of C in above-ground and below-ground tree biomass and coarse woody DOM present in the forest at the time of conversion. Similarly, the average organic N change at sites in Western Canada at least 50 years after conversion from grassland to cropland was +52% (McConkey et al., 2007a), reflecting the substantial added N in agricultural systems compared with forests. However, given the uncertainty over actual soil C–N dynamics after conversion, forest land converted to cropland was assumed not to be a source of N_2O from the soil pool. N_2O emissions are reported wherever biomass burning occurs during conversion (see section A3.5.2.1).

Biomass Change

When Forest Land is converted to Cropland, CBM-CFS3 estimates the biomass C stock loss and subsequent emissions or reductions in Forest Lands. The biomass C stock gained after the deforestation event during the conversion year are estimated using Tier 2 country-specific values. For croplands, country-specific biomass values were estimated based on grain yields, harvest index, and root-shoot ratios (Fan et al., 2017; Jansen et al., 2003; Thiagarajan et al., 2018), aligning with SOC methodology. Net emissions or reduction due to biomass changes from deforestation are calculated as the difference between the biomass C stocks in Cropland and Forest Land during the conversion year.

Data Sources

The approach used to estimate the area converted from forest to cropland is described in section A3.5.2.7. The annual area of forest conversion by RU was disaggregated to SLC polygons based on concurrent changes in the area of cropland in SLC polygons. Only polygons that showed an increase in cropland area during the appropriate time period were allocated to forest conversion, and the amount allocated was equivalent to that polygon's proportion of the total cropland increase within the RU.

Uncertainty

The uncertainty associated with C change in each reporting zone was estimated differently for Eastern and Western Canada because of differences in C change estimation methods (McConkey et al., 2007b). For Western Canada, this uncertainty was estimated, despite a mean value of 0 for the C change factor. The assumption was that the uncertainty associated with SOC change after forest land to cropland conversion in Western Canada would follow a similar pattern to that in Eastern Canada.

A3.5.5. Grassland

In Canada, agricultural land reported in the Grassland category is defined as unimproved pasture used for grazing domestic livestock, but only in geographical areas where grassland would not naturally grow into forest if abandoned, i.e., southern Saskatchewan and Alberta and a small area of southern British Columbia. These grasslands developed under millennia of grazing by large animals such as bison, and periodic burning. Essentially, the Grassland category consists of extensively managed native rangeland in Canada. The grassland definition in Canada is bounded by mainly climatic constraints and the boundary is set to regions in which the lands will not convert back to forest if abandoned. When the carbon in grasslands is lost through conversion to other land uses, it is considered a permanent loss of carbon to the atmosphere that is irreversible. This definition of grassland differs from systems that define grassland as any sort of perennial cover that loses and gains carbon as they shift between perennial and annual cover, a carbon loss that is reversible. The management of perennial lands that have been broken, cropped and seeded to perennial lands are reported in Croplands under the category of "crop mixture."

The primary direct human activities on agricultural grassland in Canada are fire suppression; seeding new plant species in the grassland; and adjusting the amount, duration and timing of grazing by domestic livestock. Methodologies for estimating emissions or removals of CO_2 as a result of direct human activities, and for estimating CH_4 and N_2O emissions from natural or prescribed fires on agricultural grassland in Canada are presented in the following section A3.5.5.1.

A3.5.5.1. Grassland Remaining Grassland

The method for estimating CO_2 is based on the premise that, on long-standing managed grassland, changes in soil C stocks over time occur following changes in soil management that influence the rates of either C additions to or C losses from the soil.

Equation A3.5–21

$$SOC = SOC_{REF} \times F_{MG} \times F_I$$

SOC	=	soil organic C stock at any given time since management and input change, Mg C ha^{-1}
SOC_{REF}	=	reference SOC stock, Mg C ha^{-1}
F_{MG}	=	C stock change factor for management regime, dimensionless
F_I	=	C stock change factor for input of organic matter, dimensionless

The total area of managed grassland is calculated as follows:

Equation A3.5–22

$$A_n = GLGL_{1990} - \sum_{1990}^{n} GLCL$$

A_n	=	total area of grassland remaining grassland in the inventory year n, ha
$GLGL_{1990}$	=	area of grassland remaining grassland in 1990, ha
$GLCL$	=	area of grassland converted to cropland since 1990, ha

Therefore, the net change in SOC because of the management of, and input changes from, grassland remaining grassland can be estimated using the IPCC Tier 1 method as follows:

Equation A3.5–23

$$\Delta C_{GGMineral} = [(SOC_0 - SOC_{0\text{-}T}) \times A] / t$$

$\Delta C_{GGMineral}$	=	net change in SOC due to management of, and input from, grassland remaining grassland, Mg C ha^{-1} yr^{-1}
SOC_0	=	SOC stock in the inventory year, Mg C ha^{-1}
$SOC_{0\text{-}T}$	=	SOC stock T years prior to the inventory year, Mg C ha^{-1}
A	=	area of grassland remaining grassland affected by management change or input change, ha
t	=	inventory time period, years (default 20 years)

If no change in management practices or input occurs, C stocks are assumed to be at equilibrium, and the change in C stocks is therefore deemed to be zero.

Several studies address the effects of grazing versus no grazing on SOC. Although the productivity of heavily grazed pasture is lower, which may lead to a decline in range conditions, this was not found to be related to declines in SOC (Biondini and Manske, 1996). The effects of the grazing regime are complex, because of the effects of grazing on the plant community as well as on the C input to soil from both above-ground and below-ground plant growth (Schuman et al., 2002; Liebig et al., 2005). An additional influence of the grazing regime is the increased return of C in fecal matter as the stocking rate increases (Baron et al., 2002). Bruce et al. (1999) proposed that there was no opportunity to increase SOC from grazing management improvements on extensively managed rangeland in North America.

The addition of organic amendments and inorganic fertilizer increases the productivity of native grasslands (Smoliak, 1965), suggesting that these practices could increase SOC through greater C inputs. However, these practices are basically of academic interest, as the only economically practical management options for semi-arid grasslands are altering the grazing regime, burning, and introducing new plant species (Liebig et al., 2005).

Grasslands managed for grazing in Western Canada in the Brown and Dark Brown soil zones of Alberta, Saskatchewan and British Columbia are occasionally burned by wildfires and by prescribed burning for purposes such as brush management, habitat management, the removal of decadent vegetation, and military training exercises. The burning of managed grassland is a net source of CH_4, CO, NO_x and N_2O.

Equation A3.5–24

$$EMISSION_{BURN} = \sum (AREA_i \times FUELLOAD_i \times C_{F,i} \times G_{EF}) / 1000$$

$EMISSION_{BURN}$	=	emissions of CH_4 or N_2O from prescribed and non-prescribed burning of managed agricultural grassland, kt CH_4 or N_2O
$AREA_i$	=	area of the i^{th} managed agricultural grassland subject to burning, ha
$FUELLOAD_i$	=	average fuel load of the ith managed agricultural grassland subject to burning, Mg DM (dry matter) ha^{-1}
$C_{F,i}$	=	combustion efficiency of the ith managed agricultural grassland subject to burning, fraction, unitless
G_{EF}	=	emission factor of CH_4 (2.7 g CH_4 kg^{-1} dry matter burned) or N_2O (0.07 g N_2O kg^{-1} dry matter burned) (IPCC, 2006)
1000	=	conversion of Mg to kt

Data Sources

As discussed in section A3.5.4.2, the area reported in the Grassland Remaining Grassland subcategory was estimated using a combination of data from the COA and EO, as described in section A3.5.4.1. No detailed and comprehensive activity data are available on management changes on Canadian agricultural grassland over time, except for wild and prescribed fires. Activity data on fire area, fuel load and combustion efficiency for each burning event on managed agricultural grassland were collected through consultations (Bailey and Liang, 2013). Activity data from 2013 to 2015 were updated in 2017 and were assumed to remain constant after the sampling period.

A3.5.6. Wetlands

In Canada, the Wetlands category includes water-saturated areas on managed land associated with direct human activity, where land conversion or management can influence GHG emissions or removals. The following sections describe approaches for estimating net fluxes of CO_2, CH_4 and N_2O from peat extraction; CO_2 and CH_4 from flooded lands; and CO_2 from resource extraction in the Oil Sands Region.

A3.5.6.1. Peat Extraction

General Approach and Methods

Peat is extracted in Canada to produce horticultural peat products and related applications, rather than for use as fuel. Since the 1970s, the vacuum harvesting technique has been the dominant method of peat extraction. This technique requires an extensive network of drainage ditches to dry the peat for harvesting by heavy vacuum harvesters. Prior to the implementation of vacuum harvesting, manual block-cutting with shovels was used to extract peat blocks, resulting in a topography of high baulks and low trenches. Although these manual methods are no longer used, numerous unrestored block-cut sites remain in the landscape.

Emissions of CO_2, CH_4 and N_2O from the conversion and management of peatlands for peat extraction were estimated using an IPCC Tier 2 method in accordance with the 2006 IPCC Guidelines and the 2013 IPCC Wetlands Supplement (IPCC, 2006;2014). The approach is based on Canadian research and land management practices specific to peat extraction activity in Canada. Emission estimates include on-site CO_2, CH_4 and N_2O emissions, off-site CO_2 emissions from extracted peat, and waterborne C losses of dissolved organic carbon (DOC) from drained and rewetted sites.

Domestic GHG flux studies at peat extraction sites in Canada were reviewed and measurements compiled to develop country-specific emission factors and parameters (Table A6.5–8). Since most flux measurements reported applied only to the growing season, annual CO_2 emission factors were developed by adding measured winter values from Strack and Zuback (2013), which are consistent with the higher winter CO_2 emissions from drained peatlands than from natural peatlands. Annual CH_4 emission factors were developed on the assumption that non-growing season fluxes represent 15% of annual totals derived from natural peatland sites (Saarnio et al., 2007).

Owing to the extraction technology and desired properties of sphagnum peat, preference in site selection is given to open bogs (nutrient poor – ombrotrophic peatlands), which are classified as Other Land under Canada's land categorization framework for the LULUCF sector described in section 6.2 of Chapter 6. Therefore, only approximately 5% of pre-conversion areas meet the definition of the Forest Land category. Emission estimates are separated into the Land Converted to Peat Extraction and Peat Extraction Remaining Peat Extraction subcategories. To calculate the emissions resulting from land conversion, a period of one year is used to represent the land conversion practices of draining and clearing the surface vegetation layer in preparation for peat extraction. Subsequently, emissions from the active extraction, as well as their decommissioning rehabilitation, or rewetting and restoration, are all reported under the Peat Extraction Remaining Peat Extraction subcategory. The following sections describe the sources of GHG emissions and removals that occur on peat extraction sites during and after exploitation.

Biomass Clearing, Drainage, Active Extraction, and Unrestored Areas

Vegetation removal, drainage, the active extraction of peat, and decommissioned sites that are left unrestored all result in a loss of CO_2 uptake, enhanced peat decomposition, and DOC export, leading to a net increase in CO_2 emissions. Before extraction, vegetation removal results in a loss of biomass that is assumed to be immediately emitted to the atmosphere in the year of the land conversion. After vegetation removal, peatland sites are drained in preparation for extraction. There is currently insufficient Canada-specific emission data to support separate emission factors for areas that are drained but not yet used for extraction, therefore a combined emission factor was applied to all areas from the drainage to active extraction stages. The same combined emission factor was applied to sites that are left unrestored where vegetation is not re-established naturally or through restoration or rewetting, where persistent CO_2 emissions have been observed (Waddington et al., 2002).

In drained fields used for extraction, including unrestored areas, CH_4 emissions decline substantially. However, drainage ditches become CH_4 hot spots (Waddington and Day, 2007). To account for this observation, a combined emission factor was calculated using weighted average based on their relative areas; 95% for fields and 5% for ditches. Additionally, enhanced peat decomposition increases N_2O emissions.

The CO_2 and CH_4 emission factors for drained, actively extracted and unrestored areas were derived from Canadian studies (Table A6.5–8). Due to a lack of domestic N_2O measurements, the default emission factor for peat extraction sites in the 2013 IPCC Wetlands Supplement (IPCC, 2014) was used.

Peat Stockpiling and Production

Once peat is extracted, the C stored is emitted as it slowly decays over time. Harvested peat is left in stockpiles before being processed into various peat products. Emissions from peat stockpiles are calculated using an exponential decay model for half a year (Cleary et al., 2005). Once it is packaged into products, Canadian peat is transported off-site, largely to the United States, for non-energy uses such as horticulture, where it is assumed to decay in an aerobic environment. The estimated total organic C in the peat products is estimated using a country-specific C fraction parameter (Table A6.5–8) derived from laboratory analyses of pure peat products with a moisture content ranging from 27% to 64% (Hayne et al., 2014). An exponential decay function using a constant annual decomposition rate of 0.05 yr^{-1} (Cleary, 2003; Sharma et al., 2024) is used to account for decomposition of the peat over time and estimate the residual CO_2 emissions from the use of peat products (Mg C ha^{-1}), up to a maximum of 100 years (Table A6.5–8).

Natural Regeneration, Reclamation, Rewetting, and Restoration

Natural regeneration occurs when unrestored areas are left to naturally revegetate without intervention. Revegetation occurs more frequently at block-cut sites than at vacuum-mined sites, although the total vegetation coverage is low and moss regeneration is limited to wetter trench depressions (Poulin et al., 2005). A CO_2 emission factor for naturally regenerated block-cut areas was established to be lower than for areas drained for vacuum harvesting, while the CH_4 emission factor is observed to be higher, likely due to greater revegetation and wetter conditions at block-cut sites (Table A6.5–8).

After decommissioning a peat-extraction site, there are three common land management interventions applied to reclaim or restore the area: tree plantations, active rewetting, and restoration by applying the Moss Layer Transfer Technique (MLTT). In sites where trees have been planted, the annual uptake of CO_2 by trees is calculated using a meta-model of black spruce tree yield of merchantable volume over time (Fortin and Lavoie 2022), which is then converted to biomass growth using methods consistent with the CBM-CFS3 (Boudewyn et al., 2007). While these tree plantations increase CO_2 sequestration in tree biomass, they do not offset the large CO_2 emissions resulting from the drained peatlands (Garcia Bravo, 2015) (Table A6.5–8).

Rewetting practices increase anaerobic conditions, which reduce peat decay and DOC export, thereby decreasing CO_2 emissions while increasing CH_4 emissions (Strack and Zuback, 2013) (Table A6.5–8). Since the 1990s, the MLTT has been used in Canada for the restoration of peatlands dominated by *Sphagnum* mosses, with the aim of restoring sites to peat-accumulating ecosystems. This technique consists of rewetting and spreading fields with fresh moss diaspores topped with a layer of straw mulch to support moss regeneration (Rochefort et al., 2003). Canadian research on MLTT restored sites has demonstrated that the CO_2 from the re-establishing sphagnum-dominated peatland vegetation will eventually offset the CO_2 emitted from the decaying peat over time (Nugent et al., 2018). While there was insufficient Canada-specific data to support a linear relationship with the net CO_2 emissions and removals over time at MLTT restored sites, the data demonstrated that on average sites flipped from a net source to a net sink at approximately 12 years post-restoration, based on the intercept of the plotted line of available domestic data (Figure A3.5–18). Therefore, two emission factors for MLTT-restored sites were developed by averaging net CO_2 emissions and removals for all available data before and after this 12-year threshold (Table A6.5–8). CH_4 emissions for MLTT-restored sites did not vary over time and were averaged using Canada-specific data and weighted using the relative area of emissions from fields (95%) and ditches (5%) when appropriate to the study.

Data Sources

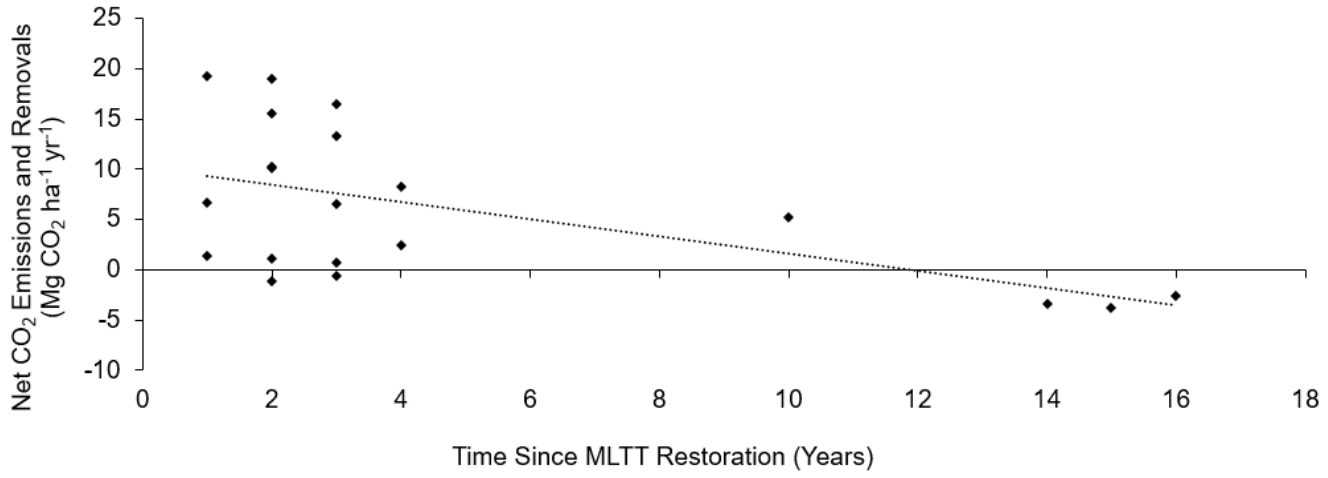
An EO mapping approach based on the manual delineation and interpretation of aerial photography, satellite imagery and ancillary data was developed to map the extent of peatland areas disturbed by peat extraction for the circa 1990, 2007, 2013 and 2022 time periods. Through image interpretation, the total disturbed area was assigned to one of the following five land management subcategories: active extraction areas, unrestored areas, rehabilitated areas, rewetted and MLTT restored areas. Geospatial data developed by the Peatland Ecology Research Group and information provided by industry experts were used to aid in subcategory allocation. In addition, for a subset of sites, the pre-disturbance land cover class (forest, shrubby or open bog peatland) was determined to identify the land category type converted (Forest Land or Other Land).

Annual area estimates were developed using interpolation between mapped time periods and extrapolation after 2022. Annual area estimates for various land management categories were then refined based on secondary data sources. The three main secondary data sources were industry statistics on peatland areas managed for peat extraction in 2015, 2016, 2020, and 2021 compiled by the Canadian Sphagnum Peat Moss Association (CSPMA), a survey of unrestored peat extraction sites in the provinces of Quebec and New Brunswick (Poulin et al., 2005), and a database on restored site locations provided by the University of Laval Peatland Ecology Research Group. Secondary data sources were used to provide a basis of comparison check for the total areas converted to peat extraction historically and current production areas, and to complement limitations in the ability of the mapping approach to identify land management subcategories. Historical peat production statistics for pre-1990 were obtained from Warner and Buteau (2000), and interpolated between missing years. National peat production statistics were used to represent the annual amount of extracted peat transported off-site after 1990 (NRCan, 2025).

Uncertainty

Given the increased availability and quality of EO imagery and ancillary information over time, areas for the 2013, and 2022 mapping time period reduced the uncertainty associated with the overall estimate of the total areas converted for peat extraction. However, considerable uncertainty is associated with identifying land management subcategories. Uncertainty surrounding the CSPMA industry statistics is linked to the different interpretations of land management category definitions (e.g., restoration) and the incomplete coverage of lands not managed by industry association members.

Figure A3.5–18 **Domestic Data of Net CO_2 Emissions and Removals after Restoration with Moss Layer Transfer Technique**



There are a limited number of country-specific GHG measurements for the various categories of decommissioned sites. However, the long-term monitoring of restoration sites indicates that rewetting and restoration success varies depending on management (e.g., effectiveness of the blocking of the secondary drainage network, timing of restoration procedures and quality of plant material spread) and post-restoration weather conditions (González and Rochefort, 2014). Therefore, emission factors may not represent the full range and success rates of the rehabilitation and restoration techniques applied. The large variation in moisture content among peat products may contribute substantially to the uncertainty of estimates of off-site CO_2 emissions from extracted peat.

A3.5.6.2. Flooded Land

General Approach and Methods

Flooded lands include reservoirs used for hydroelectric generation, flood control, irrigation, water supply, and recreation. Emissions are estimated for all known reservoirs since 1832 with a minimum surface area of 100 ha and are reported in accordance with the 2013 IPCC Wetland Supplement (IPCC, 2014) and the 2019 Refinement (IPCC, 2019) using a Tier 2 approach. Canada's estimates include all major flooding events since 1832.

Two complementary methodologies are used to estimate GHG fluxes from flooded lands, depending on land conversion practices. When there is evidence of forest clearing and/or burning prior to flooding, immediate and residual emissions from all forest C pools are estimated using CBM-CFS3 (see section A3.5.2.1). It is believed that the default IPCC approach, which assumes that all biomass C is emitted upon flooding, likely overestimates immediate forest conversion emissions from reservoir creation, since most submerged forest biomass decays over an extended period. Emissions from forest clearing for infrastructure development are reported under the Forest Land Converted to Settlements subcategory. Emissions resulting from the use and disposal of wood products that are harvested before flooding are reported under the Harvested Wood Products category (see section A3.5.3).

In the absence of evidence of forest clearing, it is assumed that all vegetation was simply flooded, leading to CO_2 and CH_4 emissions from a fraction of the submerged C. The proportion of the area flooded that was previously forested is used to attribute these emissions to either the Forest Land Converted to Flooded Land subcategory or the Other Land Converted to Flooded Land subcategory.

Reservoirs typically take about one year to fill after dam construction. After reservoirs are flooded, emissions of CO_2 are tracked for 100 years, reported under the Land Converted to Wetlands subcategory for the first 20 years and under Wetlands Remaining Wetlands for the following 80 years, after which they are assumed to return to baseline levels (IPCC, 2019). CH_4 emissions are reported under Land Converted to Wetlands for the first 20 years, and under Wetlands Remaining Wetlands thereafter, reflecting ongoing emissions from the anaerobic decomposition of submerged organic matter (IPCC, 2019).

Country-specific CO_2 and CH_4 emission factors were developed using the G-res model (Prairie et al., 2017), which uses algorithms derived from a large meta-analysis of global reservoir measurements of GHGs, while allowing integration of site-specific characteristics (UNESCO/IHA, 2025; Harrison et al., 2021) into the calculation framework. The model accounts for climate zone, reservoir age, morphometry, and organic carbon inputs, and was adapted for Canada using public datasets (e.g., GRanD database) and expert knowledge from hydropower utilities and the G-res developers. The use of the G-res modelling framework to develop emission curves allowed the incorporation of Canadian-specific characteristics and consideration of regional biases within Canada, including cold climate regimes, boreal landscapes, and geological features (Harrison et al., 2021). Using an internal ECCC database (unpublished) created to compile detailed physical, hydrological, and environmental data for over 150 Canadian reservoirs, G-res model runs carried out estimate emissions for reservoirs across Canada, integrating temperature, precipitation, and catchment productivity, factors that strongly influence diffusive, ebullitive, and degassing fluxes (Prairie et al., 2021; Harrison et al., 2021).

Based on the G-res model runs, regional emission curves were developed. The methodology uses model derived decay models for CO_2 emissions (see Equation A3.5–25) and CH_4 emissions (see Equation A3.5–26), which reflect the influence of reservoir age and area on emission dynamics. Decay factors applied in these equations ($\alpha = 0.33\ yr^{-1}$ for CO_2 and $\alpha = 0.01419\ yr^{-1}$ for CH_4) were applied from the G-res framework (Prairie et al., 2021) based on the global calibration. These values represent the contrasting emission trajectories: CO_2 declines rapidly after impoundment due to depletion of labile carbon and oxygenated conditions, while CH_4 decreases more gradually because of persistent anaerobic decomposition in sediments. For reservoirs where site-specific emission factor data were unavailable, average values were derived from the closest RU (see Table A6.5–9), ensuring that estimates reflect the most geographically relevant conditions. Emission factors for CO_2 tend to be higher than Tier 1 defaults, while CH_4 emission factors were lower, suggesting that the default approach likely underestimates CO_2 and overestimates CH_4 emissions for Canadian conditions.

Equation A3.5–25

$$CO_2 - C\ emissions = (D \cdot 10^{-\alpha \cdot (t - t_0)}) - B) \cdot A$$

D = CO_2 reservoir-specific diffusive constant, g CO_2-C m^{-2} yr^{-1}
α = CO_2 decay factor 0.33 yr^{-1} (Prairie et al., 2021)
t = current inventory year
t_0 = year of impoundment (flooding)
B = baseline flux, g CO_2-C m^{-2} yr^{-1}
A = reservoir area, ha

Equation A3.5–26

$$CH_4\ emissions = ((D \cdot 10^{-\alpha \cdot (t - t_0)}) + E_b + G_d) \cdot A$$

D = CH_4 reservoir-specific diffusive constant, g CH_4 m^{-2} yr^{-1}
α = CH_4 decay factor 0.01419, yr^{-1} (Prairie et al., 2021)
t = current inventory year
t_0 = year of impoundment (flooding)
E_b = ebullitive flux, g CH_4 m^{-2} yr^{-1}
G_d = degassing flux, g CH_4 m^{-2} yr^{-1}
A = reservoir area, ha

Figure A3.5–19 illustrates the normalized decay of diffusive CO_2 and CH_4 fluxes following reservoir impoundment. The CO_2 curve shows a rapid decline toward an asymptotic baseline, while CH_4 decreases gradually, reflecting its lower decay constant. To present net anthropogenic emissions, Canada applied the G-res methodology with a baseline adjustment for pre-impoundment CO_2 fluxes. This approach, consistent with IPCC 2019 Refinement (IPCC, 2019), subtracts natural background emissions from rivers, wetlands, and other aquatic systems to avoid attributing natural ecosystem processes to human activity. Accounting for these baseline fluxes prevents overestimation of reservoir-related emissions (Soued et al., 2022; Prairie et al., 2021; Harrison et al., 2021).

Reservoir areas, used as the best available estimate of the area converted to managed flooded lands, were mapped using Sentinel satellite imagery to assess spatial variability in Canadian reservoirs over a 10-year period. Analysis of these 10-year periods enabled the derivation of minimum and maximum surface extents of reservoirs, thereby capturing seasonal fluctuations and permanent water coverage. These measurements provide a more accurate representation of reservoir dynamics, which are essential for improving GHG emission modeling and refining input parameters for platforms such as G-res.

Data Sources

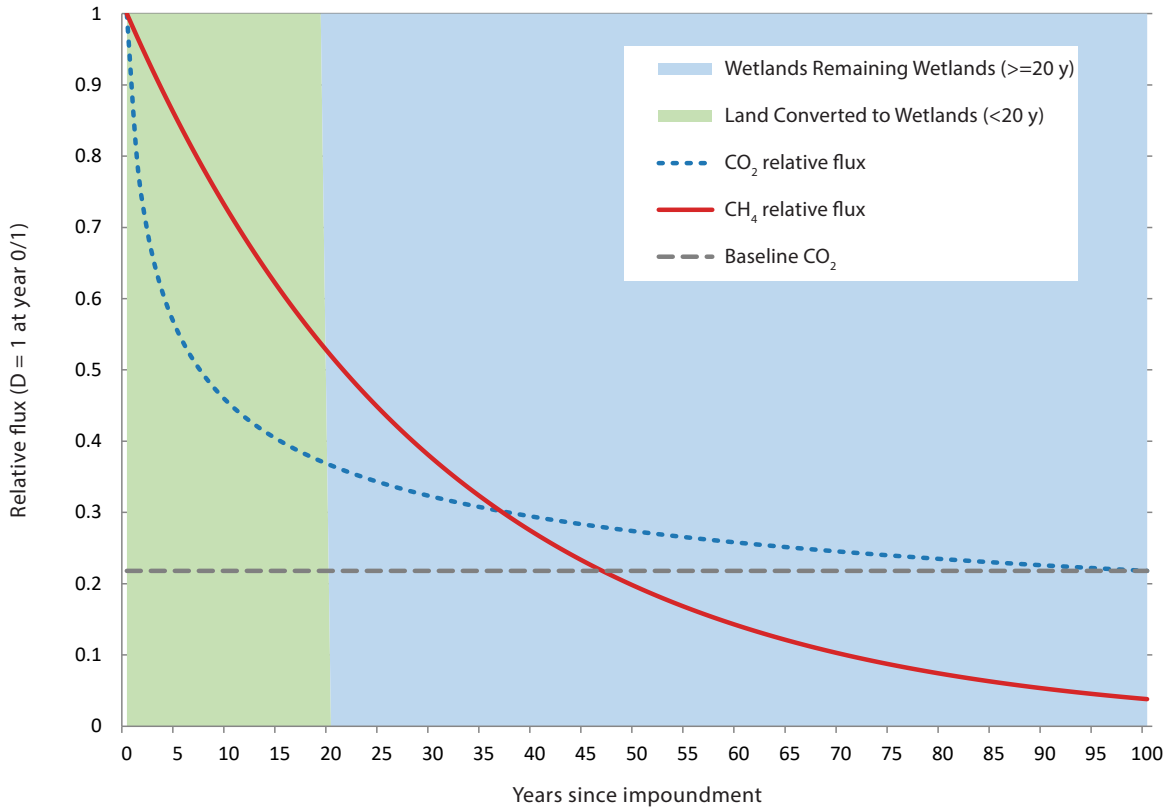
Area estimates for Canadian reservoirs were developed using multiple key data sources. These included forest conversion data linked to reservoir impoundment in reporting zones 4 (Taiga Shield East) and 5 (Boreal Shield East) (see section A3.5.2.7), the Canadian Reservoir Database (Duchemin, 2002), and official industry numbers obtained through correspondence[10] (Eichel, 2006). The Canadian Reservoir Database, which contains records of hydro reservoirs, which were updated and cross-checked with provincial and private utility data to verify construction dates and reservoirs characteristics. The GRanD database V1.3 provided globally consistent reservoir data, including geospatial and hydrological attributes, used as default inputs for the G-res model. In addition, a geospatial dataset was developed using Sentinel satellite imagery, with support from ECCC and the Université du Québec à Montréal (UQAM). This dataset includes minimum and maximum surface area estimates for major reservoirs, capturing seasonal and long-term variability to improve the accuracy of GHG emission modeling.

Uncertainty

Uncertainty in CO_2 and CH_4 reservoir emissions was estimated by combining the variability in emission factors and reservoir area using a standard error propagation method. For reservoirs with measured emission factors, the standard error from observations was applied, while reservoirs without measurements used regional averages or proxies from nearby reconciliation units, introducing additional uncertainty. Reservoir area uncertainty was derived from the minimum and maximum seasonal extents in the internal ECCC geospatial dataset (unpublished) and converted to a standard deviation assuming a 95% confidence interval. Uncertainty in emissions were first calculated at the reservoir level and then aggregated to national totals using the root-sum-of-squares method. Final results are expressed as 95% confidence intervals.

10 Tremblay A, Hydro-Québec. 2010. Personal communication dated November 19, 2010, to Dominique Blain, Environment and Climate Change Canada.

Figure A3.5–19 **Normalized Example of Diffusive Flux Decay After Reservoir Impoundment**



Note: Flux values are normalized to the initial post-impoundment flux (set to 1), so the y-axis is unitless. For example, 0.5 = 50% of the initial flux.

Important sources of uncertainty that are not fully captured in the quantified estimates include:

- **Global basis of G-res**: Emissions estimates rely on globally derived empirical relationships, introducing uncertainty where direct measurements of diffusion, bubbling, and degassing under Canadian conditions are limited.
- **Seasonal variability**: Some reservoirs display marked seasonal variability in CO_2 fluxes, which is not considered in estimate development. For example, anecdotal evidence suggests that algal blooms in the spring could be associated with this variability, especially in reservoirs subjected to anthropogenic nutrient inputs.
- **Organic carbon inputs**: Variability in watershed productivity and land use affects the amount and composition of organic carbon entering reservoirs, influencing decomposition and CH_4 production.

A3.5.6.3. Resource extraction

General Approach and Methods

Peatlands are the dominant ecosystem in northern Alberta (Government of Alberta, 2025) and are regularly disturbed by oil and gas activities (Rooney et al., 2012, Volik et al., 2020). The 2006 IPCC Guidelines (IPCC, 2006), 2013 IPCC Wetland Supplement (IPCC, 2014), and 2019 Refinement (IPCC, 2019) do not provide default emission factors for peatland disturbances from mining activities, in particular the displacement and storage of peat soils as well as practices such as burying of peat under fill and low-level disturbance such as compaction resulting from the passage of heavy machinery. To address this, Canada has compiled domestic scientific information to develop emission factors for estimating emissions and removals from these disturbances. This implementation is the first step in a multi-phase improvement plan (Table 8–5) to estimate GHG emissions and removals from peatland and forested peatland disturbances associated with the main resource extraction activities across Canada, starting with the Oil Sands Region (OSR) in northern Alberta due to the availability of high-quality data. Note that peat extraction activities are addressed separately in section A3.5.6.1.

Oil and gas mining activities that disturb peatlands in the OSR can be classified into three categories: exploration, extraction, and transport. Exploration, primarily involves the clearing of above-ground biomass and surveying using heavy machinery (e.g., seismic lines). These actions cause long-lasting impacts to peatlands by compacting peat (Lovitt et al., 2018) and altering vegetation communities (Dabros et al., 2021), specifically by hindering tree reestablishment in treed peatlands (Sutheimer et al., 2024). Extraction in the OSR occurs via surface mining or in situ methods. Surface mining activities, including direct oil extraction and tailings ponds construction, generally cause the largest disturbances, as peatlands are cleared of vegetation, drained, and excavated. In-situ mining is generally less impactful than surface mining because the peat is retained on-site; after above-ground biomass is cleared, a layer of mineral fill caps the peat, creating a stable platform over the extraction site. Transportation activities include linear disturbances, such as roads and pipelines. Pipeline construction involves clearing vegetation along a right-of-way and excavating a trench to install the pipe. Site-preparation techniques have varied over time and between developers, but current directives aim to standardize procedures and reduce environmental impacts (Alberta Energy Regulator, 2025).

Emissions and removals estimated using this methodology are reported under several land-use categories. Activities that clear only above-ground biomass and allow regrowth, such as seismic lines, exploratory wells, or rights-of-ways, are reported under the Wetlands Remaining Wetlands subcategory for 100 years post-disturbance to capture long-term impacts on peatland carbon dynamics (Dabros et al., 2022; Davies et al., 2025). Complete land-use conversions, including surface mines, well pads, and roads are reported under the Wetlands Converted to Settlements subcategory, with emissions or removals resulting from the conversion tracked for 20 years (IPCC, 2006), and any residual emissions reported under Settlements Remaining Settlements for an additional 80 years. Only ecosystems that meet the definition of the Wetlands category are included in this methodology. Forested peatlands meeting Forest Land category definition are considered upland and reported as forest conversion (see section A3.5.2.7).

This methodology accounts for immediate emissions from activities involving in situ burning of residuals, reported as CO_2, CH_4, CO, and N_2O. The net balance of residual emissions from organic matter decay and removals from vegetation regrowth are tracked as the net ecosystem exchange of CO_2.

Country-specific emission factors for this methodology were developed using a modelling framework called the Canadian Model for Peatlands (CaMP; Bona et al., 2020, 2024). The CaMP is a module within the Generic Carbon Budget Model (GCBM), a spatially explicit model that builds on the CBM-CFS3. It tracks carbon dynamics through annual vegetation growth, turnover, litter input, peat accumulation, and decay, linking water-table fluctuations to oxidative or anoxic decay processes in peat pools (Bona et al., 2020) and ecosystem carbon pools can be tracked back to IPCC reporting categories. For this analysis, CaMP was parameterized separately for open bogs, treed bogs, open fens, and treed fens. Growth of vegetation layers were parameterized using biomass and productivity rates from a peatland parameter database (Bona et al., 2018), and yield curves were developed to simulate the growth of small trees (Bona et al., 2020). A model spin-up procedure (Bona et al., 2020) was used to populate initial organic matter pools, except for peat pools. For peat, over 18 000 observed soil profiles specific to the OSR were used to calculate average initial peat carbon values by peatland type (Bauer et al., 2024; ECCC unpublished Alberta Soils Database). Climate parameters specific to the OSR, including mean annual temperature (McKenney et al., 2011) and drought code (Vitolo et al., 2019) were also used in the CaMP runs.

Similar to the CBM model, the CaMP uses disturbance matrices to quantify carbon transfers between pools or to the atmosphere following disturbances. These matrices were compiled through consultations with oil sands practitioners to better understand the fate of carbon in biomass, dead organic matter, and peat pools, as well as impacts to the water-table, for activities related to oil and gas extraction, exploration, and transportation infrastructure (CPP, 2014; Lapointe-E. and Suthar, 2021). To generate emission factors, OSR disturbances were grouped into four broad categories: (1) high- and (2) low-impact vegetation clearing, (3) peat capping (mineral fill), and (4) peat drainage and excavation. Within each disturbance type, the fate of residuals from biomass clearing varied by company, land practitioner, and accordingly, the four disturbance types were further split into three residual treatment categories: (a) mulched and spread, (b) left intact, or (c) piled and burned, yielding 12 distinct combinations.

To generate immediate and residual emissions and removals for each type of oil and gas disturbance, the 12 disturbance matrices were applied across four peatland types (open bog, treed bog, open rich fen, and treed rich fen) using CaMP. Three vegetation recovery options were simulated depending on the disturbance type; (1) zero vegetation recovery for capping and excavation disturbances, (2) non-tree recovery, and (3) with-tree recovery for high- and low-impact vegetation clearing (e.g., seismic lines), representing, respectively, a transition from treed to open peatland and regrowth including trees for treed peatland. This resulted in emissions and removals for all combinations of disturbance type, residual treatment, peatland type, and recovery scenario.

Mathematical models were fit to each CaMP output to generate immediate emission factors (CO_2, CO, CH_4, N_2O), and non-linear trajectories of residual CO_2 emissions and removals. Immediate emission factors, applied only in the first year, represent scenarios where woody biomass was piled and burned during vegetation clearing. Due to a lack of peatland type specific data, immediate emissions from the burning of small trees and shrubs were averaged across bogs and fens, resulting in emission factors of 30.5 t CO_2 ha^{-1}, 2.4 t CO ha^{-1}, 0.0052 t CH_4 ha^{-1}, and 1.95 x 10^{-5} t N_2O ha^{-1}. Long-term residual CO_2 emission and removals were fit to a non-linear model to capture exponential decay from heterotrophic respiration and, when applicable, carbon sequestration from vegetation regrowth (Equation A3.5–27).

Equation A3.5–27

$$E_{i,j,k,l} = \sum_{t=1}^{t=n} (a_{i,j,k,l} e^{-b_{i,j,k,l} t} + c_{i,j,k,l} t + d_{i,j,k,l})$$

$E_{i,j,k,l}$	=	net emissions/removals from wetland disturbance specific to i, j, k, l, t CO_2 ha^{-1}
a, b, c, d	=	parameters, including linear "recovery" trajectory specific to i, j, k, l, dimensionless (see Table A6.5–10)
t	=	time since disturbance, years
i	=	peatland type: open bog, treed bog, open fen, or treed fen
j	=	disturbance type: low-impact vegetation clearing, high-impact vegetation clearing, peat capping, or peat drainage and excavation
k	=	biomass treatment: mulched and spread, left intact, or piled and burned
l	=	vegetation recovery option: zero, non-tree, or with tree

Data Sources

The majority of oil sands mining takes place within the Alberta portion of reporting zone 10 (Boreal Plains). Time-series activity data of peatland disturbances were derived primarily from the Enhanced Human Footprint Inventory (HFI; 2022 version) developed by the Alberta Biodiversity Monitoring Institute (ABMI, 2025). This dataset provides wall-to-wall coverage of the OSR with complete annual temporal coverage from circa 1900 to 2022. Polygonal boundaries of each mapped feature were delineated and attributed at high spatial resolution using existing GIS datasets, refined with high-resolution satellite imagery and expert knowledge of the region. The HFI dataset (Figure A3.5–20) was filtered to include only features associated with oil and gas mining, which were then grouped into the following disturbance classes: Roads, Clearing unknown, Infrastructure, Pipelines, Conventional seismic lines, Low-impact seismic lines, Surface mining and Tailing ponds.

The peatland types from the Alberta Merged Wetland Inventory (AMWI), a ground-validated dataset with coverage back to circa 2000, were used to represent historical peatland pre-disturbance conditions following consultation with provincial scientists (Government of Alberta, 2025). The Spatialized Canadian National Forest Inventory (SCANFI) canopy-cover map (Guindon et al., 2024) classifies areas as Open, Treed, or Forested, providing details on forest cover for each peatland type (Figure A3.5–20). The spatial intersections between HFI disturbances, AMWI peatland types, and SCANFI canopy classes were used to produce annual land-use change area estimates at the disturbance-by-peatland-by-canopy level.

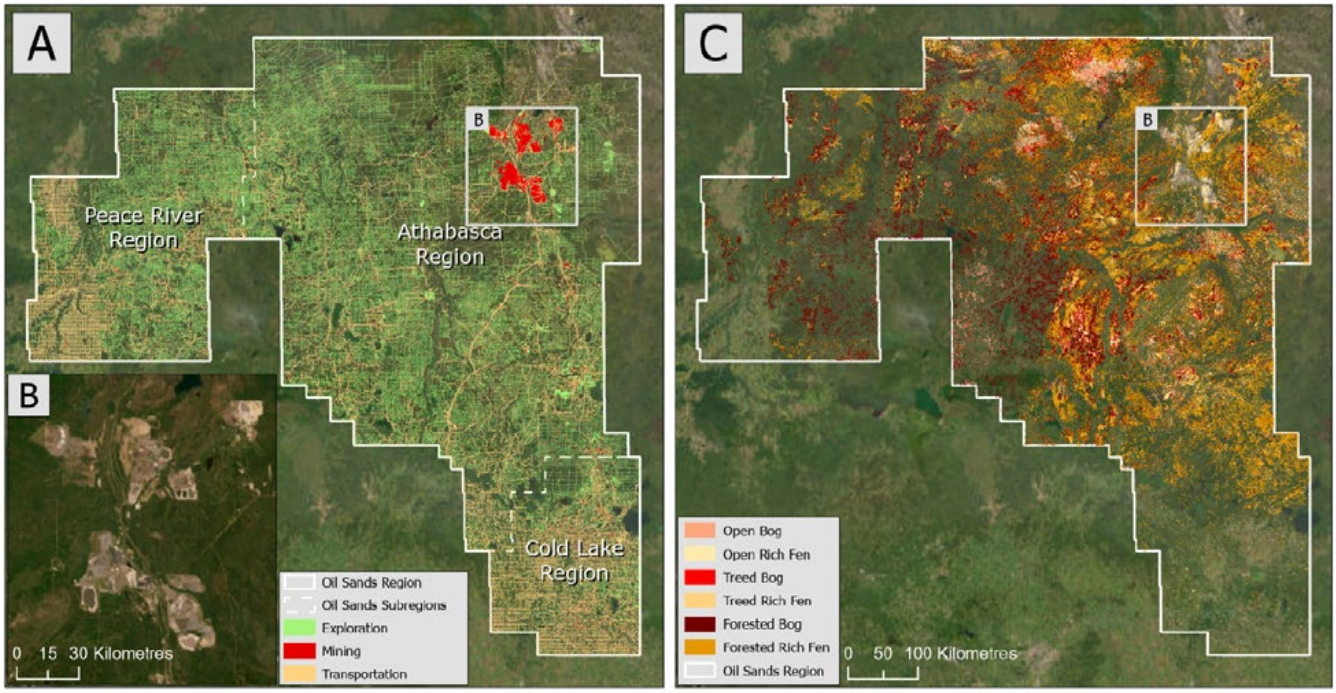
Since the wetland map was created after mining activities started in the OSR, pre-disturbance land cover was unknown for some locations. To account for this, a historical peatland disturbance adjustment was applied using post-2000 peatland disturbance proportions by class, peatland type, and OSR subregion (Cold Lake, Peace River, Athabasca) to refine estimates of peatland disturbance prior to 2000. This step corrects for underestimations resulting from the map being based on conditions in 2000. Similarly, a pre-2020 forest adjustment was applied to estimate historical Open, Treed, and Forested proportions per subregion based on canopy-by-peatland distributions of non-disturbed areas, and to reallocate earlier disturbance overlays accordingly.

Additional spatial attributes included well status (production vs. exploration) and OSR subregions to enable region-specific analysis. The HFI pipeline polygons, which include surrounding clearings, were further split between excavated trench and cleared right-of-way segments using proportional splits based on Alberta pipeline installation practices. The final adjusted values were used as activity data inputs for emissions calculations.

Uncertainty

A Monte Carlo uncertainty analysis was conducted on the subset of model parameters to which the methodology was most sensitive, to quantify the range and distribution of uncertainty in emissions and removals. First, a range of emission factor models was generated by varying the CaMP model runs using initial peat carbon pool values with a 90% confidence interval, and by varying decay rates for each dead organic matter pool within literature-based realistic ranges. Two additional national-scale map products (Webster et al., 2018, Pontone et al., 2024), were also used to estimate uncertainty in the areal extent of each wetland type that overlaps with each disturbance type. A Monte Carlo approach was then applied to randomly assign combinations of emission factors and activity data for each disturbance type, with a bootstrap analysis producing 1000 iterations of potential emissions and removals. This procedure yielded a distribution of uncertainty for each category and associated GHG estimates.

Figure A3.5–20 **Oil and Gas Mining Disturbance Activities in Northern Alberta Wetlands**



Note: (A) Oil sands subregions with mapped mining disturbances from the HFI (ABMI, 2025); (B) close-up of surface mining in the Athabasca oil sands subregion; and (C) peatland types from the AMWI (Government of Alberta, 2025) with canopy-cover classes from SCANFI (Guindon et al., 2024), shown on satellite imagery.

A3.5.7. Settlements

This category comprises estimates of removals of CO_2 from Settlements Remaining Settlements (C sinks in urban trees) and emissions from Land Converted to Settlements (conversion of forest land, unmanaged grassland and wetlands). The following sections describe the approaches developed to estimate net C sequestration by urban trees, emissions from the conversion of non-forest land (unmanaged grassland or tundra) to settlements in the Canadian Arctic and Subarctic, conversion of cropland, and conversion of wetlands (peatlands) to settlements. Approaches, methods and data sources for estimating emissions from the conversion of forest land to settlements are covered in sections A3.5.2.1 and A3.5.2.7.

A3.5.7.1. Settlements Remaining Settlements

General Approach and Methods

In Canada, the management and monitoring of urban trees is done at the level of individual municipalities, and there is no centralized authority or organization with responsibility for compiling national-scale urban tree information. Taking into consideration the lack of specific species class information and the considerable resources required to develop such information, an approach based on urban tree crown (UTC) cover area was developed to estimate CO_2 sequestration by urban trees in Canada. The approach involves the sampling of digital aerial photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas. The growth of urban trees in Canada was estimated using an IPCC Tier 2A approach (IPCC, 2006):

Equation A3.5–28

$$\Delta C_G = \sum AT \times CRW$$

ΔC_G = annual C accumulation attributed to biomass increment of urban trees in Settlements Remaining Settlements, tonnes C yr^{-1}

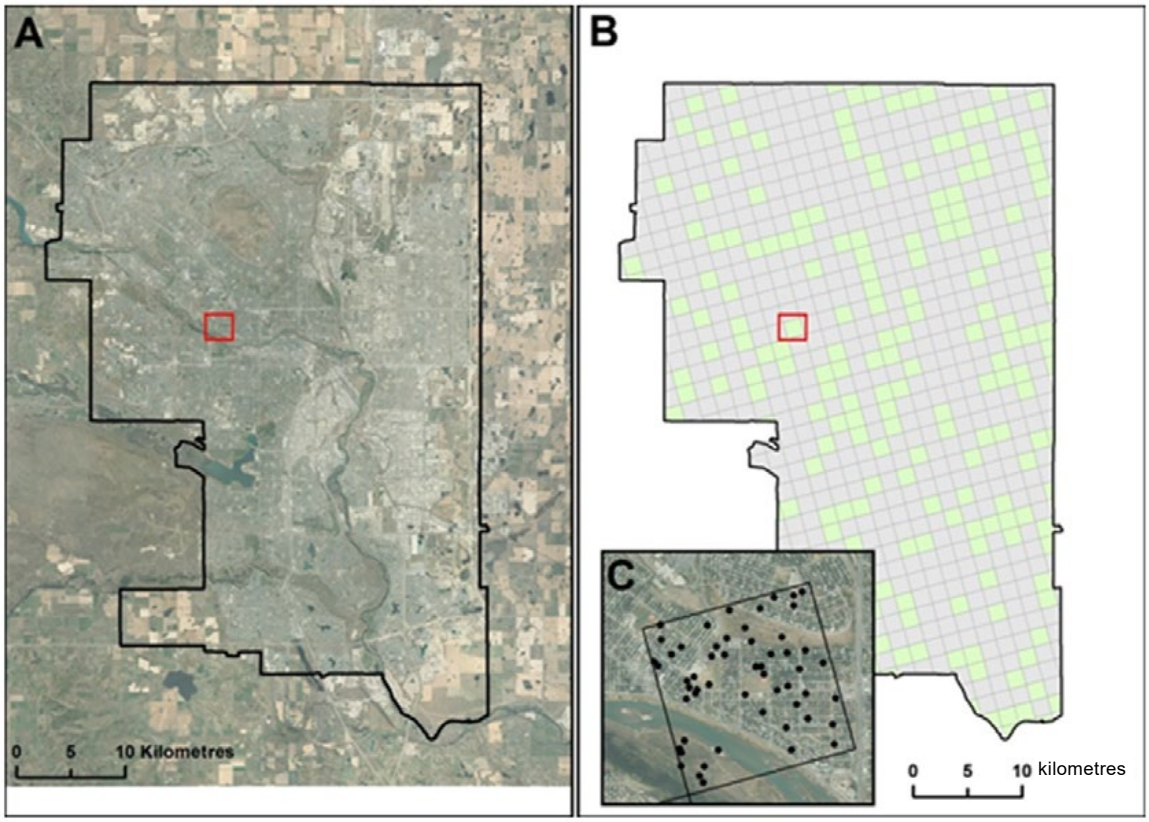
AT = total crown cover area of urban trees, ha

CRW = crown cover area-based growth rate (CRW) for urban trees, tonnes C (ha^{-1} crown cover) yr^{-1}

The total urban area of Canada in 2012 was estimated using the boundaries of Statistics Canada's 2011 populated place digital boundary layer,[11] as it was the most nationally consistent delineation of urban areas available. The 1990 urban boundaries were based on Statistics Canada's 1990 polygon layer, which were then manually edited through the visual interpretation of aerial photos and the 1990 GeoCover (MDA-Federal, 2004) ortho-rectified image data set, to reduce known over-bounding errors (Statistics Canada, 2010). The resulting 1990 urban layer represented a smaller total area (1.5 Mha) than the total urban area identified for 2012. Among the 947 population centres (2.4 Mha) in Canada, 69 (1.5 Mha) with populations greater than 30 000 individuals were extracted from the Statistics Canada data set. This subset captured all major Canadian cities and represented 62% and 67% of the total urban area in 1990 and 2012, respectively. Furthermore, this subset includes the urban centres that represented approximately 79% and 76% of Canada's population in 1990 and 2012, respectively (Statistics Canada, 2011; McGovern and Pasher, 2016). While the population centres selected did not completely represent all populated places in Canada, many of the smaller communities that were filtered out are parts of an overall matrix of forest or agricultural land that may be captured under other land categories.

The 69 population centres were spatially allocated to 18 of the 60 RUs (see section A3.5.1). The 18 RUs represented 97% and 99% of the total area and population, respectively, of the 947 population centres. The estimated proportion of UTC cover in each RU was developed using a point-based sampling approach (Pasher et al., 2014). A grid cell approach was used to ensure the adequate spatial distribution of sampling cells (Figure A3.5–21). Random points at a density of 55 points/km^2 on digital aerial photos or high-resolution satellite imagery were interpreted manually and classified into broad categories of tree crown or non-tree crown cover.

Figure A3.5–21 **Sampling Grids and Point Sampling over Georeferenced Aerial Photo**



Note: Background imagery: (A) Calgary, Alberta urban area boundary; (B) 1 km × 1 km grid cells representing a 25% sampling rate with randomly selected grid cells shown in green; and (C) close-up of a single grid cell (20 points km^{-2} sampling). Orthophoto courtesy of City of Calgary.

11 Statistics Canada. Populated Place spatial data and information available online at: http://www12.statcan.gc.ca/census-recensement/2011/geo/bound-limit/bound-limit-2011-eng.cfm.

The same sampling point locations were used for both the 1990 and 2012 UTC assessments, although sampling cells and points that fell outside the 1990 urban boundaries were not included to ensure that sampling was restricted to represent urban areas for that time period. A quality control process was implemented which involved random checks by alternative interpreters or reinterpretation. The percent UTC cover for each RU was calculated as the proportion of all points identified as tree canopy out of the total points that were assessed within the RU. The national-scale UTC cover estimate was 29% in 1990 and 27% in 2012.

The total crown cover area of urban trees for each RU was estimated by multiplying the % UTC cover by the total urban area estimates for the associated RU in 1990 and 2012. Although urban areas have increased by 6% from 1990 to 2012, the national-scale estimate of crown cover changed little, with some regional variation in trends. Gains in crown cover area (e.g., tree growth and planting) tended to offset losses (e.g., tree removal, mortality and urban land-use change).

The crown cover area-based growth rate (CRW) values for the 18 RUs (see Table A6.5–11) are derived from assessments carried out in 16 Canadian cities using the same methodology used to develop CRW values for the United States. In RUs where cities were not assessed using that approach, values from proxy cities were used based on an ecologically similar Canadian RU, except for RU 41, Pacific Maritime, for which the assessment for the U.S. city of Seattle was used (Steenberg et al., 2023). These assessments take into consideration the tree species, the age of trees, and environmental conditions in each RU to determine gross sequestration rates. Net C sequestration was estimated to be 74% of gross sequestration, accounting for urban tree growth characteristics and tree mortality and decomposition (Nowak et al., 2013). These growth and sequestration rates are applied to the 18 RUs and, as a result, estimates of UTC cover area and the net sequestration rate are the main drivers of overall removal estimates. Interpolation and extrapolation were used to develop a consistent time series for the period from 1990 to the latest inventory year.

An analysis on urban trees (Tree Canada, 2019) suggested that 13% of biomass from tree mortality in urban centres is used for firewood. As a result, the volume of firewood harvested from urban trees was estimated by multiplying the C stocks for individual population centres by the estimated 2.4% mortality rate among urban trees taken from Tree Canada (2018) and 13% of C from dead trees was assumed to be used as firewood (Tree Canada, 2019). The firewood was aggregated by RU and assumed to supply a portion of the firewood demand estimated from consumption surveys described in section A3.5.3. The transfer of carbon to firewood is still reported in the Settlement category and is attributed to the difference between the gross and net annual sequestration rates estimated by the i-tree model.

Uncertainty

The uncertainties associated with the estimates of urban area, UTC cover and the C sequestration rate all contribute to the overall uncertainty associated with estimated CO_2 removals by urban trees. The result of these combined uncertainties using a Tier 2 Monte Carlo analysis associated with each RU using the field data on urban trees collected in Canada and the city of Seattle, provides an estimated total uncertainty of 38% for 1990 and 2012. This uncertainty estimate does not include the estimation error related to the use of biomass equations or conversion factors or to measurement error (Nowak et al., 2013).

The uncertainties associated with the 1990 and 2012 urban areas were not quantified by Statistics Canada. An error estimate of 10% was used for the 2012 urban area following the approach used in the United States' 2012 national GHG inventory report (U.S. EPA, 2013). The error associated with the 1990 urban area estimate was assumed to be slightly higher at 15% than that for 2012, based on expert judgment. This approach is similar to the uncertainty estimate for the boundary delineation (15%) used for developing forest conversion estimates (Leckie, 2011).

The uncertainty associated with UTC estimates was based on the standard error in the sampling approach calculated for each sampling period (1990 and 2012). Standard errors for the UTC estimates were low (0.2% for the national UTC estimate) given the very high number of sampling points used.

A3.5.7.2. Cropland Converted to Settlements

Data Sources

Urban and industrial expansion has been one of the main drivers of the conversion of cropland to settlements in Canada. The areas of cropland converted to settlements were estimated based on the land-use maps for 1990, 2000 and 2010 developed in Huffman et al. (2015a). Areas converted during the 1990 to 2000 and 2000 to 2010 periods were calculated by spatial analysis for each RU, divided by the number of years, to develop constant annual conversion rates. Converted areas were extrapolated after 2010. The total area of cropland converted to settlements during the 1990 to 2000 and 2000 to 2010 time periods was 184 kha and 115 kha, respectively, with most of the change due to urban expansion in reporting zones 7 (Mixedwood Plains) and 11 (Sub-humid Prairies). This is largely due to urban expansion in the main populated centres, such as Toronto, Hamilton, Oshawa, Montreal, and Edmonton.

Uncertainty

Given that the highest conversion rates are caused by urban expansion, an independent assessment of converted areas was conducted by comparing the land cover in each map against the visual interpretation of ortho-rectified Landsat imagery over urban centres. The sampling strategy used in this assessment was to perform the analysis on five main census metropolitan areas (CMA[12]), which account for 45% of the total area change from cropland to settlements. Polygons from the 2011 census were used to define the boundary of each CMA, and over 400 stratified random points were used to verify the land cover class in areas in which there were examples of either change or no-change from cropland to settlements, separated by a minimum distance of 1 km, to avoid statistical bias. The minimum mapping unit for the accuracy analysis was defined as a circle with a radius of 100 m to prevent errors due to the presence of noise in each classified map. The class in each location was assigned based on the class of most of the pixels, to account for changes in land use. An overall accuracy of 80% and 84% was obtained for the areas of change computed from these maps, which concurs with the accuracy assessment carried out by Huffman et al. (2015a).

A3.5.7.3. Grassland Converted to Settlements

General Approach and Methods

Nearly half of Canada's land mass is in Arctic/Subarctic regions and includes all land categories (IPCC, 2006), excluding Cropland. An approach was developed to capture the CO_2 emissions associated with land-use changes by identifying the drivers and the amount of biomass C stocks in Northern Canada. It included the following components: (i) manual digitizing of land use polygons in Canada's Arctic/Subarctic for 1990, 2000, 2010, and 2020, based on ortho-rectified Landsat imagery spanning over 130 million hectares, including areas in reporting zones 1 (Arctic Cordillera), 2 (Northern Arctic), 3 (Southern Arctic), 4 (Taiga Shield East), 5 (Boreal Shield East), 8 (Hudson Plains), 10 (Boreal Plains), 13 (Taiga Plains), 16 (Boreal Cordillera), 17 (Taiga Cordillera) and 18 (Taiga Shield West); and (ii) the estimation of pre-conversion vegetation classes, with associated aboveground and belowground biomass carbon stocks determined through expert consultation (Lapointe-E., 2022).

A comprehensive analysis was initially conducted for the years circa 1990, 2000, and 2010 through image interpretation using Landsat-5 imagery to manually digitize sites undergoing change (McGovern et al., 2016). Building on this previous work, a 2020 mapping year was added using Landsat-8 imagery to identify new anthropogenic disturbances in Northern Canada (Figure A3.5–22). A wide range of human disturbances such as airstrips, roads, power lines, seismic lines, urban areas, mines, and smaller features like well sites and roadside clearings were identified using snow- and ice-free imagery.

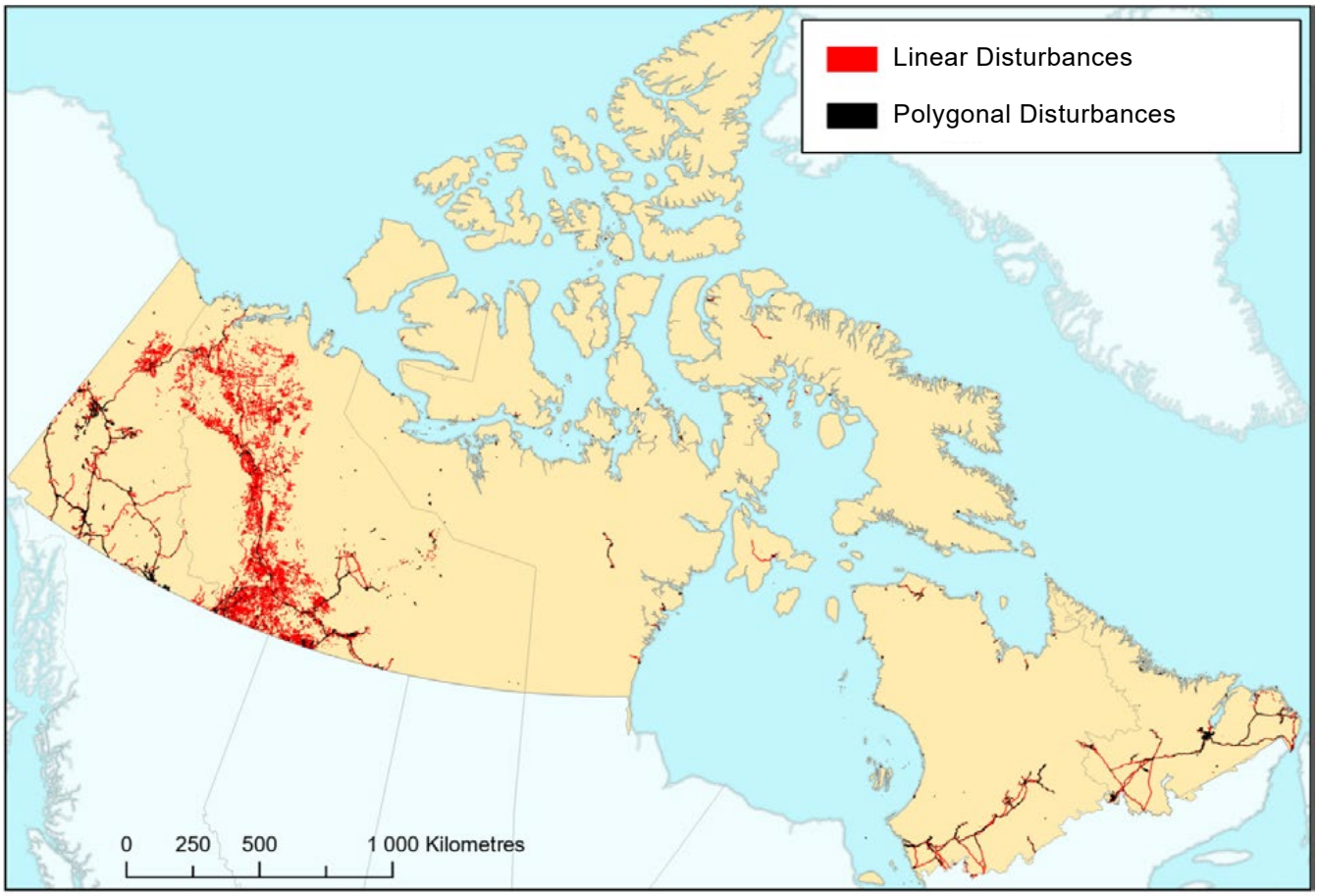
Preexisting GIS datasets of anthropogenic development were used to initialize the search for areas with a high probability of land-use change. Mapping was then expanded outwards from these regions based on the identification of additional disturbances. The resulting spatial dataset provides a comprehensive mapping product for human disturbances in Canada's northern regions. An interpretation guide, similar to the one produced for the Canadian Forest Service (Dyk et al., 2015), was used to ensure consistency in the detection, digitization, and categorization of disturbances.

The human disturbances mapped as linear features in the spatial dataset do not have associated widths. To convert these into areas and align them with polygonal features, experts were consulted in 2020 and 2021 to provide typical widths for each development activity (Lapointe-E., 2022). Due to the broad range of values obtained for roads and the lack of detailed road types in the dataset, additional attributes from Statistics Canada's National Road Network (NRN) were used. Manual measurements on satellite images were also conducted to estimate the width of the cleared areas on either side of the vehicle lanes. With over 28 000 road features in the dataset, a sampling-based approach was used, grouping features into seven road classes. The average width from the sampled data was used to estimate the width cleared for each road class. The full range of manual measurements aligned with the minimum and maximum values obtained from the expert consultation.

Land-use change rates were derived from the difference in polygon area within each time period (i.e., 1990-2000, 2000-2010, 2010-2020), divided by the total number of years in the period to produce a constant annual rate of change.

12 This term has been defined by Statistics Canada as the area consisting of one or more neighbouring municipalities with a population of 100 000 inhabitants or more.

Figure A3.5–22 **Location of Land-Use Change Events in Canada's North**



Biomass Change

The vegetation in this region consists of forest patches in the Boreal Cordillera and Taiga Plains, while the remaining zones are dominated by low vegetation such as shrubs, mixed grass-dwarf shrubs, lichen, moss, wetlands, and areas of bare soils in varying proportions.

The pre-conversion vegetation cover type for each land-use change polygon was derived from the Land Cover of Canada (LCC) map developed by the Canada Centre for Remote Sensing (CCRS) at NRCan (Latifovic, 2019). This map was produced using machine learning models to classify land cover from cloud-free mosaics of satellite images collected during the summer when snow and ice were minimal. The LCC map was selected because it provides full coverage of the study area and offers relevant information for 10 vegetation classes at a local scale (30 m resolution). Area-weighted proportions of LCC classes in the immediate vicinity of each site were used to represent pre-conversion land cover conditions. Furthermore, deforestation events above 60° latitude were used to ensure that areas associated to the Forest Converted to Settlements were excluded to avoid double counting.

Carbon stocks used to determine biomass losses were obtained from the expert consultation process held in 2020-21 (Lapointe-E., 2022). The above-ground biomass estimates are based on primary literature, including field sampling and remote sensing, as well as expert understanding of the relationship between climate and plant productivity in northern environments (Bona et al., 2018; Wulder et al., 2020). For below-ground biomass carbon stock estimates, participants in the consultation concluded that using ratios provided by Poorter et al. 2012 (21% for boreal forest and 69% for tundra) was the most feasible approach due to limited data in literature and insufficient evidence to derive estimates for each of the 10 LCC vegetation classes. Given the diversity of vegetation types and landscapes across this region, above-ground biomass carbon stocks were allocated at a sub-RU level. Table A6.5–13 summarizes the biomass carbon stocks values.

Carbon loss from land-use changes was estimated by multiplying the annual area affected by their corresponding biomass loss factor. Annual area rates and emissions for years after 2020 were extrapolated based on the period from 2010 to 2020, assuming a constant yearly rate. All development activities involved the conversion of Arctic tundra vegetation to Settlements, and all pre-conversion biomass C emitted upon clearing and no carbon gain assumed after conversion, following the IPCC Tier 1 approach (IPCC, 2006).

Soil Carbon and Non-CO_2 emissions

Due to the complex interactions between development practices and permafrost, and limited scientific understanding of the processes that result in emissions and removals in these ecosystems, emissions from soil disturbance in this region cannot be accurately quantified. The expert consultation (Lapointe-E, 2022) determined that additional research is required to quantify emissions and removals associated with the diverse development practices in Canada's North.

Uncertainty

An error propagation approach was used to estimate uncertainty for this category. The estimated uncertainty ranges from 15% to 66% due to the challenges in collecting ground data to determined cleared areas around linear features and biomass carbon content across this extensive region.

A3.5.7.4. Wetlands Converted to Settlements

General Approach and Methods

The methodology for resource extraction, specifically oil sands mining disturbances, is detailed in section A3.5.6.3. Disturbed areas included in this methodology meet the definition of Wetlands, with most emissions and removals assigned to the Wetlands Converted to Settlements subcategory, where peat removal (e.g. surface mining) or capping (e.g., roads, well pads) is the main source of emissions, and a smaller portion assigned to the Wetlands Remaining Wetlands subcategory for disturbances primarily involving vegetation clearing that allows regrowth (e.g., seismic lines).

A3.6. Methodology for Waste Sector

The Waste sector consists of four categories: Landfills, Biological Treatment of Solid Waste, Incineration and Open Burning of Waste, and Wastewater Treatment and Discharge. This section of Annex 3 details the accounting methodologies that are used to describe the greenhouse gas (GHG) emission estimates for these categories with a focus on the following categories and gases:

- Methane (CH_4) emissions from Landfills (municipal solid waste and industrial wood waste landfills).
- CH_4 and Nitrous oxide (N_2O) emissions from Biological Treatment of Solid Waste (composting and anaerobic digestion).
- Carbon dioxide (CO_2), CH_4 and N_2O emissions from Incineration of Waste (municipal solid waste, hazardous, clinical and sewage sludge waste).
- CO_2, CH_4 and N_2O emissions from Wastewater Treatment and Discharge (municipal and industrial).

A3.6.1. Emissions from Landfills

A3.6.1.1. General Approach and Methods

In Canada, the Landfills category comprises two types of landfills: Municipal Solid Waste (MSW) Landfills and Industrial Wood Waste (WW) Landfills. Decay of waste in landfills produces significant amounts of CH_4 and CO_2. However, as the CO_2 is from biogenic sources, it is not included in total waste emissions (to avoid double counting or one-sided equations; the CO_2 emissions from materials of biological origin are accounted for in the Agriculture and Land-Use, Land Use Change and Forestry sectors). Emissions of N_2O from landfills are not estimated as they are not significant, and no quantification methodology is provided by the IPCC (IPCC, 2006, 2019).

Emissions for MSW and WW landfills are calculated separately at the provincial and territorial level. Emissions from MSW landfills are reported to the United Nations Framework Convention on Climate Change (UNFCCC) under category 5.A.1, Managed Waste Disposal Sites, while emissions from WW landfills are reported under category 5.A.1 for industrial pulp and paper landfills and 5.A.2, Unmanaged Waste Disposal Sites for the solid wood industry.

Methane generated from landfills is calculated using a first-order decay (FOD) model, in accordance with Volume 5, Chapter 3, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, hereafter referred to as the 2006 IPCC Guidelines (IPCC, 2006). The IPCC FOD model considers that following an initial period of aerobic conditions, waste deposited in a landfill will decay at a constant rate; resulting in a decrease of emissions from that original deposit over time as the amount of decomposable material is reduced. The aerobic conditions are simulated by including a lag of 6-months before the onset of decay. Assuming that the waste is deposited in landfills at a consistent rate throughout the year, the mean date of deposition if July, making the start of decay January, or the beginning of the following year timestep (IPCC, 2006).

Landfill gas capture, flaring and utilization practices are increasingly common in Canadian landfills. To account for this in the emissions estimates, CH_4 in landfill gas that is captured by facilities is subtracted from the total CH_4¬ generated to determine the amount that is released annually. To account for flaring efficiency (assumed 99.7%) a small amount (0.3%) of the CH_4 from landfill gas that is flared is included in the waste estimates, while emissions associated with utilization of landfill gas are reported in the Energy sector. The amount of CH_4 that remains uncollected and is emitted by a landfill through its cover is further reduced by the oxidation of some of the CH_4 into CO_2 by methanotrophic bacteria found in the landfill cover material.

The calculation of CH_4 emissions from waste landfilled is summarized by Equation A3.6–1. The stepwise calculations that make up the FOD model are represented by Equation A3.6–2 to Equation A3.6–5. Methane generation is calculated on a by-material basis.

Equation A3.6–1 **(modified from 2006 IPCC Guidelines Eq. 3.1)**

$$CH_4\ emitted_T = (CH_4\ generated_T - R_T) \times (1 - OX) + CH_4\ flared_T \times (1 - Efcy_{flr})$$

$CH_4\ emitted_T$	=	CH_4 emitted from landfills in year T (tonne)
T	=	inventory year
$CH_4\ generated_T$	=	CH_4 generated by landfilled waste in year T (tonne)
R_T	=	CH_4 recovered through landfill gas capture in year T (tonne)
OX	=	oxidation factor (fraction)
$CH_4\ Flared_T$	=	amount of CH_4 flared in year T (tonne)
$Efcy_{flr}$	=	flaring efficiency (fraction)

Equation A3.6–2 **(modified from 2006 IPCC Guidelines Eq. 3.2)**

$$DDOC_{m,T} = Waste\ deposited_{m,T} \times DOC_m \times DOC_{f\,m}$$

$DDOC_{m,T}$	=	mass of decomposable degradable organic carbon from material m that is deposited in year T (tonne)
m	=	type of waste material type deposited (e.g., food, paper, etc.)
T	=	year
$Waste\ deposited_{m,T}$	=	mass of waste material m deposited in year T (tonne)
DOC_m	=	fraction of degradable organic carbon in waste type m
$DOC_{f\,m}$	=	fraction of degradable organic carbon (DOC) that can/does decompose, for waste type m

Equation A3.6–3 **(modified from 2006 IPCC Guidelines Eq. 3.4)**

$$DDOCma_T = DDOCmd_T + (DDOCma_{T-1} \times e^{-k})$$

T	=	inventory year
$DDOCma_T$	=	$DDOC_m$ (decomposable DOC, from waste material m) accumulated in the landfill at the end of year (tonne)
$DDOCma_{T-1}$	=	$DDOC_m$ accumulated in the landfill at the end of year (T-1) (tonne)
$DDOCmd_T$	=	$DDOC_m$ deposited into the landfill in year T (tonne)
k	=	decay rate constant ($year^{-1}$)

Equation A3.6–4 **(modified from 2006 IPCC Guidelines Eq. 3.5)**

$$DDOCm\ decomp_T = DDOCma_{T-1} \times (1 - e^{-k})$$

$DDOCm\ decomp_T$	=	$DDOC_m$ (decomposable degradable organic carbon, from waste material m) that decomposed in the landfill in year T (tonne)
T	=	inventory year
$DDOCma_{T-1}$	=	$DDOC_m$ accumulated in the landfill at the end of year (T-1) (tonne)
k	=	decay rate constant ($year^{-1}$)

Equation A3.6–5 **(2006 IPCC Guidelines Eq. 3.6)**

$$CH_4\ generated = DDOCm\ decomp_{m,T} \times FracCH_4 \times 16/12 \times MCF$$

$CH_4\ generated$	=	amount of CH_4 generated from decomposable material
$DDOC_m\ decomp_{m,t}$	=	$DDOC_m$ (decomposable degradable organic carbon, from waste material m) that decomposed in year T (tonne)
$FracCH_4$	=	fraction of CH_4, by volume, in landfill gas
$16/12$	=	molecular weight ratio CH_4/C
MCF	=	methane correction factor

The equation parameters used, including material-specific DOC and DOC_f values and decay rate constants, are presented in section A3.6.1.2 for MSW landfills and in section A3.6.1.3 for industrial wood waste landfills. For more details on the parameters themselves, such as how they are developed and guidance on selecting appropriate values, see Volume 5, Chapter 3, of the 2006 IPCC Guidelines (IPCC, 2006).

A3.6.1.2. Municipal Solid Waste Landfills

A3.6.1.2.1. Model Parameters for Municipal Solid Waste Landfills

Degradable Organic Carbon

The degradable organic carbon (DOC) represents the portion of the organic carbon in the waste that is available for decomposition. It is a characteristic of the materials deposited. DOC is generally measured as a fraction of wet weight of the waste material, with the exception of sewage sludge, which is measured in dry weight. The total DOC is determined by the composition of the waste entering into the landfill. The material-specific DOC values used are shown in Table A3.6–1.

Fraction of Degradable Organic Carbon Which Decomposes

The decomposable degradable organic carbon (DOC_f) is an estimate of the fraction of DOC in waste that decomposes in the landfill. The material-specific DOC_f values are taken primarily from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019). The values are shown in Table A3.6–1.

Table A3.6–1 **Waste Material Degradable Organic Carbon Content and Fraction of Degradable Organic Carbon that Does Decay**

Material	DOC	DOC Source	DOC_f	DOC_f Source
Food	0.15	IPCC (2006)	0.70	IPCC (2019)
Paper	0.40		0.50	
Wood	0.43		0.10	
Yard and Garden	0.20		0.70	
Textiles	0.24		0.50	
Textiles – Natural	0.40		0.50	
Textiles – Synthetic	0.00		0.00	Inert
Leather	0.39		0.10	ECCC estimate that leather is less decomposable waste
Rubber	0.39		0.00	IPCC (2006), Footnote Table 2.4 (Natural rubber doesn't decompose in landfill)
Rubber and Leather	0.39		0.05	Assumed 50/50 mix of Rubber and Leather
Soil and Dirt	0.03	ECCC Estimate	0.10	ECCC estimate that soil & dirt is less decomposable waste
Soiled Paper	0.40		0.50	IPCC (2006), (2019) default (bulk waste)
Diapers and Sanitary Products	0.24	IPCC (2006)	0.50	
Pet Waste	0.24	ECCC Estimate	0.50	
Mixed Construction Debris	0.22	ECCC Estimate	0.10	Assuming degradable portion is wood
Inert Construction Debris	0.00	ECCC Estimate	0.00	Inert
Plastics	0.00	IPCC (2006)	0.00	Inert
Glass				
Metals				
Concrete				
Hazardous		ECCC Estimate		
Oils, Paints and Solvents				
Asphalt				
Electronics				
Ash				
Sludge (Dry Wt)	0.06	ECCC Analysis (weighted mean)	0.70	IPCC (2019, 19R_V5_Waste_Model.xls)
Sludge (Wet Wt)	0.40			
Raw Sludge (Dry Wt)	0.50	IPCC (2019)		
Raw Sludge (Wet Wt)	0.05			
Digested Sludge (Dry Wt)	0.30			
Digested Sludge (Wet Wt)	0.10			
Industrial Sludge	0.09	IPCC 2019		
Other – Residential	0.10	ECCC Estimate	0.50	IPCC (2006), (2019) default (bulk waste)
Other – ICI	0.05			
Other – C&D	0.00			
Other – Unknown	0.05			
Other Inert	0.00		0.00	Inert

Methane Correction Factor

The CH_4 correction factor (MCF) accounts for the decomposition of waste under different management practices. It is used to account for the higher portion of CH_4 that is generated under the anaerobic conditions found in managed landfills as compared to unmanaged landfills, which generally produce less CH_4 from a given amount of waste (IPCC, 2006). All MSW landfills in Canada are assumed to be anaerobic managed landfills (MCF = 1.0).

Decay Rate Constant (k)

The decay rate constant, k, represents the rate at which CH_4 is generated in the FOD reaction after waste has been landfilled. The value of k can be affected by moisture content, nutrient availability, temperature and pH, among other factors. The decay rate constants specified in the 2006 IPCC Guidelines for the boreal-temperate wet and dry climate zones are typically used (IPCC, 2006). The "wet" and "dry" climates are defined by the ratio of mean annual precipitation to potential evapotranspiration: wet climates are defined as when mean annual precipitation is greater than the potential evapotranspiration, while dry climates are defined as when mean annual precipitation is less than the potential evapotranspiration. The material-specific decay rate constants, by climate, are shown in Table A3.6–2. The estimates of waste landfilled by climate zone, for each province, are discussed in section A3.6.1.2.2.

Table A3.6–2 **Decay Rate Constants and Half-Lives of Waste Materials, by Climate**

Material	Decay Rate, k (yr^{-1})		Half-Life (yr)		Source
	Dry	Wet	Dry	Wet	
Food	0.06	0.185	12	4	IPCC (2006)
Paper	0.04	0.06	17	12	
Textiles	0.04	0.06	17	12	
Textiles – Natural	0.04	0.06	17	12	
Textiles – Synthetic	0	0	0	0	Inert
Wood	0.02	0.03	35	23	IPCC (2006)
Yard and Garden	0.05	0.1	14	7	
Soiled Paper	0.05	0.1	14	7	ECCC estimate (equivalent to 'Paper')
Rubber	0	0	0	0	Inert in landfills (IPCC 2006 Table 2.4 Footnote)
Leather	0.02	0.03	35	23	ECCC estimate that Leather is slowly degrading waste
Rubber and Leather	0.02	0.03	35	23	
Diapers and Sanitary Products	0.05	0.1	14	7	IPCC (2006)
Pet Waste	0.06	0.185	12	4	
Mixed Construction Debris	0.02	0.03	35	23	Assumed to be 50% wood (2006 IPCC Guidelines – Wood)
Inert Construction Debris	0	0	0	0	Inert
Soil and Dirt	0.02	0.03	35	23	ECCC estimate that degradable carbon in soil is slowly degrading
Plastics	0	0	0	0	Inert
Oils, Paints and Solvents	0	0	0	0	
Glass	0	0	0	0	
Metals	0	0	0	0	
Hazardous	0	0	0	0	
Concrete	0	0	0	0	
Asphalt	0	0	0	0	
Other Inert	0	0	0	0	
Electronics	0	0	0	0	
Ash	0	0	0	0	
Sludge (Dry Wt)	0.06	0.185	12	4	IPCC (2006)
Sludge (Wet Wt)	0.06	0.185	12	4	
Raw Sludge (Dry Wt)	0.06	0.185	12	4	
Raw Sludge (Wet Wt)	0.06	0.185	12	4	
Digested Sludge (Dry Wt)	0.06	0.185	12	4	
Digested Sludge (Wet Wt)	0.06	0.185	12	4	
Industrial Sludge	0.06	0.185	12	4	
Other – Residential	0.05	0.09	14	8	ECCC estimate (IPCC Bulk Waste; C&D Other is all intert materials)
Other – ICI	0.05	0.09	14	8	
Other – C&D	0	0	0	0	
Other – Unknown	0.05	0.09	14	8	

Application of decay rate constants by material type, rather than as bulk averages for all waste, improves estimation of methane generation by accounting for the differences between decay rates of individual materials and the variations in waste composition over time. For example, food waste has a decay rate constant of 0.185 (yr^{-1}) or a half-life 3.7 years in wet climates, whereas paper has a decay rate constant of 0.06 (yr^{-1}) or a half-life 11.6 years in the same climate. In this example, food exhibits increased decay and release of emissions in the early stages of decomposition, with emissions decreasing more quickly as compared to paper. In contrast, paper initially produces fewer emissions per unit mass, but the emission generation rate decreases less quickly, resulting in relatively higher methane generation rates at later periods.

Fraction of Landfill Gas that is methane

The FracCH_4 value in Equation A3.6–5 represents the fraction of CH_4 in generated landfill gas (volume fraction) from decay of waste. The 2006 IPCC Guidelines (IPCC, 2006) recommended default of 0.5 is used for all time periods and regions. Note that this value differs from the ultimate landfill gas methane concentration, which may differ based on atmospheric inputs (aerobic or semi-aerobic conditions or collection-system over-draw) and based on CO_2 absorption into leachate as bicarbonate.

Methane Recovery

Methane emissions are reduced by the recovery of landfill gas, which is commonly practiced in Canada. Data on methane recovery is collected through voluntary surveys, typically conducted every second year. Facility operators report quantities (volume or mass) of landfill gas or CH_4 recovered by flaring or utilized for energy production to Environment and Climate Change Canada (ECCC) as part of the voluntary surveys. The facility reported quantities stem from various methods, varying by sites; nearly all reported values are from measured flow rates of landfill gas through the collection and recovery systems, calibrated to a standard temperature and pressure and reported with methane concentration of the landfill gas (note that the standard temperatures used vary across sites), The reported landfill gas or CH_4 are then converted to mass (tonnes) of CH_4 recovered by ECCC for compilation. Time series gaps are filled by ECCC using facility-level interpolation and extrapolation, taking into account starting and cessation dates of landfill gas collection, flaring and utilization systems. CH_4 recovery data is also gathered from environmental compliance reports and provincial databases, where available.

Emissions from Flaring and Utilization

Methane in landfill gas is destroyed (oxidized to CO_2) by flaring or when combusted for energy purposes. Methane escaping flaring due to combustion inefficiencies are included in the emission totals (combustion by flaring is considered to be 99.7% efficient). CH_4 released from flaring is added to the CH_4 released from landfills to obtain the total CH_4 emitted. Methane escaping combustion for energy purposes due to inefficiencies are estimated and reported as part of the Energy sector and are not included in the Waste totals.

Oxidation through Landfill Cover

Methane emissions from landfills are reduced further by the oxidation of CH_4 into CO_2 by methanotrophic bacteria in landfill cover material. A broad range of provincial regulations mandate that Canadian landfills be capped with a daily cover of material such as soil, compost, woody material or fill. When a landfill is no longer operational, it is capped with a final, more robust cover.

The 2006 IPCC Guidelines' (IPCC, 2006) default factor of 0.1 for managed landfills covered with CH_4 oxidizing material is used for all regions and years.

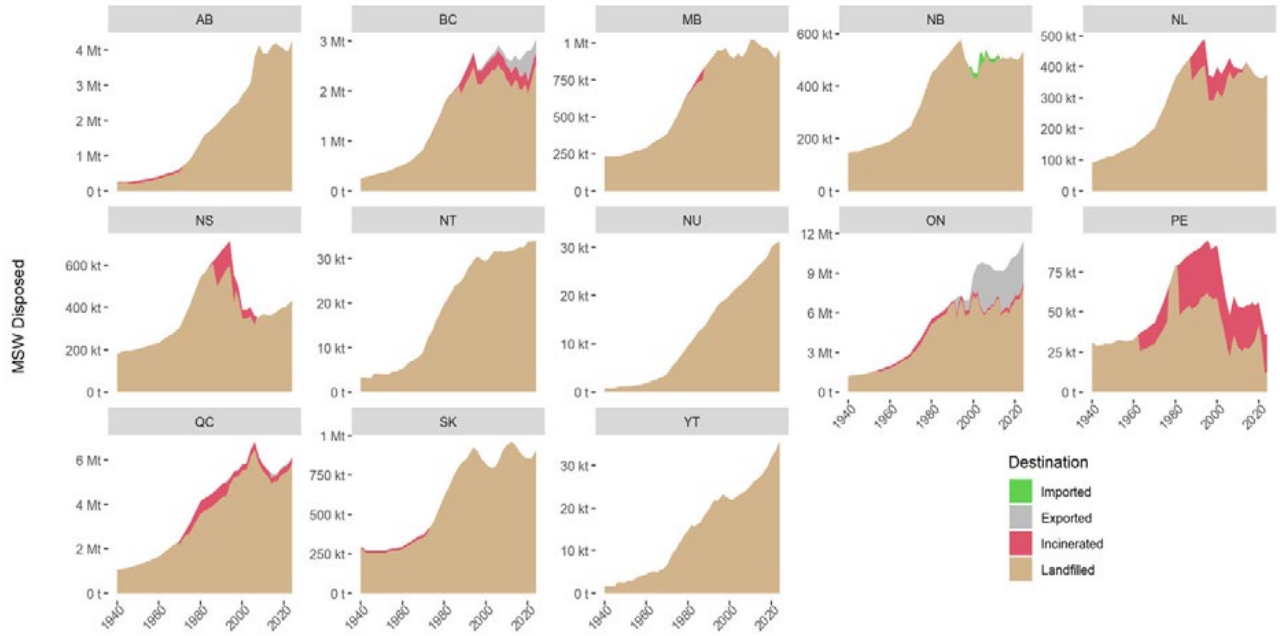
A3.6.1.2.2. Data Sources Municipal Solid Waste Landfills

Most landfilling of waste in Canda is handled by municipal landfill sites; these include both municipally operated and private facilities that specialize in the landfill disposal of waste. Consistent and comprehensive data on the quantity and type of waste landfilled across all landfill sites in Canada are unavailable. There are, however, data available on the total amount of MSW disposed, which is the sum of MSW landfilled, incinerated and exported (for landfill or incineration) abroad. The quantity of waste landfilled can be calculated from the total disposed by subtracting the amount exported and incinerated.

The primary source of data is the Statistics Canada Waste Management Industry Survey, conducted every two years (Statistics Canada, n.d.[a]). Historical disposal data is available from the Levelton report, prepared for Environment Canada (Levelton, 1991). Some additional disposal data is gathered directly from provinces (Prince Edward Island [PE], for example).

The Statistics Canada and Levelton data only include MSW (solid waste). Municipal solid waste, as defined by Statistics Canda for the Waste Management Industry Survey, does not include soil and fill (used for landfill cover; or contaminated), bottom ash, and sewage sludge. Sewage sludge landfilled must be accounted for separately. These are estimated based on the calculated sludge production from the wastewater emissions calculations, accounting for incineration, export and use as agricultural amendment or land-reclamation. See section A3.6.4.1.1 for further details on sludge accounting.

Figure A3.6–1 **Canadian Municipal Solid Waste Disposed and Disposal Fates**



The total waste landfilled is determined from the amount disposed after accounting for amounts incinerated and amounts exported, and adding the amount of sewage sludge landfilled, as represented by Equation A3.6–6. The resulting distribution of waste disposed is shown in Figure A3.6–1. On this figure negative exported waste values correspond to imported waste.

Equation A3.6–6 **Waste Landfilled in Municipal Landfills**

$$Total\ Waste\ Landfilled = [MSW_{Disposed} - MSW_{Incinerated} - MSW_{Exported}] + Sewage\ Sludge_{Landfilled}$$

$Total\ Waste\ Landfilled$	=	mass of waste landfilled, tonnes
$MSW_{Disposed}$	=	mass of MSW disposed in Canada
$MSW_{Incinerated}$	=	mass of MSW incinerated in Canada, tonnes
$MSW_{Exported}$	=	net mass of MSW exported (or imported) to (from) the United States, tonnes
$Sewage\ Sludge_{Landfilled}$	=	mass of sewage sludge landfilled, tonnes

Waste disposal amounts for 1941 to 1980 for all provinces and territories are calculated using national per capita disposal rates obtained from the available literature (Levelton, 1991) and population from Statistics Canada (Statistics Canada, n.d.[b], n.d.[c]). Levelton (1991) presented per capita disposal rates at 5- to 20-year increments. Disposal rates were linearly interpolated for intermediary years. Disposal rates for 1985 and 1990 published in the report were extrapolations and are not included in preparation of the National Inventory Report (NIR) data. Disposal rates for the provinces and territories from 1981 to 1993 are linearly interpolated between the per capita disposal rate in 1980 from Levelton (1991) and the per capita disposal rate in 1994 (1995 in PE) from Statistics Canada.

Waste disposal data from 1994 onward are obtained through Statistics Canada's biennial Waste Management Industry Survey (Statistics Canada, n.d.[a]) which compiles waste disposal data for every even year. Disposal quantities are linearly interpolated for intermediary years (e.g., 1995, 1997, etc.). When survey data are not available for the latest inventory year, the most recent waste disposed quantities are extrapolated on a per capita basis.

Waste disposal quantities for PE and the territories are suppressed in Statistics Canada tables for most years, for confidentiality reasons. Waste disposal data for PE has been obtained from the province for the years 1995 to 2000 and 2004-2018 and 2023-2024. Data gaps in the disposal time series by province and territory were bridged through linear interpolation of per capita disposal rates applied to the provincial/territorial population. Extrapolation is of disposal, where required, is based on holding the per capita disposal rates constant.

Data on the amount of waste incinerated are discussed in section A3.6.3. Waste exports are not directly tracked by Canada. An ECCC internal database of waste exports to the United States has been compiled from U.S. state databases, congressional reports and by contacting state officials. Where data are not available for the most recent reporting years, the last data point is held constant.

Sewage sludge produced is estimated as part of the wastewater treatment organics flow calculations. The amount of sewage sludge landfilled can be estimated in a manner similar to that used for MSW, accounting for incineration and export, but also anaerobic digestion, compost and land application. The accounting of sewage sludge landfilled is detailed in section A3.6.4.1.1 and Equation A3.6–32.

The total amount of waste landfilled is calculated from the MSW disposed, accounting for exports and incineration. The quantities of sludge landfilled are then added. The final amount of waste landfilled is shown in Table A3.6–3 and Figure A3.6–1.

Table A3.6–3 **Waste Landfilled in Municipal Solid Waste Landfills (Million Tonnes)**

Year	Food	Paper	Diapers, Sanitary Products and Pet Waste	Textiles	Rubber and Leather	Raw Sludge (Dry Wt)	Digested Sludge (Dry Wt)	Yard and Garden	Wood	Mixed Construction Debris	Other	Inert	Total
1941–1989	53.18	155.77	0	4.91	2.26	0	0	51.74	15.82	8.42	30.17	96.93	419.2
1990	2.51	5.22	0	0.39	0.05	0.13	0.02	2.38	1.42	0.36	2.07	4.07	18.62
1991	2.55	5.29	0	0.4	0.05	0.13	0.02	2.43	1.45	0.37	2.11	4.14	18.94
1992	2.44	4.97	0	0.39	0.05	0.13	0.02	2.31	1.39	0.35	2.02	3.95	18.02
1993	2.6	5.35	0	0.41	0.05	0.13	0.02	2.47	1.48	0.38	2.15	4.22	19.26
1994	2.76	5.7	0	0.43	0.06	0.13	0.02	2.62	1.58	0.4	2.28	4.48	20.46
1995	2.7	5.6	0	0.42	0.05	0.12	0.02	2.57	1.55	0.39	2.24	4.4	20.06
1996	2.55	5.25	0	0.4	0.05	0.12	0.02	2.42	1.48	0.36	2.11	4.16	18.92
1997	2.57	5.31	0	0.4	0.05	0.12	0.02	2.44	1.49	0.37	2.14	4.2	19.11
1998	2.57	5.31	0	0.4	0.05	0.11	0.02	2.44	1.5	0.37	2.14	4.21	19.12
1999	2.74	5.69	0	0.41	0.05	0.11	0.02	2.6	1.59	0.39	2.26	4.48	20.34
2000	2.83	5.9	0	0.42	0.05	0.11	0.02	2.69	1.65	0.4	2.33	4.62	21.02
2001	2.8	5.81	0	0.42	0.05	0.11	0.02	2.66	1.63	0.4	2.31	4.58	20.79
2002	3.78	5.19	0	0.56	0.16	0.09	0.02	1.15	2.57	0	1.07	6.56	21.15
2003	3.77	5.07	0	0.56	0.16	0.09	0.03	1.17	2.56	0	1.06	6.46	20.93
2004	3.81	5.08	0	0.56	0.16	0.08	0.03	1.2	2.53	0	1.06	6.4	20.91
2005	3.86	5.12	0	0.57	0.17	0.07	0.03	1.26	2.58	0	1.07	6.46	21.19
2006	4.06	5.31	0	0.59	0.17	0.07	0.03	1.4	2.59	0	1.13	6.56	21.91
2007	4.05	5.37	0	0.6	0.17	0.07	0.03	1.41	2.59	0	1.15	6.59	22.03
2008	4.26	2.78	0.59	0.7	0.36	0.06	0.03	0.97	2.65	0	3.47	6.04	21.91
2009	4.27	2.79	0.59	0.7	0.36	0.06	0.03	0.96	2.65	0	3.47	6.05	21.93
2010	4.27	2.74	0.6	0.69	0.35	0.05	0.03	0.97	2.5	0	3.44	5.88	21.52
2011	4.32	2.78	0.62	0.71	0.36	0.05	0.03	0.97	2.54	0	3.48	5.96	21.82
2012	4.35	2.79	0.63	0.72	0.36	0.05	0.03	0.99	2.48	0	3.5	5.85	21.75
2013	4.13	2.62	0.59	0.67	0.34	0.04	0.03	0.96	2.34	0	3.31	5.54	20.57
2014	4.13	2.6	0.59	0.66	0.34	0.04	0.03	0.96	2.36	0	3.32	5.59	20.62
2015	4.17	2.63	0.59	0.67	0.35	0.03	0.03	0.97	2.38	0	3.35	5.65	20.82
2016	4.2	2.62	0.61	0.67	0.35	0.04	0.03	0.99	2.31	0	3.37	5.56	20.75
2017	4.05	2.42	0.65	0.83	0.27	0.04	0.03	0.85	2.17	0	3.55	5.62	20.48
2018	4.21	2.49	0.69	0.86	0.27	0.04	0.04	0.89	2.2	0	3.69	5.8	21.18
2019	4.26	2.52	0.7	0.87	0.28	0.04	0.03	0.9	2.24	0	3.74	5.88	21.46
2020	4.3	2.58	0.7	0.88	0.28	0.04	0.03	0.92	2.24	0	3.78	5.88	21.63
2021	3.68	2.49	0.67	1.08	0.34	0.03	0.03	0.91	2.4	0	4.03	6.08	21.74
2022	3.64	2.51	0.66	1.08	0.34	0.03	0.03	0.9	2.55	0	4.01	6.22	21.97
2023	3.79	2.62	0.69	1.12	0.36	0.04	0.03	0.93	2.66	0	4.17	6.48	22.89
2024	3.98	2.75	0.72	1.17	0.38	0.04	0.04	0.98	2.8	0	4.38	6.81	24.05

Notes:
Inert includes Glass, Metals, Ash, Concrete, Asphalt, Plastics, Inert Construction Debris, Other Inert, Electronics
Full data set, by province, territory and climate region available on request.

Municipal Solid Waste Characterization

Waste characterization is the quantification of the material composition of the waste. Municipal solid waste is characterized after accounting for exports and incineration. Sewage sludge is added to the totals landfilled afterwards and is not included in or impacted by the characterization.

Waste characterization studies with sufficient scope to describe waste composition across all regions of Canada are challenging and costly. As a result, they tend to be completed infrequently. Ideally, waste is characterized separately for every region (province and territory) and for all waste streams or sources. Waste sources, which are available from the Statistics Canada Waste Management Industry Survey and which are used for some characterizations, consist of industrial, institutional and commercial (ICI), construction and demolition (C&D) and residential waste streams.

The level of detail and material classifications vary between characterization studies. Some studies provide regional characterizations, or even characterization by region and waste source. In addition, inconsistencies are noted over time for waste classifications used; a given waste type might be used in one characterization study but not used in subsequent characterization studies. Some examples are the "Rubber and Leather" category, which were considered as one waste type in the characterization study by SMi (SMi, 2016); the "Other Inert" category, which includes the remainder of non-organic waste from the SMi study; and the "Pet Waste" category, which is included in the ECCC characterization studies (ECCC 2025) but not in previous studies.

A full characterization of waste landfilled by waste source, including sewage sludge, is shown in Chapter 7, Figure 7–1. Sources used and applicable timeframes for each source are summarized by general waste type in Table A3.6–4.The characterization study by NRCan (2006) included details for both waste disposed and recycling. Municipal recycling in Canada started in earnest in the 1990s. To reflect the waste composition before recycling, the recycling characterization and waste characterization from NRCan (2006) were combined for the 1976 to 1989 period. The characterization by Bond and Straub (1973) was completed based on data from the United States and was used on the assumption that the Canadian waste profile at the time was reasonably similar. The SMi characterization did not quantify material classes deemed to have low or negligible organic content (SMi, 2016). The ECCC Waste Characterization (ECCC 2025) is based on a rolling characterization, with reports compiled into temporal blocks representing waste composition from 2008 to 2016, 2017 to 2020, and 2021 to present.

Table A3.6–4 **Waste Characterization Sources Used**

Characterization	From	To	Characterized By	Notes
Bond and Straub (1973)	1941	1975	All of Canada	Composition is not specific to Canada
NRCan (2006) (with recycling re-categorized as disposed)	1976	1989	Province/Territory	Material sorted for recycling added to amounts disposed to reflect characterization before widespread implementation of curbside recycling
NRCan (2006)	1990	2001	Province/Territory	NRCan analysis of Statistics Canada waste management industry survey (2002)
SMi (2016)	2002	2007	Province/Territory and Waste Source (Residential, C&D, ICI)	This study only characterized waste with organic content. All other waste was lumped together as "other inert"
ECCC (2025)	2008	2016		Data from reports published between 2008 and 2016
ECCC (2025)	2017	2020		Data from reports published between 2017 and 2020
ECCC (2025)	2021	Present		Data from reports published between 2021 and present (some earlier data used where necessary)

Waste Deposited by Climate Region

The 2006 IPCC Guidelines (IPCC, 2006) define a wet climate as having a mean annual precipitation greater than the mean annual potential evapotranspiration and a dry climate as having a mean annual precipitation less than the mean annual potential evapotranspiration. To determine the proportion of waste landfilled in either wet or dry climate zones (by province), the known quantities of waste disposed of at the largest (approximately 300) landfills were mapped against long-term mean annual precipitation and mean annual potential evapotranspiration (1941 to 2023; Climate Research Unit, University of East Anglia, 0.5 degrees spatial resolution; CRU Version 4.08; Figure A3.6–2). The resulting proportions of wet and dry climate for each province and territory are found in Table A3.6–5, and illustrated on Figure A3.6–2.

Figure A3.6–2 **Long-Term Climate Regions in Canada and Largest Landfill Sties**

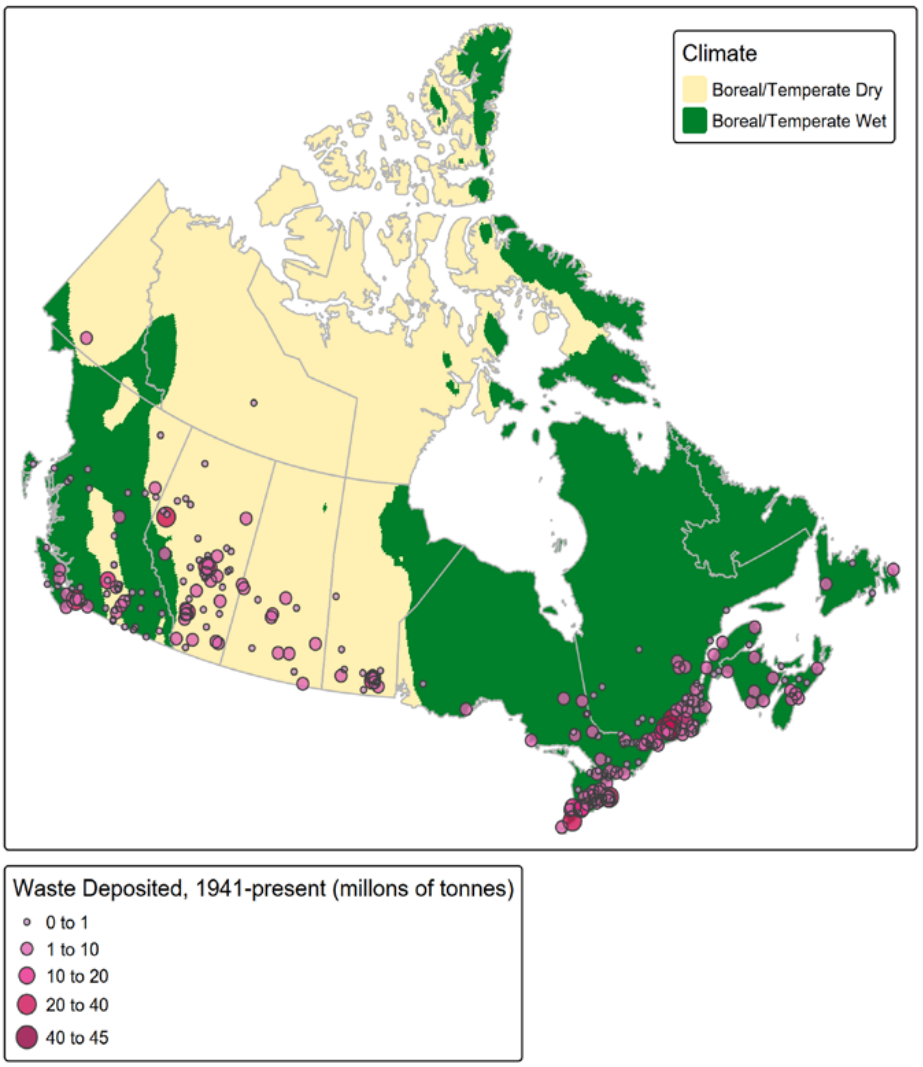


Table A3.6–5 **Proportion of Waste Landfilled in Wet or Dry Climate Regions of Each Province or Territory**

Region	Boreal / Temperate Dry	Boreal / Temperate Wet
AB	0.99	0.01
BC	0.29	0.71
MB	1	0
NB	0	1
NL	0	1
NS	0	1
NT	1	0
NU	0	1
ON	0.03	0.97
PE	0	1
QC	0	1
SK	1	0
YT	1	0

Methane Recovery

Landfill gas capture at large MSW facilities is common across Canada. Given its relatively high concentration of CH_4, captured landfill gas can be used for heat and/or electricity production. Facilities may also choose to flare the captured gas. Note that any emissions resulting from the production of heat or electricity using landfill gas are reported under the Energy sector. See Chapter 7, Figure 7–1, and Table A3.6–6 for CH_4 recovery totals.

Data on landfill gas capture are collected through biennial, voluntary surveys conducted by Environment and Climate Change Canada. Gaps in the time series for reporting facilities are filled using linear interpolation. If data gaps exist before the earliest record for a facility, the landfill gas recovery is extrapolated back in time to the year when operation of flaring or CH_4 utilization first began at that facility (and not extrapolated if these dates are unknown). If survey results for the latest years are not available, the most recent data are held constant.

The amount of CH_4 recovered for each province is calculated from the volume of gas captured by all facilities in that province. National totals are shown in Table A3.6–6.

While flaring of captured landfill gas greatly reduces CH_4 emissions through combustion (oxidation), a small portion (0.3%) of CH_4 is released during the combustion process. As such, a flaring efficiency of 99.7% is used to calculate the total CH_4 generated from landfills (U.S. EPA, 1995).

Table A3.6–6 **CH_4 Generated, Recovered and Emitted from Municipal Solid Waste Landfills in Canada**

Year	CH_4 Generated in Landfills (kt)	CH_4 Flared (kt)	CH_4 Emitted from Flaring (kt)	CH_4 Utilized[a] (kt)	CH_4 Oxidized by Landfill Cover (kt)	Total CH_4 Recovery (Flaring + Utilization) (kt)	Total CH_4 Emitted (kt)
1990	844	69	0.2	56	72	125	647
1991	871	84	0.3	72	71	156	644
1992	896	105	0.3	77	71	182	643
1993	915	109	0.3	83	72	191	651
1994	938	117	0.4	87	73	203	661
1995	964	123	0.4	112	73	234	657
1996	986	111	0.3	153	72	264	650
1997	1000	88	0.3	185	73	273	655
1998	1014	81	0.2	186	75	267	673
1999	1027	75	0.2	179	77	254	696
2000	1046	78	0.2	179	79	257	710
2001	1066	118	0.4	177	77	294	695
2002	1083	122	0.4	173	79	295	709
2003	1094	136	0.4	182	78	317	699
2004	1102	152	0.5	178	77	330	694
2005	1109	162	0.5	169	78	330	701
2006	1116	151	0.5	180	78	331	706
2007	1127	168	0.5	193	77	361	689
2008	1136	167	0.5	200	77	367	693
2009	1146	223	0.7	200	72	423	651
2010	1155	239	0.7	214	70	452	632
2011	1161	244	0.7	219	70	463	628
2012	1167	248	0.7	220	70	468	630
2013	1173	233	0.7	229	71	462	641
2014	1172	211	0.6	240	72	450	649
2015	1170	194	0.6	254	72	447	651
2016	1168	195	0.6	221	75	416	678
2017	1168	200	0.6	216	75	415	678
2018	1166	203	0.6	214	75	416	675
2019	1168	211	0.6	211	75	422	671
2020	1171	223	0.7	205	74	427	669
2021	1174	221	0.7	209	75	428	671
2022	1171	230	0.7	204	74	433	664
2023	1168	239	0.7	199	73	438	657
2024	1169	239	0.7	199	73	438	658

Note:
a. CH_4 emitted from combustion for utilization as heat and power is captured in Energy.

A3.6.1.2.3. Emissions Estimates for MSW Landfills

Methane emissions are calculated as the net CH_4 generated (estimated using the first-order decay model) minus total CH_4 recovery (facility-reported), and reductions from oxidization and emissions from flaring and utilization (calculated based on generation and recovery). Estimates are presented in Table A3.6–6.

A3.6.1.3. Industrial Wood Waste Landfills

A3.6.1.3.1. Data Sources

Industrial wood waste emissions are calculated based on the amount of wood waste residuals estimated to be disposed of in private landfills. This category captures wood waste that does not enter municipal waste management streams in Canada and thus is not accounted for in the MSW component of the Landfills category.

Wood waste disposed of in Canada originates from two primary sources; the solid wood industry (e.g., sawmills) and the pulp and paper industry (e.g., paper manufacturing). Quantities of wood waste residuals from the pulp and paper industry are derived from a literature review, consultations with industry experts and survey data prepared by the National Council for Air and Stream Improvement (NCASI, 2022). Based on the available pulp and paper industry survey data (from 2005 through 2020) landfilling of residuals in the pulp and paper sector in Canada is ongoing; estimates are available for the quantity of wood waste, boiler ash, wastewater treatment residuals and other waste sources (primarily causticizing residuals). Prior to 2005 activity data are available for the province of Quebec, which are used to establish relative quantities of these waste types nationally (the province of Quebec represents a significant portion – up to approximately 40% – of the national pulp and paper industry). Quantities of wood waste disposed for the remaining provinces and territories prior to 2005 were estimated based on an extrapolation of pulp and paper industry-specific production data available from Statistics Canada (Statistics Canada, n.d. [d]) and Natural Resources Canada (NRCan, 2001). Gross-domestic product data for the pulp and paper industry available from Statistics Canada (tables 36-10-0388 and 36-10-0462) were used to estimate the provincial distribution of pulp and paper residuals prior to 2005. The pulp and paper industry gross domestic product data are available beginning of year 1981. For years prior to this, the quantity of waste landfilled was assumed to be constant at the 1981 value. Quantity estimates for pulp and paper residuals are reported in bone dry tonnes.

Estimates of wood waste residuals disposed of in industrial wood waste landfills from the solid wood industry are derived from various studies for the period from 1990 to 2004 (NRCan, 1997, 1999, 2005). It is estimated that historical wood waste residuals disposed in private landfills are composed of approximately 15% residuals from solid wood waste sources (NRCan, 1997). Specific to Canadian sawmills (i.e., the solid wood industry), the increasing demand for waste recovery and waste-to-energy applications has reduced solid wood residuals to negligible amounts. As such, waste residuals are specified as zero for this industry from 2010 onwards. For the period prior to 1990, solid wood waste residuals are unknown and assumed to be the same as in 1990. Quantity estimates for solid wood residuals are reported in bone dry tonnes and converted to hydrated tonnes using an assumed moisture content of 20% (Tchobanoglous et al., 1993) to calculate emissions.

The national values for wood waste disposed of and landfilled are shown in Table A3.6–7. The final estimated amount of wood waste landfilled by province is shown in Table A3.6–8.

A3.6.1.3.2. Model Parameters

A summary of the industrial wood waste model parameters is provided in Table A3.6–9. Both the pulp and paper and solid wood waste emissions calculations are based on the FOD approach detailed above. Independent model parameters are used for each wood waste category as shown in the table. Based on industry survey information on site operations, the model assumes that no landfill gas capture technologies are used at industrial wood waste landfills.

Table A3.6–7 Quantity of Industrial Wood Waste Landfilled in Canada

Year	Wood Waste Landfilled Bone Dry Tonnes (BDt)					
	Pulp and Paper				Solid Wood	Total
	Wood Waste	Ash	Waste Water Treatment Residuals	Other		
1941–1969	792 247	0	54 040	173 336	0	1 019 623
1970	781 970	0	53 339	171 087	1 086 637	2 093 034
1971	773 958	0	58 471	170 497	1 086 637	2 089 564
1972	804 768	0	66 784	178 511	1 086 637	2 136 699
1973	842 859	0	76 301	188 262	1 086 637	2 194 060
1974	880 556	0	86 448	198 061	1 086 637	2 251 702
1975	697 257	0	73 860	157 940	1 086 637	2 015 694
1976	803 183	0	91 398	183 227	1 086 637	2 164 445
1977	806 192	0	98 173	185 231	1 086 637	2 176 233
1978	876 299	0	113 802	202 792	1 086 637	2 279 529
1979	891 845	0	123 144	207 889	1 086 637	2 309 515
1980	857 590	0	125 559	201 368	1 086 637	2 271 154
1981	826 677	0	128 022	195 541	1 086 637	2 236 877
1982	741 135	0	121 133	176 609	1 086 637	2 125 515
1983	816 828	0	140 618	196 103	1 086 637	2 240 186
1984	845 668	0	153 058	204 558	1 086 637	2 289 921
1985	841 598	0	159 874	205 121	1 086 637	2 293 230
1986	827 633	0	241 279	205 770	1 086 637	2 361 319
1987	807 350	0	330 519	205 315	1 086 637	2 429 821
1988	762 454	0	417 675	198 987	1 086 637	2 465 753
1989	693 091	0	493 944	186 394	1 086 637	2 460 066
1990	600 821	0	548 166	167 365	1 086 637	2 402 989
1991	547 716	0	634 929	159 092	1 030 904	2 372 641
1992	474 817	0	699 037	145 083	976 718	2 295 654
1993	479 303	0	705 640	146 454	922 531	2 253 927
1994	511 930	0	753 674	156 423	868 344	2 290 371
1995	525 963	0	774 334	160 711	814 157	2 275 166
1996	506 420	140 672	604 891	154 740	759 970	2 166 694
1997	519 802	216 584	548 680	158 829	705 784	2 149 679
1998	499 460	277 478	457 838	152 613	648 000	2 035 388
1999	295 172	368 794	387 708	441 492	597 410	2 090 576
2000	303 828	379 610	399 078	454 440	543 223	2 080 179
2001	283 367	354 045	372 203	423 837	489 037	1 922 489
2002	290 031	362 371	380 956	433 803	434 850	1 902 010
2003	294 548	368 015	386 889	440 560	380 663	1 870 675
2004	297 359	371 527	390 581	444 764	328 537	1 832 766
2005	212 865	383 290	356 119	458 846	272 289	1 683 409
2006	162 713	413 654	355 937	444 300	218 103	1 594 706
2007	112 560	444 018	355 755	429 754	163 916	1 506 003
2008	102 754	433 984	339 407	426 589	109 729	1 412 464
2009	92 949	423 951	323 059	423 425	55 542	1 318 926
2010	83 143	413 917	306 711	420 260	1 355	1 225 387
2011	73 337	403 884	290 364	417 096	0	1 184 680
2012	63 531	393 850	274 016	413 931	0	1 145 328
2013	53 726	383 817	257 668	410 767	0	1 105 977
2014	43 920	373 783	241 320	407 602	0	1 066 625
2015	48 858	330 040	200 112	381 063	0	960 073
2016	53 796	286 297	158 903	354 524	0	853 520
2017	77 087	306 149	182 239	398 964	0	964 437
2018	100 377	326 000	205 574	443 403	0	1 075 354
2019	70 374	294 175	164 769	419 065	0	948 383
2020	40 371	262 349	123 964	394 727	0	821 411
2021	39 140	245 100	163 275	389 130	0	836 645
2022	37 909	227 851	202 586	383 533	0	851 879
2023	37 909	227 851	202 586	383 533	0	851 879
2024	37 909	227 851	202 586	383 533	0	851 879

Note: Where no data was available, linear interpolation was used between data points.

Table A3.6–8 **Wood Waste Landfilled by Province (Bone Dry Tonnes)**

Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	330 426	1 093 530	21 596	86 036	50 139	29 269	341 971	277	602 611	118 794
1991	323 097	1 059 992	21 386	86 752	49 665	28 366	340 273	263	602 089	118 485
1992	311 055	1 015 860	20 723	84 826	48 131	27 182	330 526	249	586 052	115 229
1993	302 663	980 287	20 401	84 848	47 394	26 226	326 791	235	581 547	114 168
1994	302 364	963 687	20 835	89 184	48 421	25 773	336 386	221	602 611	117 974
1995	296 718	934 551	20 769	90 670	48 283	24 988	337 174	207	606 781	118 564
1996	281 417	882 777	19 802	87 006	46 039	23 601	322 057	194	580 446	113 347
1997	275 584	853 202	19 719	88 392	45 859	22 804	322 536	180	584 024	113 825
1998	285 033	620 806	21 477	116 926	24 554	20 168	301 762	0	697 773	108 888
1999	273 218	639 107	23 622	130 138	31 423	26 966	307 058	0	699 506	108 890
2000	261 416	637 110	24 272	124 825	34 769	20 916	324 825	42	685 593	102 216
2001	238 250	573 435	35 145	106 515	22 687	24 004	287 005	41	660 899	96 767
2002	221 588	564 121	26 617	114 788	28 226	19 611	286 014	40	642 484	107 233
2003	213 777	527 419	24 245	130 009	26 786	19 391	287 496	0	611 177	125 541
2004	197 084	598 032	20 044	143 178	29 992	23 549	280 282	0	439 261	183 478
2005	190 105	539 392	20 083	72 724	27 416	23 712	244 358	0	486 847	146 845
2006	199 671	543 677	22 402	73 073	31 874	15 597	225 236	0	514 296	23 407
2007	156 921	485 533	20 862	80 339	31 436	21 835	222 847	0	507 038	20 171
2008	163 704	446 612	21 882	66 986	33 129	21 561	209 297	0	468 494	8 230
2009	168 085	389 507	18 600	66 241	18 169	19 409	183 864	0	449 726	19 212
2010	168 840	354 289	10 727	69 429	11 193	19 702	170 589	0	406 400	14 557
2011	158 537	377 739	11 404	63 290	10 753	16 608	152 602	0	382 534	11 213
2012	164 691	379 951	12 405	61 896	10 771	9 861	128 512	0	365 358	11 884
2013	180 287	368 352	13 830	62 554	10 329	14 424	114 014	0	327 652	14 534
2014	166 281	389 543	13 065	52 629	11 582	11 180	111 947	0	296 175	14 224
2015	159 753	358 821	11 322	49 256	8 579	9 881	97 952	0	253 292	11 218
2016	151 638	317 371	10 345	44 999	6 656	7 921	88 975	0	209 461	16 154
2017	159 252	353 344	12 852	50 622	7 327	9 161	105 842	0	245 577	20 461
2018	173 429	379 061	17 343	54 517	8 004	10 063	122 897	0	286 780	23 260
2019	163 699	347 228	15 838	47 840	6 258	10 506	102 125	0	234 160	20 729
2020	157 624	299 233	17 320	41 800	4 535	5 987	89 370	0	184 367	21 176
2021	180 157	276 737	22 030	43 364	6 754	6 975	92 707	0	194 124	13 797
2022	181 214	261 265	27 524	45 480	7 953	8 543	88 085	0	212 160	19 656
2023	185 722	252 650	30 976	46 248	7 597	6 402	79 440	0	222 534	20 310
2024	191 891	247 458	31 659	52 996	6 515	8 194	64 391	0	230 125	18 649

Table A3.6–9 **Wood Waste Landfills Model Input Parameter Summary**

Waste Type		Parameter	Value	Basis
Pulp and Paper	All	Oxidation Factor (Ox)	0.1	IPCC 2006/2019 – value for covered landfills; consistent with NCASI 2022 survey
		Methane Correction Factor (MCF)	1	IPCC, 2006/2019 – value for managed, anaerobic sites; consistent with NCASI 2022 survey
		Methane Fraction in Landfill Gas (F)	0.5	IPCC 2006/2019 – default
	Wood Waste	DOC_f	0.1	IPCC, 2019 – value for less decomposable wastes (wood/engineered wood products)
		k (yr^{-1})	0.03	IPCC 2006/2019 default for wood (slowly degrading waste), Table 3.3, wet climate
		DOC	0.5	IPCC 2006/2019 value for wood waste residuals (Table 2.4) – dry weight basis
	Ash	DOC_f	0	Assumed to be inert (negligible degradable organic carbon content)
		k (yr^{-1})	0	
		DOC	0	
	WWTR	DOC_f	0.1	IPCC, 2019 – value for less decomposable wastes (wood/engineered wood products)
		k (yr^{-1})	0.03	IPCC 2006/2019 default for wood (slowly degrading waste), Table 3.3, wet climate
		DOC	0.44	IPCC 2006/2019 value for P&P wastewater treatment residuals (Table 2.5) – converted to dry weight basis
	Other (causticizing residuals)	DOC_f	0	Analysis by Lavallée (1996)
		k (yr^{-1})	0	
		DOC	0	
Solid Wood Waste		Oxidation Factor (Ox)	0	IPCC 2006/2019 – value for uncovered landfills
		Methane Correction Factor (MCF)	0.8	IPCC 2006 default for deep unmanaged landfills
		Methane Fraction in Landfill Gas (F)	0.5	IPCC 2006/2019 (default)
		DOC_f	0.1	IPCC, 2019 – value for less decomposable wastes (wood/engineered wood products)
		k (yr^{-1})	0.03	IPCC 2006/2019 default for wood (slowly degrading waste), Table 3.3, wet climate
		DOC	0.43	IPCC 2006/2019 value for P&P wastewater treatment residuals (Table 2.5) – wet weight basis

A3.6.2. Biological Treatment of Solid Waste (5.B)

The Biological Treatment of Solid Waste category consists of the following two emission sources: composting and anaerobic digestion.

A3.6.2.1. Composting (5.B.1)

The greenhouse gas emissions estimated from composting in Canada include CH_4 and N_2O. Since CO_2 emissions released by composting result from the decomposition of organic material from biomass sources, these emissions are not included in the national total.

A3.6.2.1.1. Methodology

A Tier 3 method is used to estimate emissions from composting facilities. Feedstock-specific emission factors developed through a literature review are applied to quantities of treated compost, as shown in Equation A3.6–7 and Equation A3.6–8. Emissions are calculated at a facility level and combined to create emissions estimates at provincial and national levels.

Equation A3.6–7 **CH_4 Emissions from Composting**

$$CH_4 Emissions = \sum_i (M_i \cdot EF_i) \cdot 10^{-3}$$

$CH_4\ Emissions$ = total CH_4 emissions in inventory year, Gg CH_4
M_i = mass of organic wet waste treated by type i, Gg
EF = emission factor for treatment i, g CH_4/kg waste treated by waste type
i = composting feedstock at facility i

Emission factors for various feedstocks include those for yard waste (1.72 g/kg), MSW (1.51 g/kg), biosolids/manure (3.54 g/kg) and a mixture of the aforementioned wastes co-composted (1.09 g/kg) based on wet weight (ECCC, 2020a).

Equation A3.6–8 **N_2O Emissions from Composting**

$$N_2O\ Emissions = \sum_i (M_i \cdot EF_i) \cdot 10^{-3}$$

$N_2O\ Emissions$	=	total N_2O emissions in inventory year, Gg N_2O
M_i	=	mass of organic wet waste treated by type i, Gg
EF	=	emission factor for treatment i, g N_2O/kg waste treated by waste type
i	=	composting feedstock at facility i

Emission factors for various feedstocks include those for yard waste (0.25 g/kg), MSW (0.18 g/kg), biosolids/manure (0.18 g/kg) and a mixture of the aforementioned wastes co-composted (0.11 g/kg) based on wet weight (ECCC, 2020a).

A3.6.2.1.2. Data Sources

The activity data used to estimate CH_4 and N_2O emissions from composting are based on commercial/municipal facility-level information collected from industry surveys (from 1992 forward), technical reports, and facility websites. To address missing data from facilities, the previous years data was carried forward to the missing year(s), with the years 1990 and 1991, which are specified as equal to the 1992 survey results.

A3.6.2.1.3. Residential Waste Composting

Greenhouse gas emissions from the residential composting of organic waste are estimated based on IPCC Tier 1 methods using the quantity of residential waste disposed in outdoor composting bins or piles and CH_4 and N_2O emission factors from literature. The quantity of organic waste disposed of in residential settings using outdoor composting bins or piles is calculated as the product of the weight of compost produced per household (3 kg per week, as suggested in Andersen et al., 2011) and the number of Canadian households participating in at-home composting (25% from 2007 to present and 20% prior to 2007) based on Statistics Canada's Households and the Environment Survey (HES).

The HES is also used to estimate that home composting is practiced 10 months of the year on average in Canada (Statistics Canada, n.d. [e]). To account for this, a multiplier of 10/12 is applied to the emissions estimates. It was assumed that due to the cooler climates of the territories composting is not widely practiced, and emissions for these regions are assumed to be negligible.

Emission factors for CH_4 (4.2 kg CH_4 per tonne wet waste) and N_2O (0.55 kg N_2O per tonne wet waste) were available from literature (Andersen et al., 2011). Using the annual weight of residential waste composted at home and the emission factors detailed above, CH_4 and N_2O emissions were calculated using Equation A3.6–7 and Equation A3.6–8.

A3.6.2.2. Anaerobic Digestion at Biogas Facilities (5.B.2)

Methane is the only greenhouse gas considered for emissions from anaerobic digestion of solid waste in Canada. Emissions of N_2O from anaerobic digestion are negligible according to the 2006 IPCC Guidelines and are therefore not estimated for this sector. Since CO_2 emissions released by anaerobic digestion result from the decomposition of organic material from biomass sources, these emissions are not included in the national total.

A3.6.2.2.1. Methodology

Greenhouse gas emissions from anaerobic digestion of solid waste at biogas facilities are estimated for Canada using a Tier 3 method. The Tier 3 method includes determination of the CH_4 component of the biogas at the facility-level, a portion of which is lost through on-site leakages in the system. The loss from on-site leakages in the system is calculated as 2.1% of the CH_4 in the biogas produced. This value was developed from compiling losses found in primary literature and survey data from municipal, industrial and wastewater digesters (ECCC, 2020b). Losses from biogas upgrading and incomplete combustion are not included in on-site leakage loss. Losses from venting are not reported as venting occurs infrequently and is not part of typical operations in Canada; it is believed these emissions are negligible. Emissions are calculated according to Equation A3.6–9.

Equation A3.6–9 **CH_4 Emissions from Anaerobic Digestion**

$$\boldsymbol{CH4\ Emissions} = \sum_{i}((\boldsymbol{B_i} \cdot \boldsymbol{M}) \cdot \boldsymbol{EF}) \cdot (\boldsymbol{D}) \cdot \boldsymbol{10^{-3}}$$

$\boldsymbol{CH_4\ Emissions}$	=	total CH_4 emissions in inventory year, Gg
$\boldsymbol{B_i}$	=	biogas production by i, m^3
$\boldsymbol{D}$	=	density of CH_4 at normal temperature and pressure
$\boldsymbol{M}$	=	Average CH_4 content of biogas from inventory facilities
$\boldsymbol{EF}$	=	emission factor for treatment i, as percentage of total CH_4 in biogas produced that is lost through onsite leakages
$\boldsymbol{i}$	=	facility i

A3.6.2.2.2. Data Sources

The activity data is based on facility level biogas production reported through in-house and industry-based surveys. In the absence of facility reported data for biogas production, a conversion factor by feedstock type is used to generate biogas production from initial feedstock input. Only municipal and industrial anaerobic digestion facilities are reported under 5.B.2, whereas wastewater anaerobic digesters are reported under CRT category 5.D. On-farm anaerobic digesters are currently not included in our Canadian inventory, but will be considered in future inventories.

A3.6.3. Incineration and Open Burning of Waste (5.C)

Waste incineration is defined in the 2006 IPCC Guidelines as the combustion of solid and liquid waste in controlled incineration facilities. Incineration emissions in Canada come from MSW incineration, hazardous waste incineration, clinical waste incineration and sewage sludge incineration. Open burning of waste includes burning garbage in backyard barrels and/or open pits. This section of Annex 3 details the accounting methodologies that are used to describe the GHG emission estimates for these categories.

In keeping with the 2006 IPCC Guidelines (IPCC, 2006), only CO_2 emissions resulting from oxidation of carbon in waste of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents, and waste oil) are considered net emissions and are included in the national CO_2 emissions estimate. CO_2 emissions from combustion of biomass materials (e.g., paper, food and wood waste) contained in the waste are biogenic emissions and are not included in national total emission estimates.

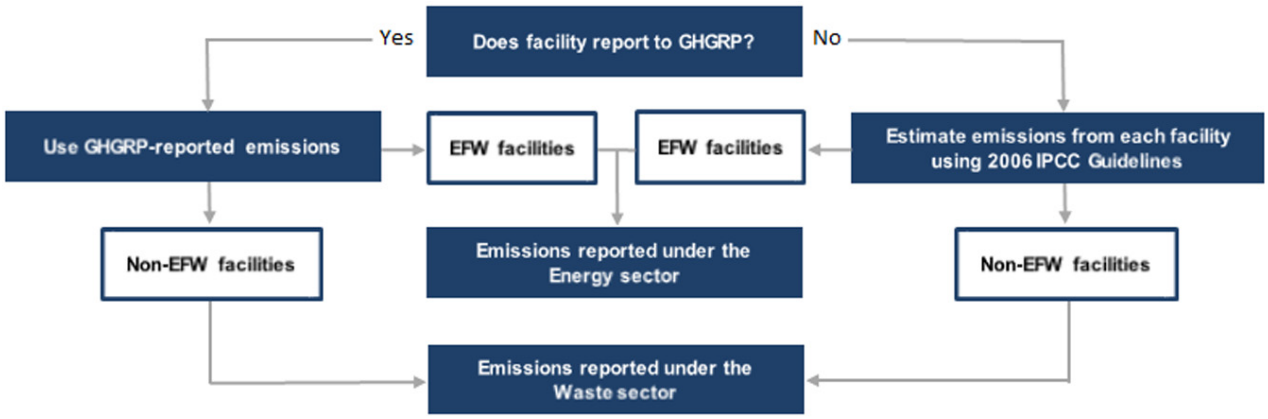
Some facilities generate energy in the form of electricity and/or heat from waste incineration. These facilities are referred to as energy-from-waste (EFW) facilities. Other facilities simply incinerate waste for disposal purposes and are referred to as non-energy-from-waste (non-EFW) facilities. In accordance with the 2006 IPCC Guidelines, emissions from waste incineration with energy recovery are reported in the Energy sector, while emissions from waste incineration without energy recovery are reported in the Waste sector. The following section describes the methodology used for all incinerators, though final emissions are reported under the appropriate sector (Figure A3.6–3).

The Greenhouse Gas Reporting Program (GHGRP) has significant coverage of the incineration sector for recent years. Over time, incineration practices have changed from many small facilities treating waste on site, to large specialized central facilities treating waste shipped in from across the provinces. Where GHGRP does not have coverage, facility-specific emission estimates were developed using the best available information.

Some facilities in Canada burn waste from multiple waste sources. For example, clinical waste is often burned alongside MSW waste. Emissions from facilities that treat more than one type of waste have been calculated according to the specific waste type but are reported under the facilities' primary waste sector. Therefore, if a facility treats small quantities of clinical waste alongside MSW, it is considered an MSW facility and the clinical waste emissions will be reported under MSW.

For the 2026 NIR, open burning of residential waste is now included in the GHG emission estimates, as detailed in this section.

Figure A3.6–3 **Decision Tree for Collecting, Estimating and Reporting GHG Emissions from Incineration Facilities**



Note:
EFW = energy-from-waste

A3.6.3.1. Data Sources

Tonnage of Waste Incinerated

The total amount of waste incinerated is used for facilities that do not report to the GHGRP. It is important to note that these data are also used to isolate the amount of waste landfilled in Canada from the amount of waste disposed of, as discussed in section A3.6.1.2.2. Therefore, even where a facility reports GHG emission totals to GHGRP, annual tonnage incinerated is still collected. The amount of waste incinerated at facilities across Canada is obtained through voluntary biennial surveys of incineration facilities conducted by ECCC. The survey has collected data every two years since 2008.

Supplemental data sources are used for facilities not included in the survey, either due to non-response or because the facility closed before the first survey was conducted. Tonnage is estimated using historical reported values (Goodick, 2002, Sawell et al., 1996; Environment Canada, 1999, 2003). Other sources include progress reports prepared by the Canadian Council of Ministers of the Environment (CCME) on issues related to dioxins, furans and mercury emissions, as clinical waste incineration was formerly a major source of these pollutants (CCME 2006, 2007, 2010). A report on solid waste incineration in Canada prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada, 2003) was also used. Quantities of material incineration in Canada are found in Table A3.6–10.

Where the time series of tonnage incinerated is incomplete for the operational lifetime of a facility, the nearest data are carried forward or backward. Facilities in the clinical waste incineration sector are treated slightly differently as it used to be common practice to have small batch incinerators located at hospitals. Over time, provinces underwent mass closures of their small batch hospital incinerators and switched to shipping waste to central specialized facilities. Missing data points for these small hospital incinerators are estimated based on interpolation using provincial population numbers.

Contents of MSW waste incinerated include paper, glass, metal, plastic, food waste, yard waste, textiles, rubber, wood and other materials. The types of clinical waste incinerated in Canada include cytotoxic waste, human or animal anatomical waste and pharmaceutical waste (Stericycle, 2014). Hazardous waste incineration includes contaminated substrates such as soils, wood, metal and other material. The hazardous waste quantities may also include inorganic wastes such as aqueous solutions containing heavy metals, or wastes such as water-based urethanes, as opposed to solvent-based urethane wastes that have high fossil fuel carbon content. Sewage sludge incineration is the incineration of biosolids resulting from the processing of municipal sewage.

Table A3.6–10 **Estimated Tonnes of Waste Incinerated**

Year	Non-EFW Facilities				EFW Facilities
	MSW	Clinical Waste	Hazardous Waste	Sewage Sludge	
1990	208 545	3 196	100 762	128 402	1 020 519
1991	208 583	3 209	109 111	137 078	1 009 863
1992	210 428	3 225	117 879	143 981	1 178 827
1993	210 233	4 794	125 109	151 667	1 064 215
1994	209 967	4 804	142 050	167 608	885 648
1995	209 354	4 816	164 727	167 607	887 873
1996	209 897	4 823	146 125	185 416	908 183
1997	122 987	4 825	129 348	178 303	907 120
1998	114 743	2 899	155 511	176 812	910 888
1999	100 474	2 902	139 420	186 514	942 739
2000	100 318	2 989	168 379	184 922	904 194
2001	100 257	3 778	179 525	189 282	892 832
2002	100 078	3 902	184 845	202 889	908 266
2003	98 485	3 859	144 036	192 192	778 658
2004	86 844	4 459	161 891	191 371	799 166
2005	73 316	4 936	160 688	188 248	791 650
2006	73 665	5 296	147 775	191 540	802 500
2007	73 218	5 158	134 854	190 014	752 336
2008	70 085	3 196	147 870	190 919	760 567
2009	52 893	3 346	133 780	192 681	748 577
2010	42 343	2 843	138 685	193 360	695 870
2011	30 652	3 363	131 024	207 415	784 768
2012	34 607	2 966	87 251	201 506	778 739
2013	27 000	3 213	91 979	200 373	777 303
2014	22 450	3 177	110 371	208 007	756 748
2015	19 707	3 054	125 736	215 471	805 802
2016	22 140	3 272	120 347	205 403	854 528
2017	23 334	3 380	121 838	201 599	881 407
2018	23 318	3 229	115 950	206 725	866 623
2019	21 958	2 871	116 615	215 480	860 908
2020	19 866	2 850	113 167	197 642	866 314
2021	20 829	3 124	101 870	197 026	857 975
2022	21 461	3 056	90 794	198 403	842 901
2023	22 181	2 787	85 702	204 865	851 159
2024	22 181	2 795	85 702	204 865	850 897

Notes:
MSW = municipal solid waste
EFW = energy-from-waste

A3.6.3.1.1. Methodology

Emission estimates are compiled at a facility level, and a distinction is made between EFW facilities and non-EFW facilities. Where GHGRP emissions are available, they are used. Where GHGRP emissions are not available, facility-specific emissions are estimated using methodologies prescribed in the 2006 IPCC Guidelines (IPCC, 2006).

Facilities Reporting to the GHGRP

GHGRP facility data are available annually from 2004 onwards, though most large incinerators started reporting in 2009. Where facilities were operating before 2009, the emissions time series was completed by assuming that tonnage incinerated is directly correlated with emissions. The surrogate data method prescribed in Volume 1, Chapter 5.3.3.2, of the 2006 IPCC Guidelines (IPCC, 2006) is used to complete the time series of emissions using annual tonnage incinerated by the facility, obtained through surveys and/or reports, as well as GHGRP data for all years for which such data are available.

Note that GHGRP reporting guidelines require that facility-reported CO_2 emissions are derived only from wastes of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents and waste oil). CO_2 from the biogenic portion of waste (e.g., food, wood, garden waste) are excluded from emissions totals.

Non-Reporting Facilities

There are a large number of incinerators that either closed before the GHGRP was launched or operated below the reporting threshold. Many of these facilities that are classified under MSW were small incinerators across Newfoundland and Labrador, but also include some larger facilities in Ontario, Quebec, British Columbia and Alberta. Estimates for these facilities were developed using the 2006 IPCC Guidelines and the best available parameters for each facility.

CO_2 Emissions

Emissions of CO_2 from MSW incineration are estimated using the mass-balance approach prescribed by Equation A3.6–10, equivalent to Equation 5.2 in the 2006 IPCC Guidelines.

Where available, facility-specific waste characterization data was used to determine the different materials of waste in the waste incinerated (factor "WF_j" in Equation A3.6–10). Where facility-specific characterization data were not available, provincial characterization data were taken from Environment Canada (Environment Canada, 1996). This report contains waste characterization data for EFW and non-EFW streams of waste incineration. Table A3.6–11 contains the default factors from the 2006 IPCC Guidelines that were used to determine the CO_2 emissions from each waste type incinerated. The default values of 60% for total carbon (% of dry weight) and 40% for fossil carbon as a percentage of total carbon was used for clinical waste, and a carbon content of 50% and fossil carbon of 90% as a percentage of total carbon were used for hazardous waste. These values come from the 2006 IPCC Guidelines (IPCC 2006).

Table A3.6–11 **Default Factors Used in Equation A3.6–10 to Determine CO_2 from Incineration**

Waste Type	Dry Matter Content (% Wet Weight)	Total Carbon (% Dry Weight)	Fossil Carbon (% Total Carbon)
Paper	90	46	1
Textiles	80	50	20
Food	40	38	0
Wood	85	50	0
Yard	40	49	0
Diapers	40	70	10
Rubber	84	67	20
Plastic	100	75	100
Metal	100	0	0
Glass	100	0	0
MSW Other[a]	100	34	35
Clinical	65	60	40
Hazardous Waste	100	50	90
Sewage Sludge	100	45	0
Organics[b]	40	44	0
Inorganics	100	3	100
Fossil Liquid Waste	100	80	100
Solvents	100	80	80
Industrial Wood	85	41	1
Industrial Sludge	100	50	90
Other Industrial Waste	100	50	90

Notes:
a. Many facilities report "other" waste, without identifying what it includes. Therefore, an average of textiles, food, garden, rubber and inert waste are used in these cases. Note that paper and plastic are always characterized separately and so are not incorporated into the "other" parameter.
b. In cases where facility waste characterization includes organics in general, the organics parameters are used. If the facility distinguishes between food and garden waste, those specific factors are used.

A default factor of 1 is used as the oxidation factor (OF) for all waste types and facilities.

Equation A3.6–10 **(modified from 2006 IPCC Guidelines Equation 5.2)**

$$CO_2\ Emissions = Waste \times \sum(WF_j \times dm_j \times CF_j \times FCF_j \times OF) \times 44/12$$

$CO_2\ Emissions$	=	CO_2 emissions in inventory year
$Waste$	=	total amount of waste incinerated
J	=	component of MSW incinerated, such as paper/cardboard, textiles, food waste, wood, plastic, garden waste, plastics, metal, glass, etc.
WF_j	=	fraction of waste type/material j in total MSW waste incinerated
dm_j	=	dry matter content of component j in total MSW waste incinerated
CF_j	=	fraction of carbon in the dry matter (i.e., carbon content) of component j
FCF_j	=	fraction of fossil carbon in the total carbon of component j
OF	=	oxidation factor
$44/12$	=	conversion factor from C to CO_2

CH_4 Emissions

CH_4 emissions from incineration are determined for each facility using default emission factors from the 2006 IPCC Guidelines. Emission factors are multiplied by the total annual waste incinerated at the facility (Equation A3.6–11). Emission factors vary depending on how the incinerator is fed (continuous, semi-continuous, or batch-type incineration) and on the incinerator type (stoker vs fluidized bed). The most appropriate emission factor was chosen for each facility. In the absence of IPCC default emission factor values for hazardous waste, CH_4, emission factors were derived using data from one hazardous waste incineration facility that had provided total emissions based on direct measurements taken in 2007. The site emitted 0.03 tonnes of CH_4 and burned 177 tonnes of hazardous waste. Therefore, the emission factor 169 g CH_4/ tonnes of hazardous waste was determined. CH_4 emissions from sewage sludge are derived using the emission factor of 9.7 kg/kt of total dried solids for fluidized bed sewage incinerators obtained from the U.S. Environmental Protection Agency (U.S. EPA, 1995). CH_4 emissions from sewage sludge incineration are dependent on the quantity of dried solids incinerated. To calculate the CH_4 emissions, the quantity of dried solids incinerated is multiplied by an appropriate emission factor.

Equation A3.6–11 **(modified from 2006 IPCC Guidelines Equation 5.4)**

$$CH_4\ Emissions = \sum(W_f \times EF_f)$$

$CH_4\ Emissions$	=	CH_4 emissions from waste incineration in inventory year
W_f	=	total amount of waste incinerated at facility f
EF_f	=	emission factor most appropriate for facility f

N_2O Emissions

As with CH_4 emissions, N_2O emissions from incineration are determined for each facility using default emission factors from the 2006 IPCC Guidelines. Emission factors are multiplied by the total annual waste incinerated at the facility (Equation A3.6–12). Emission factors vary depending on the feed type of the incinerator (continuous, semi-continuous, and batch-type incineration). Solid waste default emission factors were used in accordance with the IPCC Good Practice Guidance (IPCC, 2000) as no clinical-waste-specific values are provided. The N_2O emissions for a given site were therefore calculated using the stoker default emission factors for continuous incineration (50 g N_2O/t waste incinerated) and batch-type incineration (60 g N_2O/t waste incinerated) provided in IPCC (2006). Emissions of N_2O from sewage sludge incineration have been updated using the IPCC 2006 Guidelines default emission factor 0.99 kg/t of dried sewage sludge incinerated (IPCC, 2006). Hazardous waste N_2O emission factors were derived using the same methodology as CH_4. Direct measurements of 0.56 tonnes N_2O for 177 tonnes of hazardous waste burned in 2007 result in an emission factor of 3164 g N_2O/tonne HW.

Note that although the 2006 IPCC Guidelines provide an MSW incinerator emission factor for open burning, it is assumed that no MSW incineration facilities in Canada practice open burning. The most appropriate emission factor was chosen for each facility.

Equation A3.6–12 **(modified from 2006 IPCC Guidelines Equation 5.5)**

$$N_2O\ Emissions = \sum(W_f \times EF_f)$$

$N_2O\ Emissions$ = N_2O emissions from MSW incineration in inventory year
W_f = total amount of MSW incinerated at facility f
EF_f = emission factor most appropriate for facility f

The full list of emission factors used can be found in Table A3.6–12.

Table A3.6–12 **Default CH_4 and N_2O Emission Factors for Incineration Facilities**

Waste Type	Feed Type	Incinerator Type	CH_4 Emission Factor (g/t)	N_2O Emission Factor (g/t)
Municipal Solid Waste	Continuous	Stoker	0.20	50.00
Municipal Solid Waste	Continuous	Fluidized Bed	0.00	50.00
Municipal Solid Waste	Semi Continuous	Stoker	6.00	50.00
Municipal Solid Waste	Semi Continuous	Fluidized Bed	188.00	50.00
Municipal Solid Waste	Batch	Stoker	60.00	60.00
Municipal Solid Waste	Batch	Fluidized Bed	237.00	60.00
Hazardous Waste	Continuous	Stoker	169.49	3 163.84
Hazardous Waste	Batch	Stoker	169.49	3 163.84
Sewage Sludge	Continuous	Fluidized Bed	9.70	990.00
Sewage Sludge	Continuous	Stoker	9.70	990.00
Clinical Waste	Continuous	Stoker	0.20	50.00
Clinical Waste	Batch	Stoker	60.00	60.00
Clinical Waste	Semi Continuous	Stoker	0.20	50.00
Other Sludge	Continuous	Stoker	0.20	450.00
Other Sludge	Batch	Stoker	60.00	450.00
Fossil Liquid Waste	Continuous	Stoker	0.20	100.00
Fossil Liquid Waste	Batch	Stoker	60.00	100.00
Industrial Waste	Continuous	Stoker	0.20	50.00
Industrial Waste	Continuous	Fluidized Bed	0.00	50.00
Industrial Waste	Semi Continuous	Stoker	6.00	50.00
Industrial Waste	Semi Continuous	Fluidized Bed	188.00	50.00
Industrial Waste	Batch	Stoker	60.00	60.00
Industrial Waste	Batch	Fluidized Bed	237.00	60.00

Total Emissions

Table A3.6–13 summarizes emissions from EFW and non-EFW facilities. The EFW emissions are reported under the Energy sector, while the non-EFW emissions are reported under the Waste sector.

Table A3.6–13 **National Emissions from Incineration (kilotonnes of CO_2 eq)**

Year	Non-EFW Facilities				EFW Facilities
	MSW	Clinical Waste	Hazardous Waste	Sewage Sludge	
1990	65	2	191	39	358
1991	65	2	202	42	354
1992	65	2	214	44	420
1993	65	3	221	46	386
1994	65	3	253	51	334
1995	64	3	295	51	334
1996	64	3	259	56	341
1997	39	3	228	54	335
1998	37	2	271	53	337
1999	33	2	242	56	349
2000	33	2	280	56	338
2001	33	2	299	57	333
2002	33	2	308	61	337
2003	33	2	258	58	295
2004	28	3	275	58	301
2005	23	3	276	57	300
2006	23	3	254	58	302
2007	23	3	240	57	284
2008	23	3	259	57	287
2009	18	4	222	58	284
2010	15	3	243	58	261
2011	11	3	229	63	287
2012	12	3	108	61	342
2013	10	4	113	73	335
2014	8	4	91	79	295
2015	7	3	121	76	373
2016	8	4	112	78	415
2017	8	5	113	64	396
2018	8	5	99	67	395
2019	8	4	97	69	394
2020	8	4	86	64	463
2021	9	5	76	64	466
2022	9	5	91	71	414
2023	9	3	78	75	420
2024	8	3	67	75	428

Notes:
MSW = municipal solid waste
EFW = energy-from-waste

A3.6.3.2. Open Burning of Waste (5.C.2)

Greenhouse gas emissions from the open burning of residential waste are estimated using Tier 1 IPCC methods based on the quantity and type of residential waste burned outdoors in Canada. The quantity of residential waste burned outdoors is calculated by combining the residential waste generation rate, population, portion of the population burning their waste, the portion of waste that is burned, and the distribution of materials being burned. Residential waste generation is estimated as a part of the MSW quantification described in section A3.6.1.2.2. Population data are available from Statistics Canada (Statistics Canada, n.d. [b]). The portion of the population burning waste at home and the materials being burned are estimated from the Household Environmental Survey and a survey of Ontario residential waste burning practices (Environics, 2001). Estimated quantities of waste disposed through residential waste burning ranged from approximately 13 000 tonne/year to 15 500 tonne/year.

IPCC Tier 1 methods are used for the estimation of CO_2, CH_4, and N_2O emissions from residential waste burning (IPCC, 2006). The following equations are used to estimate CO_2, CH_4 and N_2O emissions:

Equation A3.6–13 **(modified from 2006 IPCC Guidelines, Volume 5, Chapter 5, Equation 5.2):**

$$CO_2 Emissions = MSW * \sum_j (WF_j * dm_j * CF_j * FCF_j * OF_j) * 44/12$$

CO_2 *Emissions*	=	CO_2 emissions from residential waste burning (tonne/year)
MSW	=	Weight of residential waste burned (tonne)
WF_j	=	Fraction of waste component j
dm_j	=	Dry matter content of waste component j (fraction)
CF_j	=	Fraction of carbon in the dry mater (total carbon content)
FCF_j	=	Fraction of fossil carbon in the total carbon
OF_j	=	Oxidation factor (0.58)
$44/12$	=	Conversion factor from C to CO_2

Equation A3.6–14 **(modified from 2006 IPCC Guidelines, Volume 5, Chapter 5, Equation 5.4):**

$$CH_4 Emissions = MSW * EF_{CH4}$$

CH_4 *Emissions*	=	CH_4 emissions from residential waste burning (tonne/year)
MSW	=	Weight of residential waste burned (tonne)
EF_{CH4}	=	Emission Factor for CH_4: 6,500 g CH_4 / tonne waste (wet weight basis)

Equation A3.6–15 **(modified from 2006 IPCC Guidelines, Volume 5, Chapter 5, Equation 5.5):**

$$N_2O Emissions = MSW * \sum_j (WF_j * dm_j) * EF_{N2O}$$

N_2O *Emissions*	=	N_2O emissions from residential waste burning (tonne/year)
MSW	=	Weight of residential waste burned (tonne)
WF_j	=	Fraction of waste component j
dm_j	=	Dry matter content of waste component j (fraction)
EF_{N2O}	=	Emission Factor for N_2O: 150 g N_2O / tonne waste (dry weight basis)

Default values from IPCC guidelines are used for all variables in the above equations, with the exception of the amount of waste incinerated (MSW), which is calculated as described previously.

A3.6.4. Emissions from Wastewater Treatment and Discharge (5.D)

The emissions estimates for the Wastewater Treatment and Discharge category includes CO_2, CH_4 and N_2O emissions resulting from transformation of organics and nutrients in wastewater systems; however, biogenic CO_2 emissions are not included in totals for this sector because these emissions are considered to be of biogenic origin grown in the same year as emissions occur (and are thus covered under the AFOLU sectors).

CH_4 emissions that occur from the treatment of municipal and industrial wastewater, from anaerobic digestion of sludge on-site at wastewater treatment facilities and from the emission of organics remaining in wastewater effluent are estimated in accordance with the methods provided in the 2006 IPCC Guidelines and 2019 Refinement. N_2O emissions are currently estimated as a function of the total nitrogen in wastewater in accordance with the methods described in the 2006 IPCC Guidelines and 2019 Refinement. Estimates of N_2O emission totals are dependent of the treatment technology used.

Emissions from municipal wastewater treatment are determined on a per capita basis. The per capita organics loading to wastewater and the population served by treatment type are the primary activity data for CH_4 emissions. Nitrogen loading to wastewater, estimated from per capita protein consumption, is the primary activity data for N_2O emissions.

The majority of wastewater treatment in Canada occurs at centralized municipal wastewater treatment plants, which receive influent from domestic, commercial and industrial users. There are some coastal municipalities that collect and discharge untreated wastewater to sea. Many Canadians in rural and remote areas, but also in portions of urban centres, use private or communal septic systems for wastewater treatment. Larger industries treat or pre-treat their wastewater on-site and are considered separately from municipal wastewater treatment facilities in the Industrial On-Site Wastewater Treatment category, section A3.6.4.4.

A3.6.4.1. Municipal Wastewater Treatment and Discharge – CH_4

Emissions estimates for municipal wastewater treatment facilities are calculated using the Tier 2 methods provided in the 2006 IPCC Guidelines and 2019 Refinement, with country-specific factors (IPCC, 2006, 2019). The 2019 Refinement provides updated emission factors and methods for estimating emissions from receiving water bodies.

CH_4 emissions estimates are based on population-based organic loadings, treatment technology used and receiving waterbody characteristics. CH_4 emissions occur from microbial activity during treatment, anaerobic digestion of sludge, and in the receiving waterbody.

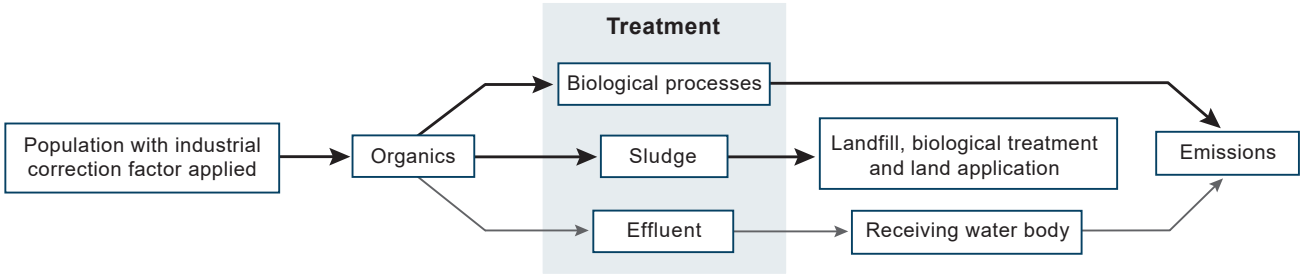
The treatment technology used influences the emissions from treatment, the removal of organics as sludge and the quantity of organics remaining in the effluent (which then contributes to emissions from the receiving water bodies). The first step in estimating CH_4 emission from wastewater is determining the population using each type of treatment technology.

Methane emissions from wastewater treatment facilities occur at three distinct steps (Figure A3.6–4):

- Wastewater treatment
- Anaerobic digestion of sludge
- Microbial activity of organics that were discharged to receiving water body

The organics entering the wastewater stream (activity data) are converted to CH_4 (or CO_2) by microbial activity at each of these three steps. The emissions from the wastewater treatment process and the organics removed as sludge or passing to the receiving body with the effluent are a function of the treatment technology.

Figure A3.6–4 **Diagram of Wastewater Organics Flow**



The total CH_4 emissions from wastewater facilities for each province or territory can be determined from the sum of emissions from each of the three steps, as shown in Equation A3.6–16. National emissions are the sum of all provincial and territorial emissions.

Equation A3.6–16

$$CH_4 = CH_{4Treatment} + CH_{4AD} + CH_{4Receiving\ water\ body}$$

CH_4	=	CH_4 emissions from wastewater, for province, p
$CH_{4\ Treatment}$	=	CH_4 emissions from the process of wastewater treatment (tonne CH_4)
$CH_{4\ AD}$	=	CH_4 emissions from anaerobic digestion of sludge on-site at wastewater treatment facilities (tonne CH_4)
$CH_{4\ Receiving\ water\ body}$	=	CH_4 emissions from the wastewater discharged to receiving water bodies (tonne CH_4)

Methodology

Emissions are ultimately a function of population and treatment technology used. The organic load—the mass of organic material introduced to wastewater—is a function of the population served. The treatment technology to which a wastewater treatment system is connected (if any) dictates the degree of emissions from the treatment process, the quantity of organics removed as sludge and the quantity of organics remaining in the wastewater effluents. The organics remaining in the effluents also contribute to CH_4 emissions (IPCC, 2019). The organics removed as sludge are sometimes processed in anaerobic digesters on-site at the wastewater treatment facilities. In these cases, CH_4 emissions from the anaerobic digestion are included in the wastewater totals.

Organics removed as sludge (after any reductions from on-site anaerobic digestion) may then become inputs for accounting and emissions calculations in other sections, including Biological Treatment of Waste (section A3.6.2), Landfills (section A3.6.1), and Incineration (section A3.6.3). Sewage sludge accounting—determining the amounts transferred to each of the aforementioned fates or sections—is discussed in this section.

Wastewater system is the term used to denote a sewershed or wastewater collection system. It does not necessarily have a wastewater treatment facility. In some cases, wastewater is collected but discharged to sea. Treatment systems may also employ more than one type of treatment technology, such as different kinds of lagoons cells run in series or in parallel.

A3.6.4.1.1. Emissions from Wastewater Treatment

Methane emissions are estimated for each province based on organics loading to wastewater, organics removed as sludge and treatment-technology-specific emission factors, as shown in Equation A3.6–17.

Equation A3.6–17

$$CH_{4\ Treatment} = \sum_t [EF_{CH4,t} \times (OrganicLoad_t - OrganicsRemovedAsSludge_t)] - Recovery$$

$CH_{4\ Treatment}$	=	CH_4 emissions from wastewater treatment, tonne CH_4
t	=	treatment technology type or category (e.g., facultative lagoon)
$EF_{CH4,t}$	=	CH_4 emission factor for wastewater treatment technology of type t, tonne CH_4/tonne BOD_5
$OrganicLoad_t$	=	organic load to the wastewater treatment/discharge systems of type t, tonne BOD_5
$Organics\ Removed\ As\ Sludge_t$	=	the organics that are removed from wastewater as sludge, measured as tonne BOD_5, estimated using Equation A3.6–21 and Equation A3.6–22
$Recovery$	=	CH_4 recovered from wastewater treatment, t (recovery from anaerobic digestion of sludge is accounted separately); presently, no recovery of CH_4 occurs from the wastewater treatment step for municipal wastewater treatment (only from sludge digestion)

Emission Factor

The emission factor for wastewater treatment and discharge is a function of the theoretical maximum CH_4 production capacity (B_0) for wastewater and a treatment technology-specific CH_4 correction factor (MCF), as shown in Equation A3.6–18 and Table A3.6–14. The maximum CH_4 producing capacity was determined to be 0.36 kg CH_4 per kg BOD_5 by AECOM (2011). The MCF is the fraction of the potential CH_4 that is produced by each treatment type and ranges from 0 to 1 (IPCC, 2006), depending on the treatment system type.

Equation A3.6–18

$$EF_{CH_4,t} = B_0 \times MCF$$

$EF_{CH_4,t}$	=	emission factor for treatment type t, tonne CH_4/tonne BOD_5
B_0	=	theoretical maximum CH_4 producing capacity, tonne CH_4/tonne BOD_5
MCF	=	methane correction factor for treatment type t, fraction

Table A3.6–14 **Emission Factors for CH_4 from Wastewater Treatment**

Treatment Category	MCF	EF	Source of MCF	BOD_5 Removal Efficiency	Source of BOD_5 Removal Efficiency	Sludge BOD_5 per BOD_5 removed from wastewater	Source of Sludge BOD_5 per BOD_5 removed from wastewater
No Treatment	N/A	N/A	IPCC (2006)	0	IPCC (2019)	0	N/A
Primary	0.03	0.0108	IPCC (2019)	0.4	IPCC (2019)	1	Envirosim (2019), Table 3
Aerobic Lagoon	0	0	IPCC (2006)	0.85	ECCC Internal Analysis	0.01	Envirosim (2019), Table 6
Anaerobic Lagoon	0.8	0.288	IPCC (2006)	0.85	ECCC Internal Analysis	0.02	Envirosim (2019), Table 6
Facultative Lagoon	0.2	0.072	IPCC (2006)	0.85	ECCC Internal Analysis	0.01	Envirosim (2019), Table 6
Other / Unspecified Lagoon	0.2	0.072	IPCC (2006)	0.85	ECCC Internal Analysis	0.01	Envirosim (2019), Table 6
Secondary Anaerobic	0.8	0.288	IPCC (2006)	0.85	ECCC Internal Analysis	0.46	Modeling as Secondary Aerobic
Secondary Activated Sludge	0.03	0.0108	IPCC (2019)	0.95	IPCC (2019)	0.46	Envirosim (2019), Table 2, Secondary with Primary & Nitrification
Trickling Filter	0.03	0.0108	IPCC (2019)	0.85	ECCC Internal Analysis	0.6	Envirosim (2019), Table 5
Trickling Filter – High Rate	0.03	0.0108	IPCC (2019)	0.85	ECCC Internal Analysis	0.75	Envirosim (2019), Table 5
Rotating Biological Contactor	0.03	0.0108	IPCC (2019)	0.85	ECCC Internal Analysis	0.23	Surampalli and Baumann (1995)
Sequencing Batch Reactor	0.05	0.018	Taseli (2018)	0.9	Literature Review	0.46	Assuming similar to Secondary Activated Sludge. Mahvi (2008)
Secondary Biofiltration	0.03	0.0108	IPCC (2019)	0.95	Literature Review	0.46	Assuming similar to Secondary Activated Sludge
Secondary with Biological Nutrient Removal	0.03	0.0108	IPCC (2019)	0.98	Literature Review / IPCC (2019) / Envirosim (2019) Assuming primary treatment included	0.46	Envirosim (2019), Table 2, Secondary with Primary & Nitrification
Septic	0.5	0.18	IPCC (2006)	1	Assuming dispersal field	0.5	IPCC (2019), Equation 6.3
Septic with Marine Outfall	0.5	0.18	IPCC (2006)	0.625	IPCC (2019), Table 6.6B	0.5	IPCC (2019), Equation 6.3
Wetland	0.17	0.0612	IPCC (2014) Wetland Supplement	0.975	Estimate	0	Assuming no dredging
Other / Unknown	0.2	0.072	Modeling as facultative lagoon	0.85	Modeling as facultative lagoon	0.01	Modelling as facultative lagoon

Notes:
MCF = methane correction factor
BOD_5 = biological oxygen demand, 5-day assay
N/A = Not available

Organic Load

Emissions of CH_4 from municipal wastewater treatment systems are determined based on the organic loading to wastewater, by province (measured as biogeochemical oxygen demand, 5-day test, or BOD_5). The organic loading is determined from the per capita organics loading rate (BOD_5/capita/day) of 0.06 kg/person/day, and an industrial and commercial input correction factor of 1.25 (IPCC, 2006). Note that the commercial input correction factor is applied both to centralized wastewater treatment systems and distributed septic systems; private septic systems are used by both domestic and industrial facilities in rural and remote regions of Canada.

The total annual organic loading of each type of wastewater treatment technology in a province is calculated as shown in Equation A3.6–19.

Equation A3.6–19

$$OrganicLoad_t = Pop_t \times IndCor \times PerCapBOD_5 \times 365 \times 0.001$$

$OrganicLoad_{(t)}$	=	annual organic load to the wastewater treatment systems of type t, tonne BOD_5
Pop_t	=	population using (connected to) wastewater systems of technology type t
$IncCor$	=	correction factor for industrial and commercial inputs to municipal wastewater, with value of 1.25 (IPCC, 2006)
$PerCapBOD_5$	=	per capita organic loading to the wastewater system, kg BOD_5/capita/day
365	=	conversion from day to year
0.001	=	conversion from kg BOD_5 to tonne BOD_5

Population Using Each Treatment Technology, By Province

There are over 3800 municipal wastewater treatment or discharge systems (wastewater system) in Canada. On top of that, much of the population uses private septic systems. The total population using each treatment technology of each province is determined by summing the number of people served by (connected to) each wastewater system (i.e., sewershed or facility) having each type of treatment. However, few wastewater treatment systems have direct measures of the number of people that they serve. Instead, the population served by each wastewater system must be estimated.

To estimate the population served by each facility, a geographic approach is taken:

1. Map population in each census metropolitan area (CMA) and each census division (CD), excluding overlapping areas with CMA, from 1990 onward, taking account of changing geographic boundaries with each census (Statistics Canada census population from 1991, 1996, 2001, 2006, 2011, 2016, 2021 censuses; Statistics Canada census administrative area boundaries [shapefiles or geodatabases] from 1996, 2016 and 2016, 2021 censuses).
2. Determine population in each region connected to municipal wastewater treatment systems and population using private or communal septic systems.
3. Distribute the CMA or CD population that discharges to municipal sewer systems between the wastewater treatment systems in that region according to the relative volume of wastewater that the systems process in a year. For example, a facility that treats 30% of the total annual wastewater of a CMA in a given year is assumed to serve 30% of the population of that CMA that is connected to the municipal sewer systems in that year.

The total population using each treatment technology for each province in each year is determined by summing the population of the wastewater treatment system having that technology, according to Equation A3.6–20.

Equation A3.6–20

$$Population_Using_System_t = \sum_{i,t} \frac{Volume\ Treated_{i,t}}{TotalVolumeTreated_{region}} * Population_{mun\ sewer,region}$$

$Population_Using_System_t$	=	the estimated population served by the municipal wastewater treatment system of type t
$VolumeTreated_{i,t}$	=	the volume of wastewater treated by, or discharged from, facility i
$region$	=	the region (census metropolitan area or census division) in which system i is located (note: census geography boundaries change over time)
$TotalVolumeTreated_{region}$	=	the total volume of wastewater treated by all municipal wastewater systems in the region in which system i is located
$Population_{mun_sewer,region}$	=	the population of the region in which system i is located in that live in residences connected to municipal sewer systems (as opposed to private septic systems)

The population discharging their wastewater to municipal sewer systems versus those discharging to private or small communal septic systems is determined from an analysis of the Households and Environment Survey (Statistics Canada. No date [c]). The septic versus sewer use can only be determined at the spatial resolution of census metropolitan area and "the rest of the province." In other words, all census divisions in a province are treated as one for determining septic or municipal treatment use.

The volume of wastewater discharged (volume treated) from most (>2500) wastewater treatment systems in Canada and the treatment technology used are reported through the Effluent Regulatory Reporting Information System (ERRIS) under the *Wastewater Systems Effluent Regulations of the Fisheries Act* (Canada, 2012). Records from this source begin in 2013. To complete the time series and fill any data gaps, the reported volumes, treatment technology and details of facility construction, upgrade and decommissioning were also gathered from older national inventories, provincial inventories and reports, annual reports of treatment facilities, municipal websites, engineering reports, scholarly articles, news articles and other available sources. Notable data sources, in addition to data gathered through ERRIS, include the national inventory of municipal waterworks and wastewater systems in Canada, 1996 (Minister of Supply and Services Canada, 1987), the Government of Quebec (Québec, 2003, 2005, 2013), the Ontario Ministry of the Environment (1985) and the Newfoundland Water Resources Portal (n.d.).

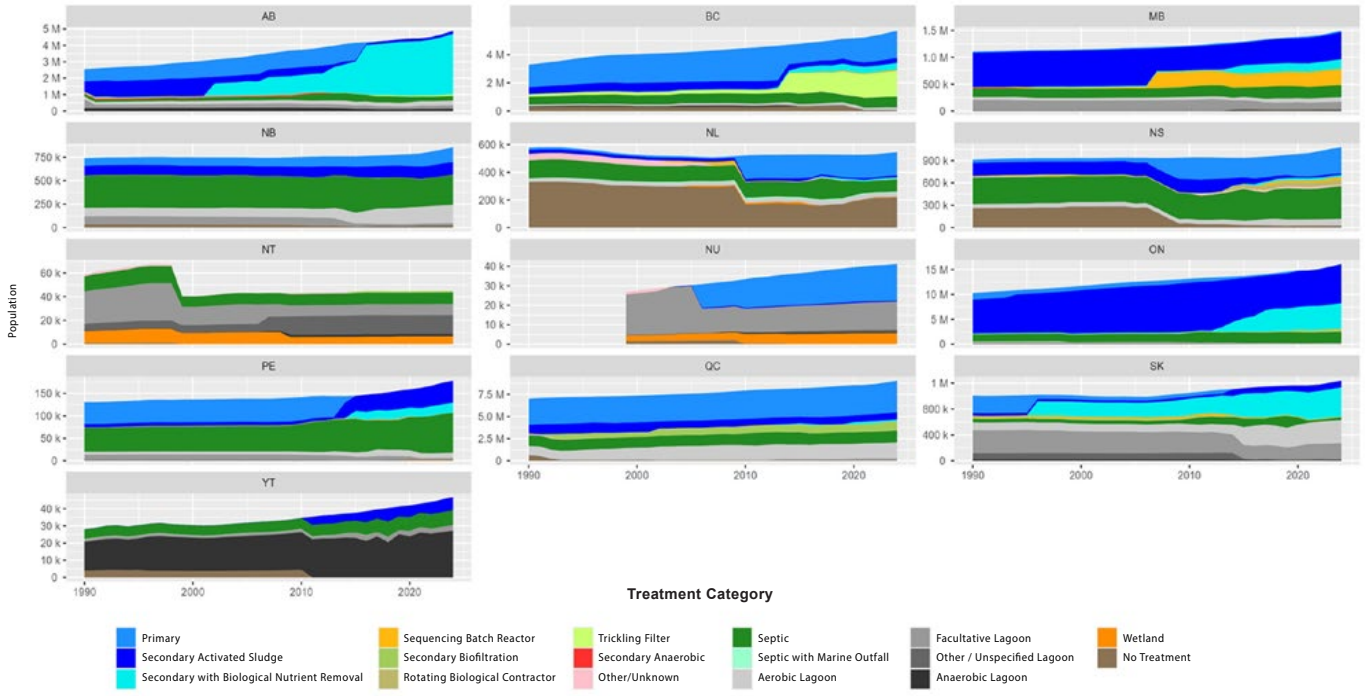
The data for septic use (and municipal wastewater system use), and volumes treated are not available for every year. Gaps in the time series of provincial and census metropolitan area septic use are linearly interpolated and extrapolated by holding values constant. Gaps in the time series of wastewater volumes are linearly interpolated and extrapolated by scaling from the nearest known value according to regional population changes.

Many small systems have no reported volumes for any year (1426 systems). This may be because the systems are below the mandatory reporting threshold of 100 m^3/day for the *Wastewater System Effluent Regulations* or because they closed before the regulations came into effect in 2014. These systems are given a token treatment volume of 50 m^3/day (which corresponds to populations of approximately 50 to 200 people, varying by region). Even with token volumes assigned, these 'small' systems represent a negligible contribution to the overall volume of wastewater treated in Canada.

The treatment technology of a given wastewater system is extrapolated by holding the earliest and last known technology constant. When the treatment technology of a given system has changed over time and the precise year of change is unknown, the technology type is interpolated by carrying the earlier technology forward until the first recorded of year of the newer technology (i.e., it is assumed that the first instance or record of the newer technology likely corresponds to the year of upgrade).

The estimated population connected to each treatment technology type, by province and territory is shown in Figure A3.6–5. Percentages of Canadian population connected to the wastewater systems of each treatment technology are shown in Table A3.6–15.

Figure A3.6–5 **Population Served by Each Treatment Technology, by Province and Territory**



Organics Removed as Sludge

Sludge removal is not measured directly at all facilities across Canada and is therefore estimated by modelling it as a function of the treatment technology. In addition to treatment technology, there are many factors at play that will impact sludge removal, such as operating temperatures and flow rates. However, average sludge removals across the various treatment technologies in use in Canada can be used to prepare provincial-level estimates.

Organics removed from the wastewater as sludge, measured as units of BOD_5, are estimated according to Equation A3.6–21 and Equation A3.6–22, using parameters shown in Table A3.6–14.

Equation A3.6–21

$$Organics_Removed_Via_Treatment_t = OrganicLoading_t \times BOD_5_Removal_Efficiency_t$$

$Organics_Removed_Via_Treatment$	=	total amount of organics (measured as BOD_5) removed from the wastewater, for treatment type t, tonne BOD_5
$OrganicLoading_t$	=	organic load to the wastewater treatment/discharge system, tonne BOD_5
$BOD\ Removal\ Efficiency_t$	=	average or typical efficiency of wastewater treatment technology, in Canada, at removing BOD_5 from wastewater (Table A3.6–14), fraction

Table A3.6–15 **Percentage of Canadian Population Using Each Wastewater Treatment Technology**

Treatment Category	1990	1995	2000	2005	2010	2015	2020	2024
Primary	25.66	23.88	23.54	23.33	23.86	18.62	15.18	15.16
Secondary Activated Sludge	35.82	39.59	40.79	37.49	36.58	27.89	24.24	24.25
Rotating Biological Contactor	0.84	0.53	0.43	0.44	0.43	0.6	0.58	0.59
Sequencing Batch Reactor	0.19	0.25	0.25	0.36	1.08	0.97	1.17	1.23
Secondary with Biological Nutrient Removal	0.41	0.43	1.25	3.79	4.54	15.63	24.18	24.84
Secondary Biofiltration	0.01	1.85	1.7	2.32	2.6	2.65	3.33	3.29
Secondary Anaerobic	0.21	0.17	0.18	0.18	0.17	0	0	0
Trickling Filter	0.84	0.81	0.88	0.86	0.86	4.12	4.41	4.64
Aerobic Lagoon	6.56	6.77	6.79	7.47	7.28	7.38	7.66	7.67
Facultative Lagoon	5.34	4.02	3.77	3.74	3.39	2.69	2.5	2.62
Other / Unspecified Lagoon	0.91	0.88	0.81	0.75	0.71	0.21	0.08	0.09
Anaerobic Lagoon	1	1.01	0.96	1.03	0.95	0.51	0.44	0.5
Wetland	0.04	0.1	0.04	0.08	0.07	0.08	0.07	0.06
Septic	16.35	16.17	15.42	15.24	15.74	16.88	14.8	14.21
Septic with Marine Outfall	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01
Other / Unknown	0.49	0.31	0.2	0.1	0.07	0.17	0.17	0.13
No Treatment	5.32	3.2	2.97	2.82	1.65	1.57	1.19	0.72

Note: Values may not add up to 100% due to rounding.

Equation A3.6–22

$$BOD_5_Removed_As_Sludge_t = Organics_Removed_Via_Treatment_t \times SludgeBOD_5_Per_BOD_5_Removed_t$$

$BOD_Removed_As_Sludge_t$ = quantity of BOD_5 (t BOD_5) removed from the wastewater as sludge for treatment type t

$Organics_Removed_Via_Treatment_t$ = total amount of organics (measured as BOD_5) removed from the wastewater, for treatment type t

$SludgeBOD_Per_BOD_Removed_t$ = treatment technology-specific factor for amount of BOD_5 removed from wastewater as sludge per unit of BOD_5 removed from wastewater during treatment (not 1:1 because of other BOD_5 removal mechanisms such as emissions)

A3.6.4.1.2. Emissions from Receiving Water Body (Organics Remaining in Effluent)

Canada uses a Tier 2 approach from the 2019 IPCC Refinement (IPCC, 2019). The emissions are calculated using Equation A3.6–23 to Equation A3.6–25. The receiving water body types are determined by mapping facility outlet locations to the nearest waterbody types, classified according to 2006 IPCC Guidelines groupings (Lake, Reservoir, River, Aqueduct/Canal/Ditch, Ocean, Estuary). The waterbody types are determined from the Natural Resources Canada CanVec Hydrographic features (NRCan, n.d.), at 1:50,000 scale, with some reclassification (for example Watercourse, Side Channel and Diversion were classified as River). Some corrections were applied, for example classifying run-of-river forebays as River (rather than Reservoir) in QC, distinguishing rivers and lakes from the unspecified types in AB and NB (based on the feature geometry) and the removal of Lagoons and "Reservoirs" less 0.25 hectares in size, which are wastewater treatment clarifiers and lagoons themselves and not receiving waterbodies. Estuaries are not differentiated from other river or ocean waterbodies in the CanVec data, so major estuaries were manually defined by ECCC. Estuaries were set based on (Environment Canada - Canadian Wildlife Service, 1993) and ECCC expert opinion. Some notable estuaries include the Juan de Fuca Straight, the Mackenzie Delta, Hudson Bay, James Bay, the lower Saint Lawrence River, the Bay of Fundy, Baie des Chaleurs, the outlets of many rivers in northern New Brunswick, including the Restigouche Miramichi, Richibucto, Boutouche, and Cocagne, the Petitcodiac rivers, and the Hillsborough River in PE. Wastewater systems and treatment facilities with uncertain geographic locations are assigned the "Unspecified Aquatic Environment." MCF values and emission factors associated with each receiving waterbody type are shown in Table A3.6–16. A country specific value for B_0 (of 0.36) is used.

Equation A3.6–23

$$CH_{4\ receiving\ water\ body} = EF_{CH_4\ receiving\ water\ body} \times OrganicLoad_{effluent}$$

$CH_{4\ receiving\ water\ body,\ p}$ = CH_4 emissions from receiving water bodies in province p

$EF_{CH_4\ receiving\ water\ body}$ = CH_4 emission factor for wastewater treatment technology, tonne CH_4 / tonne BOD_5

$OrganicLoad_{effluent}$ = organic load to the passing through wastewater treatment and discharged to the receiving water body as effluent, tonne BOD_5

Equation A3.6–24

$$EF_{CH_4\ Receiving\ water\ body} = B_0 \times MCF$$

$EF_{CH_4\ Receiving\ water\ body}$ = emission factor, kg CH_4/kg BOD_5 for wastewater discharged to receiving water bodies
B_0 = theoretical maximum CH_4 producing capacity, 0.36 kg CH_4/kg BOD_5 (AECOM 2011)
MCF = methane correction factor (MCF), fraction, Table A3.6–16

The BOD_5 discharged to receiving water bodies varies by treatment technology. The total BOD_5 discharged to receiving water bodies can be determined as a mass balance based on the removal efficiency of the treatment technology.

Equation A3.6–25

$$OrganicLoad_{effluent} = \sum_T [OrganicLoad \times (1 - BOD\ Removal\ Efficiency_T)]$$

$OrganicLoad_{Effluent}$ = quantity of organics, measured as BOD_5 discharged to receiving water bodies from treatment technology of type t, tonne BOD_5
$OrganicLoad_T$ = organic load to the wastewater treatment/discharge systems of type T, tonne BOD_5
$BOD\ Removal\ Efficiency_T$ = typical efficiency of wastewater treatment technology, in Canada, at removing BOD_5 from wastewater (Table A3.6–14)

Table A3.6–16 **Wastewater Discharge Receiving Waterbody Emission Factors**

CanVec Water Type[a] (code)	ECCC Category	2019 IPCC Category	MCF	EF (kg CH_4 / kg BOD_5)
Canal (79)[b]	Canal, Aqueduct, or Ditch	Discharge to reservoirs, lakes, and estuaries (Tier 2)	0.19	0.0684
Conduit (80)[b]				
Ditch (81)[b]				
Tidal River (89)	Estuary			
Estuary (NA)[c]				
Lake (83)	Lake			
Pond (86)				
Reservoir (87)[d]	Reservoir			
Ocean (85)	Ocean	Discharge to aquatic environments other than reservoirs, lakes, and estuaries (Tier 2)	0.035	0.0126
Diversion (82)	River			
Side Channel (88)				
Watercourse (91)				
Not Identified (20)[e]	Unspecified Aquatic Environment	Tier 1	0.11	0.0396
Liquid Waste (84)[d]	NA	NA	NA	NA

Notes:
NA = Not applicable
MCF = Methane correction factor
a. CanVec 1:50,000 Hydrographic Features (classifications differ at other scales available in the CanVec).
b. Canals, aqueducts and ditches considered slow moving and more akin to lakes than rivers for emissions.
c. Estuary Waterbody type does not exist in CanVec. It was manually defined by ECCC (from Ocean and River, originally).
d. Reservoirs under 25 hectares and Liquid Waste are considered part of the wastewater treatment systems (these are lagoons and clarifiers).
e. Some features classified as "Not Identified" in CanVec were corrected by ECCC to lake, reservoir, ocean or estuary (based on feature geometry and location).

A3.6.4.1.3. Emissions from Anaerobic Digestion of Sludge at Wastewater Treatment Facilities

Emissions from anaerobic digestion occurring at wastewater treatment plants are reported as Wastewater Emissions, in accordance with the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019). Anaerobic digestion and composting of sludge occurring off-site from the wastewater treatment plants, however, are reported under Biological Treatment (section A3.6.2).

Emissions from anaerobic digestion of wastewater sludge are estimated based on CH_4 generated (Equation A3.6–26 to Equation A3.6–29). Emissions are estimated to be fugitive losses from the digester and emissions from flaring. Emissions from utilization of biogas are reported under the Energy Sector. Methane recovery for anaerobic digestion of sludge is universally practiced in Canada. The calculations are done by facility then aggregated by province and territory.

Sludge transfers between facilities are also accounted for before calculation of wastewater treatment sludge digestion emissions. In some municipalities sludge may be transferred from smaller wastewater treatment facilities to be processed at larger ones. To date, 109 municipal wastewater treatment facilities have been identified as having an on-site anaerobic digestion of sludge.

Biogas recovery data is collected through voluntary surveys. Reported biogas collection is used in lieu of modelled collection when available. Facility-reported methane recovery (and the ratios of biogas flared to utilized) are interpolated (linear) and extrapolated (held constant) to fill any time-series gaps. When the biogas recovery method (flaring vs utilization) is not known for a facility, it is assumed that the sludge digester biogas is flared. The survey indicated that biogas recovery at municipal wastewater treatment facilities only occurs from the sludge digestion, and not the treatment process. The methane recovery from sludge digestion is plotted on Figure A3.6–6.

The TSS (Total Suspended Solids) of sludge sent to the digester is estimated based on organics (BOD_5) removed from wastewater as sludge (Equation A3.6–21), which is converted to TSS using a factor of typical sludge TSS generation per unit BOD_5 removed in treatment for common treatment categories in Canada (Equation A3.6–26 and Table A3.6–17).

The reduction in TSS from digestion is calculated using Equation A3.6–27, taking into account the fraction of volatile suspended solids (VSS), based on the typical ratio of VSS to TSS for each treatment type (Table A3.6–17). Anaerobic digestion of sludge consumes only the VSS portion of sludge.

CH_4 generated from anaerobic digestion of wastewater sludge is calculated based on reduction of TSS (or more specifically the reduction of VSS) using Equation A3.6–28.

Net emissions are estimated as fugitive loss and flaring emissions, based on Equation A3.6–29. Fugitive loss and CH_4 emissions are assumed to be 2.1% of the CH_4 produced, for anaerobic digestion of sludge at wastewater treatment facilities. Flaring emissions are assumed to be 0.3% of methane flared.

The TSS/BOD_5 and VSS/TSS ratios are approximate and averaged for a given technology category. On aggregate, however, these values are believed to provide a reasonable approximation of the mean sludge characteristics from all facilities in a region of a given type.

Figure A3.6–6 **Methane Recovery from Sludge Digestion at Municipal Wastewater Treatment**

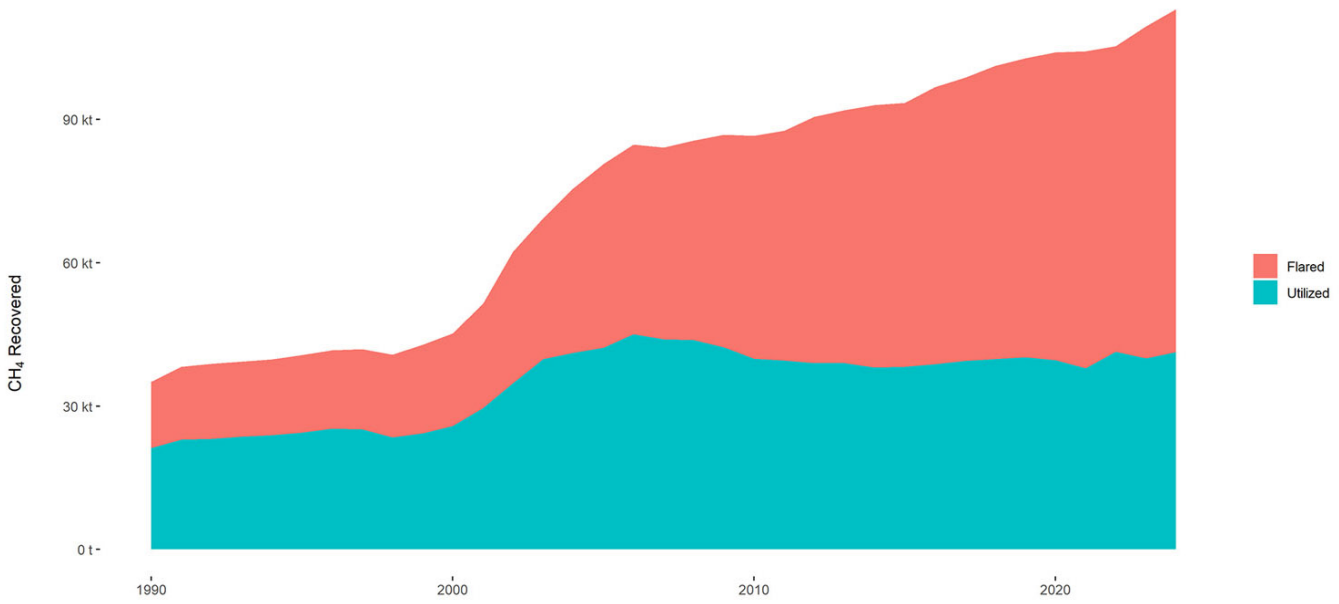


Table A3.6–17 **Sludge Characteristics (Conversion from BOD_5 to Total Suspended Solids and Volatile Solids Fraction)**

Treatment Category	SludgeTSS / BOD_5 (kg/kg)	VSS/TSS	Source
No Treatment	N/A	N/A	N/A
Primary	1.75	0.83	Envirosim (2019)
Aerobic Lagoon	0.17	0.35	Envirosim (2019)
Anaerobic Lagoon	0.55	0.45	Envirosim (2019)
Facultative Lagoon	0.33	0.33	Envirosim (2019)
Other / Unspecified Lagoon	0.33	0.33	Modelling as Facultative Lagoon
Secondary Anaerobic	0.95	0.815	Modelling as Secondary Activated Sludge
Secondary Activated Sludge	0.95	0.815	Envirosim (2019)
Trickling Filter	1.08	0.83	Envirosim (2019)
Trickling Filter – High Rate	1.23	0.84	Envirosim (2019)
Rotating Biological Contactor	1.08	0.83	Modelling as Trickling Filter
Sequencing Batch Reactor	0.95	0.815	Modelling as Secondary Activated Sludge; Mahvi (2008); U.S. EPA (1999)
Secondary Biofiltration	0.95	0.815	ECCC estimate; Equivalent to Envirosim Secondary with Biological Nutrient Removal
Secondary with Biological Nutrient Removal	0.95	0.815	Envirosim (2019)
Septic	0.25	0.5	ECCC estimate based on IPCC (2019) and Washington State (2004)
Septic with Marine Outfall	0.25	0.5	ECCC estimate based on IPCC (2019) and Washington State (2004)
Wetland	N/A	N/A	Assuming no sludge removal
Other / Unknown	0.33	0.33	Modelling as facultative lagoon

Note:
N/A = Not applicable

Equation A3.6–26

$$TSS_{Sludge} = Organics_Removed_Via_Treatment \times Sludge\ TSS\ Per\ BOD_5\ Removed$$

TSS_{Sludge} = mass of total suspended solids in sludge removed from wastewater, tonne

$Organics_Removed_Via_Treatment$ = organics removed from the wastewater by the treatment process (tonne BOD_5)

$Sludge\ TSS\ Per\ BOD_5\ Removed$ = conversion factor, mass of TSS per unit of wastewater BOD_5 removed as sludge (tonne / tonne BOD_5); a function of treatment technology (Table A3.6–17)

The reduction is TSS is based on a typical sludge digester efficiency (FracVSSRemoval), which is assumed to be a reduction of 65% of the VSS. The TSS and VSS reduction is a typical average and not necessarily representative of facility-level operations, which can have a wide variety of operating conditions (temperature, solids retention time, etc.).

Equation A3.6–27

$$TSS_{Reduction} = TSS_{Sludge} \times FracVSS \times Frac_{VSSRemoval}$$

$TSS_{Reduction}$ = mass of total suspended solids (TSS) reduced by anaerobic digestion (tonne)

TSS_{Sludge} = mass of total suspended solids in sludge (tonne)

$FracVSS$ = fraction of sludge dry weight that is volatile suspended solids (VSS), expressed as VSS/TSS; a function of the treatment technology from which the sludge originates (Table A3.6–17)

$Frac_{VSSRemoval}$ = fraction of VSS that is consumed by anaerobic digestion, 0.65 (fraction)

Equation A3.6–28

$$CH_{4,Produced} = TSS_{Reduction} \times Frac_{BiogasGen} \times FCH_{4Biogas} \times Density_{Biogas} \times 0.001$$

$CH_{4,Produced}$ = methane generated from anaerobic digestion of sludge (tonne)

$TSS_{Reduction}$ = mass of total suspended solids reduced by anaerobic digestion (kg)

$Frac_{BiogasGen}$ = volume of biogas generated per unit of TSS consumed in anaerobic digestion (m^3/tonne)

$FCH_{4Biogas}$ = fraction of biogas this is CH_4, by mass

$Density_{Biogas}$ = density of biogas (kg/m^3)

0.001 = unit conversion kg/m^3 to tonne/m^3

Equation A3.6–29 **Emissions from Wastewater Anaerobic Digesters**

$$CH_{4,Emission} = CH_{4,Produced} \times Frac_{FugitiveLoss} + CH_{4,Produced} \times Frac_{Flared} \times EF_{Flaring}$$

$CH_{4,Emission}$	=	methane emitted from anaerobic digestion of sludge at wastewater treatment facilities (tonne)
$CH_{4,Produced}$	=	methane produced from anaerobic digestion of sludge (tonne)
$Frac_{FugitiveLoss}$	=	percentage of biogas (and CH_4) emitted from fugitive loss, 0.021 (2.1%) (fraction), (see A3.6.2.2.1 for details; ECCC, 2020b)
$Frac_{Flared}$	=	fraction of biogas that is flared—assumed to be 1 (100%) unless facility-reported data indicates otherwise (fraction)
$EF_{Flaring}$	=	emission factor, CH_4 emitted from flaring 0.003 (0.3%) (fraction)

A3.6.4.1.4. Sludge Availability for Other Fates (Sludge Accounting)

Secondary to the wastewater treatment emissions, sludge produced and remaining after anaerobic digestion on-site is used to estimate the quantities of sludge landfilled. The sludge remaining after on-site anaerobic digestion is determined as shown in Equation A3.6–30. Because anaerobic digestion only consumes the VSS portion of sludge, the VSS fraction is updated as shown in Equation A3.6–31.

Equation A3.6–30 **Sludge Mass Total Suspended Solids (Dry Weight) Available After On-Site Anaerobic Digestion**

$$TSS_{Available} = TSS_{Sludge} - TSS_{Reduction}$$

$TSS_{Available}$	=	the mass of sludge total suspended solids (in other words the dry weight of sludge) available after wastewater treatment and on-site anaerobic digestion of sludge (kg TSS or kg Dry Weight Sludge)
TSS_{Sludge}	=	mass of total suspended solids in sludge, before anaerobic digestion (kg)
$TSS_{Reduction}$	=	mass of TSS reduced by anaerobic digestion (kg)

Equation A3.6–31 **Sludge Volatile Suspended Solids Fraction After Anaerobic Digestion**

$$VSS_{updated} = \frac{TSS_{Sludge} * FracVSS - TSS_{Reduction}}{TSS_{Sludge} - TSS_{Reduction}}$$

$VSS_{updated}$	=	volatile suspended solids fraction of sludge having undergone anaerobic digestion (fraction)
TSS_{Sludge}	=	mass of total suspended solids in sludge, before anaerobic digestion (kg)
$FracVSS$	=	fraction of sludge mass that is VSS, before anaerobic digestion (fraction)
$TSS_{Reduction}$	=	mass of TSS reduced by anaerobic digestion (kg)

The VSS fraction of all sludge produced in a province or territory is determined from the weighted average of sludge produced from each treatment technology after accounting for any on-site anaerobic digestion.

Sludge Distribution

Quantities of sludge incinerated and composted are reported directly from the facilities. Sludge sent to these fates are discussed in section A3.6.2 (Biological Treatment of Solid Waste) and A3.6.3 (Incineration). Sludge sent to landfill or land-applied for agriculture or land-restoration must be estimated. Sludge remaining after point source fates (compost and incineration) is distributed to landfill or land-application according to provincial ratios estimated by Cheminfo (Cheminfo, 2018).

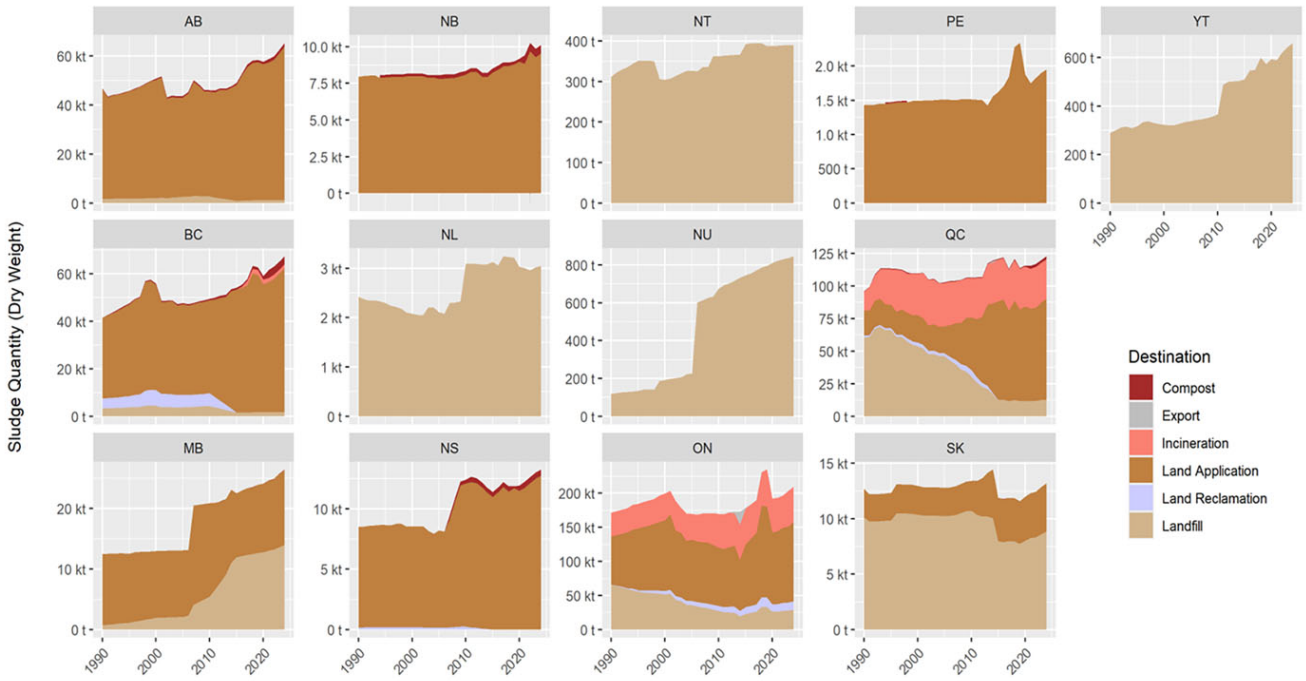
Equation A3.6–32 **Calculation of Sludge Distribution to Landfills as Part of Sludge Accounting**

$$Sludge\ Landfilled = [SS_{Available} - SS_{BiolTrtmt} - SS_{Incinerated} - SS_{Exported}] \times PropLF$$

$SS_{Available}$	=	mass of sewage sludge available from wastewater treatment, after accounting for reductions from on-site anaerobic digestion at the wastewater treatment facilities
$SS_{BioTrtmt}$	=	mass of sludge sent to biological treatment, which includes composting and anaerobic digestion (the product of which is assumed to not re-enter the pool of sludge potentially destined for landfill)
$SS_{Incinerated}$	=	mass of sludge incinerated, tonne
$SS_{Exported}$	=	mass of sludge exported, tonne
$Prop_{LF}$	=	proportion of sewage sludge remaining that is landfilled, as opposed to land-applied on agricultural land, forest or as part of land-reclamation (varies by province and over time), ratio

Estimated fates of wastewater treatment sludge are shown in Figure A3.6–7.

Figure A3.6–7 **Sludge Flow Accounting, Estimated Sludge Fates by Province and Territory**



A3.6.4.2. Municipal Wastewater Treatment/Discharge – N_2O

Methodology

Nitrous oxide (N_2O) is associated with the degradation of nitrogen components in wastewater, which are introduced from urea, nitrate and protein in human sewage as well as inputs from other household wastewater, including inputs from shower drains, sink drains, washing machines, etc. (IPCC, 2006). N_2O emissions are estimated from the both the N_2O formed during the wastewater treatment process and from N_2O formed in the receiving water body into which wastewater is discharged. Emissions from the treatment process occur from anoxic zones in the treatment process and nitrification, and are most common in treatment processes that have biological nutrient removal stages. Emissions from the receiving water body are a product of nitrogen remaining in the discharged wastewater effluent. Some of this nitrogen is converted to nitrous oxide through natural microbial processes and emitted.

Emission estimates are completed using the 2019 IPCC Refinement (IPCC, 2019) Tier 2 methodology, where emissions are calculated at the facility-level for both the treatment step and effluent discharge to receiving waterbodies using 2019 IPCC default parameters.

Methodology to Determine Nitrogen in Wastewater

The first step to calculating N_2O in wastewater is to determine the amount of nitrogen entering into the wastewater stream; this is largely a function of population and per capita protein consumption. The nitrogen introduced to wastewater is multiplied by an emission factor specific to each treatment type. The amount of nitrogen introduced into each treatment system is based on the amount of protein consumed, with adjustment to account for non-consumed protein (i.e., garburators), industrial and commercial co-discharge and additional nitrogen from household products (Equation A3.6–33).

Equation A3.6–33 **Nitrogen Entering the Wastewater Treatment System**

$$N = Pop * Protein\ Consumed * F_{NPR} * N_NH * F_{NON\text{-}CON} * F_{IND\text{-}COM}$$

N	=	the amount of nitrogen entering the treatment system (kg)
Pop	=	the population using the treatment system
$Protein\ Consumed$	=	per capita protein consumption (kg/cap/year)
F_{NPR}	=	fraction of protein that is nitrogen
$F_{NON\text{-}CON}$	=	factor for N in non-consumed protein
$F_{IND\text{-}COM}$	=	factor for industrial and commercial co-discharge
N_NH	=	factor for additional nitrogen from household products

Protein consumption is derived using the protein availability from the Food and Agricultural Organization statistical database (FAOSTAT, n.d.). Protein availability is converted to protein consumption using the previously published Statistics Canada analysis on nutrients in the food supply, with a ratio of 0.678 (Statistics Canada, 2009), which accounts for the protein available after loss. The combined FAOSTAT data combined with further accounting for protein loss is assumed to be representative of protein consumption (Table A3.6–19). The variable F_{NPR} represents the fraction of nitrogen that is protein and a value of 0.16 kg N/kg protein is used (IPCC, 2019). $F_{IND\text{-}COM}$ and N_NH are additional parameters to account for additional nitrogen inputs that may enter the wastewater stream from industrial and commercial sources as well as from the use of household productions. The values for $F_{IND\text{-}COM}$ and N_NH are 1.25 and 1.17, respectively (IPCC, 2019).

For the parameter $F_{NON\text{-}CON}$, the 2019 Refinement default factor for nitrogen inputs from waste disposed in-sink (garburators) is used. The $F_{NON\text{-}CON}$ for North America is 1.13 where food is disposed of in-sink and 1.0 when food is not disposed in-sink. For Canada, 10% of households use in-sink garbage disposal (IPCC, 2019, Table 6.10B). As no regional specific information about where in-sink garbage disposal (garburators) are permitted, it is assumed that the 10% of households using in-sink disposal are evenly distributed across Canada. To determine the total (net) N inputs from food disposed in sink, we can apply the default $F_{NON\text{-}CON}$ factor of 1.13 for food disposed in sink to the 10% of the population that does so, and the default $F_{NON\text{-}CON}$ of 1.0 for cases where food is not disposed in sink to the remaining 90% of the population, resulting in an overall $F_{NON\text{-}CON}$ values of 1.013.

Treatment Based Emissions

Depending on the type of wastewater treatment, N_2O emission factors can vary. Thus since the amount of nitrogen entering in the wastewater stream is population dependent, it is imported to estimate which fraction of the population is associated with each treatment type. This derivation of the population using various treatment types is explained in the preceding section in the discussion of CH_4 emissions from wastewater, resulting in the variable $Fraction_{tech}$. Then, N_2O emissions are developed using Equation A3.6–34, accounting for each treatment type in Canada. Emission factors are largely based on the IPCC 2019 Refinement, with some adaptation based on Canadian circumstances (Table A3.6–18). The emissions for all treatment types are then totalled to account for national and provincial totals.

Equation A3.6–34 **Direct N_2O Emissions from Wastewater Treatment Plants**

$$N_2O_{Treatment} = N_{wastewater} * Fraction_{tech} * EF_{Tech} * 44/28$$

$N_2O_{Treatment}$	=	the N_2O emissions arising directly from wastewater treatment (kg)
$N_{wastewater}$	=	the amount of nitrogen entering the wastewater stream (kg)
$EFTech$	=	EF_Tech_T is the emission factor of kg Nitrogen emitted (kg N_2O-N/kg N)
$Fraction_{tech}$	=	fraction of treatment type used in Canada, by population
$44/28$	=	the stochiometric conversion from N_2O-N to N_2O

Table A3.6–18 **N_2O Emission Factors and N Removal for Different Treatment Types**

Treatment Category	EF (kg N_2O-N/kg N)	N-Removal Fraction	EF Source	N-Removal Source
No Treatment	0	0	IPCC (2019)	IPCC (2019)
Primary	0	0.1	ECCC estimate	
Aerobic Lagoon	0	0.4		
Anaerobic Lagoon	0	0.4	IPCC (2019)	
Facultative Lagoon	0	0.4	ECCC estimate	
Other / Unspecified Lagoon	0	0.4	Model as facultative lagoon	
Secondary Anaerobic	0	0.4	IPCC (2019)	
Secondary Activated Sludge	0.016	0.4		
Trickling Filter	0.016	0.4		
Trickling Filter – High Rate	0.016	0.4		
Rotating Biological Contactor	0.016	0.4		
Sequencing Batch Reactor	0.016	0.4		
Secondary Biofiltration	0.016	0.8	ECCC estimate	
Secondary with Biological Nutrient Removal	0.016	0.8	IPCC (2019)	
Septic	0.0045	0.68		
Septic with Marine Outfall	0	0.15		
Wetland	0	1	ECCC estimate	
Other / Unknown	0.016	0.4	Model as facultative lagoon	

Discharge (to Receiving Waterbody) Based Emissions

N_2O emissions from municipal wastewater treatment facilities are estimated using the amount of nitrogen discharged to the aquatic environment. The first step for calculating the effluent emissions is to determine the nitrogen remaining in the effluent, as a portion of this nitrogen will be removed during the treatment process (Table A3.6–18). Nitrogen removal can vary between 0% for instances of no treatment, up to 68% when septic tanks and land dispersal fields are used. Parameters are drawn from table 6.10c of the 2019 IPCC Refinement (IPCC, 2019); ECCC estimated some of the EF and N-removal parameters for treatment technology not included in the 2019 IPCC Refinement. Wetlands are assumed to removal all N from wastewater due to the long residence time and high uptake by vegetation.

After accounting for nitrogen removed at wastewater treatment, the remaining nitrogen introduced to the wastewater stream is multiplied by an emission factor of 0.005 kg N_2O-N / kg N_2O-N in wastewater, as shown in Equation A3.6–35.

Equation A3.6–35

$$N_2O = EF_{N2O\text{-}N} \times N_{wastewater} \times 44/28$$

N_2O = N_2O emissions in the inventory year, kg N_2O/year
$EF_{N2O\text{-}N}$ = emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N
$N_{wastewater}$ = nitrogen in wastewater, kg N/yr
$44/28$ = stoichiometric factor to convert nitrogen to N_2O

Nitrogen removed from sludge is not estimated because of a lack of data on nitrogen concentration in sewage sludge. The 2006 IPCC Guidelines default value of 0 is used.

Table A3.6–19 **Canadian Protein Supply and Consumption**

Year	Protein Supply (FAOSTAT, g/capita/day)	Protein Consumption (g/capita/day)	Protein Consumption (kg/capita/year)
1990	96.1	35.1	24.5
1991	96.2	35.1	24.6
1992	95.9	35.0	24.5
1993	95.8	35.0	24.5
1994	99.6	36.3	25.4
1995	98.0	35.8	25.0
1996	98.7	36.0	25.2
1997	100.5	36.7	25.7
1998	103.3	37.7	26.4
1999	107.1	39.1	27.4
2000	106.1	38.7	27.1
2001	105.1	38.3	26.8
2002	105.3	38.4	26.9
2003	104.0	38.0	26.6
2004	104.8	38.3	26.8
2005	102.1	37.3	26.1
2006	103.5	37.8	26.5
2007	104.4	38.1	26.7
2008	104.7	38.2	26.8
2009	103.1	37.6	26.4
2010	111.0	40.5	28.4
2011	110.2	40.2	28.2
2012	112.4	41.0	28.7
2013	111.2	40.6	28.4
2014	107.9	39.4	27.6
2015	107.0	39.1	27.3
2016	111.9	40.8	28.6
2017	114.1	41.7	29.2
2018	117.6	42.9	30.0
2019	116.1	42.4	29.7
2020	115.5	42.2	29.5
2021	113.0	41.3	28.9
2022	115.8	42.3	29.6
2023	115.8	42.3	29.6
2024	115.8	42.3	29.6

A3.6.4.3. CO_2 Municipal Wastewater Treatment/Discharge – CO_2

CO_2 emissions from wastewater are of biogenic origin. According to the 2006 IPCC Guidelines, CO_2 from the combustion or decay of short-lived biogenic material removed from where it was grown is reported as zero in the Waste sector. Therefore, these emissions are not considered for wastewater treatment.

A3.6.4.4. Industrial Wastewater Treatment and Discharge – CO_2, CH_4 and N_2O

Estimates for CO_2, CH_4 and N_2O emissions from industrial facilities with on-site wastewater treatment are determined by facility following a Tier 3 approach (IPCC, 2006).

Data Sources and Methodology

A Tier 3, facility-level approach is used for Industrial Wastewater Treatment and Discharge, making use of facility-reported data obtained through the GHGRP (emissions), the National Pollutant Reporting Program (NPRI; N discharge to receiving water bodies) and facility reported data through voluntary surveys (methane recovery and emissions). Treatment technology, organic product (BOD_5), N loads to wastewater, and methane recovery can vary considerably by facility and by production levels, making general estimation difficult. For this reason, facility reported emissions, N-discharges and methane recovery are necessary to develop emission estimates.

The primary data source of emissions estimates is the GHGRP, which requires any facility emitting >10,000 tonnes of CO_2 eq to report their emissions to ECCC. Facilities are required to report CH_4, N_2O and any non-biogenic CO_2 emissions from wastewater treatment, among other GHG sources. These data are used directly in the NIR for the Industrial Wastewater Treatment and Discharge sector.

CH_4 recovery data from industrial wastewater treatment are gathered through voluntary surveys. Note that, unlike estimates for municipal wastewater or landfills, CH_4 recovery is not subtracted from methane generation because facility-reported emissions (GHGRP) represent the net emission and recovery has already been accounted for.

The GHGRP facility-level emissions are supplemented using calculated emissions based on the voluntarily reported biogas recovery for facilities that reported biogas recovery but fall below GHGRP reporting thresholds, or for time periods before GHGRP reporting began. Emissions calculated from recovered biogas are based on an assumed CH_4 fugitive loss of 2.1% and flaring CH_4 emissions of 0.3%. Emissions from biogas utilization are reported under the Energy sector.

Total Organic Product (BOD_5) is not reported in CRT Table 5.D because these data are not available. The GHGRP reporting for this sector only includes emissions and does not include data related to organic product. While ECCC conducts a voluntary survey of biogas methane recovery from industrial wastewater treatment, this survey is limited in scope (to facilities with methane recovery) and does not include sufficient information to extrapolate organic product across all industrial wastewater treatment facilities.

N_2O emissions from discharge to receiving water bodies are calculated based on facility-reported discharges of N to receiving water bodies, reported through the NPRI. N_2O emissions are calculated from the N loading to a receiving water body using Equation A3.6–35, and the same emission factor(s) as for domestic wastewater effluents. Note, however, that for industrial wastewater discharges, the receiving water body types are not yet determined, meaning all effluents emissions are calculated from the "Unspecified Waterbody" type. The N_2O emissions reported to the GHGRP are facility/treatment based and should not include emissions from receiving water bodies. Some double counting where facilities may have included receiving water body emissions in their submissions to GHGRP are possible but expected to be minor and are reduced through quality-control review during reporting.

CH_4 emissions from effluents discharged to receiving water bodies are not estimated. Organic product (BOD_5) of industrial wastewater effluents is neither reported through NPRI, nor available from other mandatory reporting programs. Organic product in effluent cannot be easily predicted (it varies by facility-level production levels and treatment technology).

CO_2 emissions from industrial wastewater treatment are facility-reported, through the GHGRP. These originate from facilities that have on-site treatment of wastewater containing fossil (non-biogenic) organic inputs, such as chemicals manufacturing, oil refineries or methanol production, and treatment of ethylene glycol, for example, can produce non-biogenic CO_2 emissions from their wastewater treatment. Non-biogenic CO_2 wastewater treatment emissions are reported in CRT Table 5 using category 5.E because there is no accommodation in CRT Table 5.D.2 for non-biogenic CO_2.

To address time series consistency, emissions, effluent discharges, and biogas recovery are extrapolated back to 1990 (or forward between voluntary-survey years, if necessary), by facility. Earliest and latest values are held constant through time. Data gaps are completed using linear interpolation. This is necessary because the GHGRP and NPRI programs started in 2004 and 2011, respectively.

ANNEX 4

COMPARISON OF SECTORAL AND REFERENCE APPROACHES, AND THE NATIONAL ENERGY BALANCE

A4.1. Comparison of Reference Approach with Sectoral Approach 519
A4.2. Reference Approach Methodology 520
A4.3. National Energy Balance 522
A4.4. CRT Implied Emission Factors 524

This annex presents the energy and the CO_2 emission results from the reference approach (RA), a comparison of the results from the RA with those estimated by the sectoral approach (SA), and a summary of the national energy balance, which is the main energy data source for both the RA and the SA. Section A4.4 contains a general discussion on the merits of using implied emission factors.

A4.1. Comparison of Reference Approach with Sectoral Approach

A comparison of results from the RA and the SA is a check of energy available versus consumed by all sectors, and the corresponding CO_2 emissions from fossil fuel combustion. Checks of RA and SA results for all years from 1990 to 2024 are an integral part of reporting under the Paris Agreement to the United Nations Framework Convention on Climate Change (UNFCCC).

Direct comparison of energy consumption in the RA and SA shows significant discrepancies since the SA total does not include some of the non-energy use of fossil fuels and feedstocks. Comparison of the RA and SA shows an 11.8% or larger variation in energy. Excluding the non-combustion energy of certain feedstocks and fossil fuels ensures that the RA and the SA are comparing similar sources. When the RA energy amounts include adjustments for non-energy use of fossil fuels and feedstocks, the difference between the SA and adjusted RA varies from -1.97 to 1.95%. Table A4–1 shows the energy consumption from the common reporting tables (CRT) generated RA output and the applied adjustments associated with non-energy use of fossil fuels and feedstock in comparison with the SA.

No adjustments were necessary for the emissions estimate in the RA since the online CRT reporting software, supplied by the UNFCCC, correctly removes emissions associated with non-energy and feedstock use and allocates them to industrial processes and product use sectors. Comparison of the RA and SA emission estimates, as seen in Table A4–1, shows an overall -1.27% to 3.98% variation.

Table A4–1 **Comparison of Reference Approach and Sectoral Approach for Canada**

	1990	2005	2019	2020	2021	2022	2023	2024
OVERALL ENERGY COMPARISON								
Reference Approach (PJ)								
without Adjustment	7 122	9 042	9 683	8 898	9 132	9 362	9 200	9 385
with Non-Energy Use of Fossil Fuels and Feedstock Adjustment	6 332	7 931	8 518	7 762	7 975	8 211	7 996	8 135
Sectoral Approach (PJ)	6 335	7 985	8 640	7 840	8 013	8 244	8 157	8 204
Percent Difference without Adjustment (%)	12.4	13.2	12.1	13.5	14.0	13.6	12.8	14.4
Percent Difference with Adjustment (%)	**-0.04**	**-0.68**	**-1.41**	**-0.99**	**-0.46**	**-0.39**	**-1.97**	**-0.84**
Non-Energy Use of Fossil Fuels and Feedstocks								
Non-Energy Use of Gaseous Fuels (PJ)	169	163	151	148	157	149	156	156
Non-Energy Use of Liquid Fuels (PJ)	518	847	933	921	925	929	972	1 016
Non-Energy Use of Solid Fuels (PJ)	103	102	80	67	75	73	75	79
OVERALL EMISSION COMPARISON								
Reference Approach (Gg CO_2)	415 397	514 567	517 809	466 350	477 555	488 439	472 822	478 459
Sectoral Approach (Gg CO_2)	411 473	511 674	520 112	466 445	475 107	485 797	478 882	477 459
Percentage Difference (%)	**0.95**	**0.57**	**-0.44**	**-0.02**	**0.52**	**0.54**	**-1.27**	**0.21**
Liquid Fuels								
Reference Approach (Gg CO_2)	207 995	250 346	242 852	206 546	215 663	223 926	213 926	219 784
Sectoral Approach (Gg CO_2)	203 262	243 890	242 396	206 587	213 139	221 297	217 833	217 259
Percentage Difference (%)	**2.33**	**2.65**	**0.19**	**-0.02**	**1.18**	**1.19**	**-1.79**	**1.16**
Solid Fuels								
Reference Approach (Gg CO_2)	86 944	102 517	48 300	40 382	36 613	29 475	26 091	18 066
Sectoral Approach (Gg CO_2)	86 860	104 089	48 785	39 943	36 072	28 965	25 764	17 926
Percentage Difference (%)	**0.10**	**-1.51**	**-0.99**	**1.10**	**1.50**	**1.76**	**1.27**	**0.78**
Gaseous Fuels								
Reference Approach (Gg CO_2)	120 006	161 172	225 908	218 661	224 500	234 390	232 035	239 793
Sectoral Approach (Gg CO_2)	120 899	163 163	228 181	219 155	225 117	234 888	234 515	241 458
Percentage Difference (%)	**-0.74**	**-1.22**	**-1.00**	**-0.23**	**-0.27**	**-0.21**	**-1.06**	**-0.69**

A4.2. Reference Approach Methodology

The RA follows the 2006 Intergovernmental Panel on Climate Change (IPCC) Guideline's methodology with the use of country-specific energy contents (in higher heating value [HHV]/gross calorific value [GCV]) by fuel types and emission factors. Canada uses HHVs/GCVs to report the energy content of fuels which is in-line with reporting requirements either in GCVs or net calorific values (NCVs). Fuel supply and demand reported by industries, to Statistics Canada (StatCan), in various surveys that feed into the compiled *Report on Energy Supply and Demand in Canada* (RESD) (StatCan, n.d.) are in physical units. Chapter 3, section 3.5.1 International Bunker Fuels, and annex sections A3.1.4.2.2 Civil Aviation, and A3.1.4.2.3 Navigation present fuel allocation for bunkers.

For primary fuels (crude oil, ethane, natural gas liquids, coal, and natural gas), the stock change data have been adjusted to account for inter-product transfers, stock variation and other adjustments, all of which are reported separately in the RESD and all of which directly impact fuel availability. Apparent consumption is determined using this adjusted stock change number. Similarly, the stock change data for secondary fuels takes into consideration inter-product transfers, international bunkers, stock variation and other adjustments.

Once apparent consumption is determined, country-specific fuel energy contents and carbon emission factors allow for the calculation of carbon content and emissions. The sources of energy content values, and applied emission and oxidation factors, are listed in Table A4–2.

For the RA, the RESD supplies the energy content values, with the exceptions of coal, crude oil, heavy fuel oil, LPGs, natural gas, NGLs, petroleum coke and still gas, where weighted factors, calculated yearly, account for the quantity and variation of energy content at the point of consumption, such as commercial usage or self-generated usage. For example, in provinces with natural gas production, there are unique emission factors for marketable natural gas, sold to consumers, and non-marketable natural gas, combusted by the producers of natural gas. The composition of non-marketable natural gas includes more complex hydrocarbons and less methane (CH_4) than marketable natural gas which, typically, contains over 92% methane.

Table A4–2 Reference Approach Energy Contents and Emission Factors for Canada

Fuel Types			Energy Content, GCV			Carbon Emission Factor – 2024 Value (t C/TJ GCV)	Reference	Oxidation Factors	Comments
			2024 Value	Unit	Reference				
Liquid	Primary Fuels	Crude Oil	39.52	TJ/ML	Refer to notes	18.83	Refer to notes	1.0	Weighted energy content and emission factor are based on country-specific data.
		Ethane	17.22	TJ/ML	4	15.46	2	1.0	Total available ethane is consumed as a feedstock in industrial processes.
		Orimulsion	NA	–	–	NA	–	1.0	-
		Natural Gas Liquids	25.46	TJ/ML	–	16.35	–	1.0	Propane and butane from natural gas liquids.
	Secondary Fuels	Bitumen	44.46	TJ/ML	4	21.11	3	1.0	Use of asphalt.
		Gas/Diesel Oil	38.35	TJ/ML	4	19.06	2	1.0	Use of diesel fuel oil.
		Gasoline	33.45	TJ/ML	4	18.81	2	1.0	Use of motor gasoline.
		Jet Kerosene	37.40	TJ/ML	4	18.67	2	1.0	Use of aviation turbo fuel.
		Liquefied Petroleum Gases (LPG)	27.16	TJ/ML	4	16.59	2	1.0	Country-specific weighted factors for propane and butane from petroleum refineries.
		Lubricants	39.16	TJ/ML	4	19.66	3	1.0	Use of lubricating oils and greases.
		Naphtha	35.17	TJ/ML	4	19.34	3	1.0	Use of naptha specialties.
		Other Kerosene	37.68	TJ/ML	4	18.53	2	1.0	Use of kerosene & stove oil.
		Other Oil	38.8	TJ/ML	4	19.35	2	1.0	Use of light fuel oil.
		Petroleum Coke	35.86	TJ/ML	4	23.17	4	1.0	Country-specific weighted emission factors based on available emission factors for refining and upgrading (of oil sands to synthetic crude oil).
		Refinery Feedstocks	35.17	TJ/ML	4	19.34	3	1.0	Use of petrochemical feedstock in industrial processes.
		Residual Fuel Oil	42.5	TJ/ML	4	20.25	2	1.0	Use of heavy fuel oil.
		Shale Oil	NA	–	–	NA	–	–	-
		Still Gas	39.35	TJ/ML	4	13.57	4	1.0	Country-specific weighted emission factor based on factors from refinery and from upgrading (of crude from oil sands to synthetic crude oil) activities.
	Other Liquid Fuels	Aviation Gasoline	33.52	TJ/ML	4	19.24	3	1.0	Use of aviation gasoline.
		Other Product Feedstocks	39.82	TJ/ML	4	19.84	3	1.0	Use of other products.
Solid	Primary Fuels	Anthracite	31.60	TJ/kt	4	26.73	3	0.988	Use of anthracite.
		Other Bituminous Coal	28.38	TJ/kt	4	21.26	6	0.988	Use of Canadian bituminous coal.
		Sub-bituminous Coal	22.63	TJ/kt	4	25.04	6	0.994	Use of sub-bituminous coal.
		Lignite	16.29	TJ/kt	4	24.49	5, 6	0.996	Use of lignite.
		Oil Shale	NA	–	–	NA	–	–	-
		Peat	NA	–	–	NA	–	–	-
	Secondary Fuels	Coke	28.83	TJ/kt	4	30.02	2	1.0	Previously reported as Coking Coal.
		BKB & Patent Fuel	NA	–	–	NA	–	–	-
		Coke Oven Gas	19.14	TJ/GL	4	9.79	2	–	Use of coke oven gas.
	Other Solid Fuels	Foreign Bituminous Coal	29.82	TJ/kt	4	23.63	5, 6	0.987	Use of Foreign bituminous coal.
Gaseous	Primary Fuels	Natural Gas	38.52	TJ/GL	4	13.79	2	1.0	Country-specific weighted emission factor based on proportion of marketable and non-marketable natural gas.
Biomass		Municipal Solid Waste	10.50	TJ/kt	1	26.05	1	1.0	Consists of biomass combustion, for energy purposes, at landfills.
		Solid Biomass	16.51	TJ/kt	4	21.88	7, 8	1.0	Consists of industrial and residential biomass consumption.
		Liquid Biomass	17.90	TJ/kt	4	18.62	3, 9	1.0	Consists of spent pulping liquor, ethanol and biodiesel.
		Gas Biomass	42.78	TJ/Gl	1	13.54	1	1.0	Consists of methane from landfill gas, sludge gas and digester gas.

Notes:
References: (1) IPCC (2006); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada (n.d.), #57-003 (2024 data); (5) ECCC (2016); (6) ECCC (2023); (7) ECCC (2020); (8) ECCC (2024); (9) ICFPA/NCASI (2011).
NA = Not applicable; GCV = gross calorific value; BKB = Charcoal briquettes; NGL = natural gas liquids; LPG = liquified petroleum gas.

A4.3. National Energy Balance

This section provides a general background on the national energy balance and its data quality framework. In Canada, the Centre for Energy and Transportation Statistics (CETS) of StatCan is responsible for the collection, compilation and dissemination of energy data under the authority of the Statistics Act (Government of Canada, 1985). The RESD is the primary source of activity data used to estimate GHG emissions for the Energy sector. Emission estimates for the Industrial Processes and Product Use sector also use the non-energy and feedstock information from the RESD as a source of activity data. The RESD is an accounting of energy forms in Canada from import and export activities through to production, stock change, inter product transfer (i.e., natural gas to hydrogen) and domestic consumption (refer to Figure A4–1 for the 2024 energy flow diagram [CCEI, 2025]). It consists of information on crude oil, natural gas, coal, refined petroleum products (RPPs), electricity, steam, non-energy use of fossil fuels, feedstock and other secondary energy forms for all Canadian industrial sectors and other energy use, such as the transportation, residential and commercial sectors.

Energy and fossil fuel data are collected using a mix of annual and monthly surveys, along with census data from industry, federal agencies (such as the Canadian Energy Regulator [CER]), provincial energy departments and agencies (such as the Alberta Energy Regulator [AER] and the Alberta Utilities Commissions [AUC]), and the Canadian Energy and Emissions Data Centre (CEEDC). See Figure A4–2 for a sample of the energy and fossil fuel data inputs to the RESD. The oil and gas information provided by the AER is considered accurate, since it is tied to, oil and gas exploitation permits and federal and provincial royalty schemes.

Figure A4–1 **2024 Energy Balance Flow Diagram for Canada (RESD) (CCEI, 2025)**

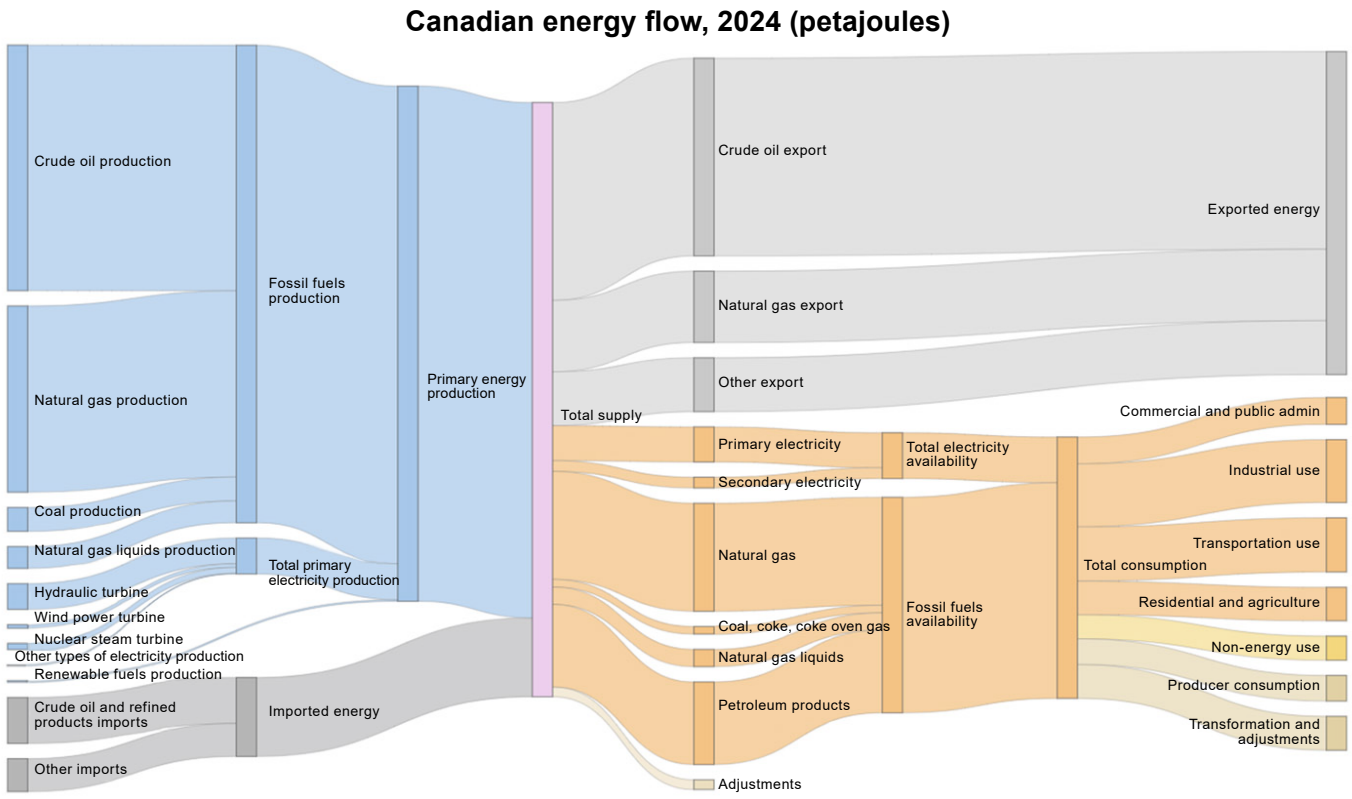
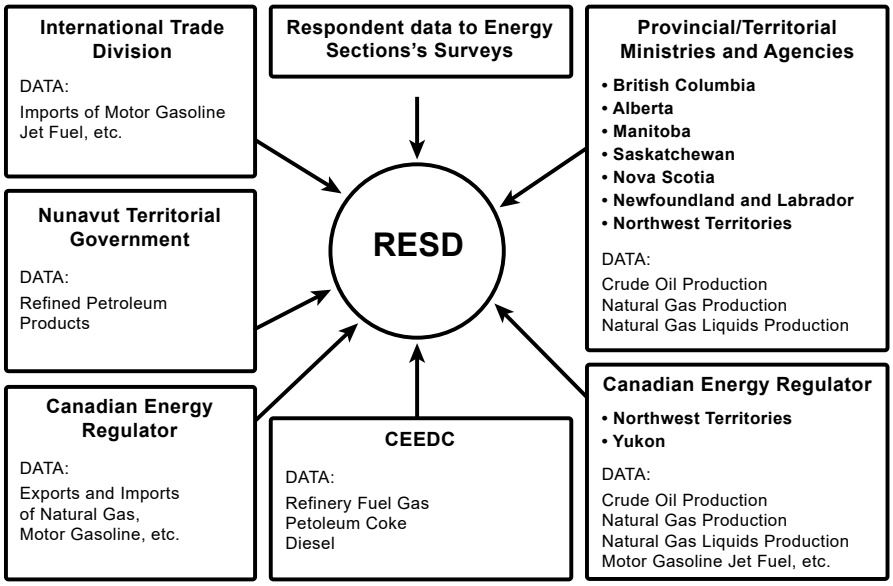


Figure A4–2 **Fossil Fuel and Energy Data Input into the RESD**



Notes:
RESD = Report on Energy Supply and Demand
CEEDC = Canadian Energy and Emissions Data Centre

Various federal departments use the RESD for energy efficiency programs, policy development, energy and emission forecasting, and reporting to the UNFCCC. The CETS's quality management system for the RESD includes an internal and external stakeholder review process, with StatCan's complete documentation of their quality assurance framework and quality guidelines available online (StatCan, 2017, 2019). CETS has also established partnerships with various federal government departments, provincial energy ministries, industrial associations and centres of excellence to assist with the quality assurance process.

The following quality criteria are essential to the development of the RESD as set out by StatCan: relevance, accuracy and reliability, timeliness and punctuality, accessibility and clarity, coherence and comparability, and interpretability and metadata.

There are also other internal data quality checks of the information collected through provincial energy departments and various supply, disposition and consumption surveys. For example, the quantities of crude oil reported by the producer are compared to reported receipts from pipeline companies, and the volume data reported by pipelines is verified against refinery receipts. CETS also applies both a top-down approach through the supply and disposition surveys and a bottom-up approach through the Industrial Consumption of Energy (ICE) survey to verify the quality of the data for manufacturing industries. The ICE survey collects fuel consumption data directly from manufacturing industries following the North American Industry Classification System. In addition, the Annual Survey of Secondary Distributors of Refined Petroleum Products (SRPP) collects data on sale volumes for use in reallocating volumes of heavy fuel oil, light fuel oil, diesel, biodiesel blended diesel fuel, and ethanol-blended gasoline to the appropriate consuming sectors. The SRPP survey was necessary due to the deregulation of allowable sales of these products from only primary producers (refineries) to include secondary resellers/distributors. Prior to this improvement, fuel volumes reported in the commercial sector incorrectly included all sales by refineries to secondary distributors. The deregulation of the sale of these four fuels started around the year 2000. A consistent approach was applied to the historical dataset to address the misallocated fuel volumes between 2000 and 2008 since the SRPP only started collecting sale volumes from 2009 onward.

Also, as part of CETS's quality framework, an annual "work-in-progress" review has been established with Environment and Climate Change Canada and Natural Resources Canada to review the ICE and RESD data prior to their official release. Industrial stakeholders also participate in the review of ICE data through the Canadian Industry Partnership for Energy Conservation (CIPEC) group. CEEDC also participates in the review of refinery data and the industrial energy statistics.

A4.4. CRT Implied Emission Factors

UNFCCC expert reviewers use the CRT reporting software generated implied emission factors (IEFs) as an initial check for possible outliers. There is merit in the use of IEF checks, especially for a direct comparison of the same commercial fuel between countries, since each of these fuels meets standardized specifications for quality and composition, with an accepted range of carbon content and heating value. Commercial fuels like motor gasoline, diesel and light fuel oil have similar specifications globally, resulting in IEFs that differ by only a few percentage points. However, the percentage difference for fuels like non-marketable (raw) natural gas, crude oil or coal (i.e., bituminous, sub-bituminous, etc.) can vary greatly due to differences in local geology, deposits or fuel categorizations (the latter being especially true in the case of coal).

These checks for IEF outliers are less reliable when fuels are grouped as solid, liquid, gaseous and biomass in CRT categories 1.A.1 to 1.A.4. For countries consuming both commercial and non-commercial fuels, and particularly for energy-producing nations where non-commercial/non-marketable fuels are readily available and consumed in significant quantities, IEF checks can result in more outliers for certain sectors and fuel groupings (i.e., gaseous and liquid fuels). Generally, countries with large primary energy production (bitumen, crude oil, natural gas, etc.) will consume a greater proportion of non-commercial fuels compared to countries with little or no primary energy production and who mostly consume commercial fuels. For these situations, recognizing the impact on IEFs of national circumstances by either increasing its range or conducting IEF checks on a fuel-by-fuel basis would provide more relevant quality checks.

In Canada, shifting the focus of IEF checks from groups of fuels to individual fuels allows a better understanding of their influence on the generation of outliers.

- It allows for an appreciation of the relative proportion of commercial and non-commercial fuel consumed within each fuel grouping.
- It demonstrates how the mix of commercial and non-commercial fuels with wide-ranging carbon and energy densities affects the IEF for each fuel.

For example, Canada's implied emission factors can be relatively high for liquid fuels due to the combustion of significant quantities of petroleum coke and still gas. In the case of gaseous fuels IEFs can be high because some energy producers consume large quantities of non-marketable natural gas.

Table A4–2 illustrates the wide range of carbon contents between fuel groups, and shows that even within the commercial secondary liquid fuels group, the carbon content ranges from 13.57 to 23.17 t C/TJ. For CRT categories consuming a greater portion of still gas or petroleum coke (refinery/upgrader fuels) relative to commercial grade refined petroleum products, the overall IEF for liquid fuels will appear to be an outlier since it will be higher than international averages.

Since Canada produces large quantities of fossil fuels, the following categories will most likely generate IEF outliers; 1.A.1.b Petroleum Refining, 1.A.1.c.i Manufacture of Solid Fuels, and 1.A.1.c.ii Oil and Gas Extraction. As mentioned, IEF category checks should be on a fuel-by-fuel basis or by assessing Parties that have a similar industry makeup; this would generate more comparable results and analysis.

OZONE AND AEROSOL PRECURSORS

The Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC)[1] and reporting requirements (modalities, procedures and guidelines [MPGs] for the transparency framework under the Paris Agreement[2]) recommend that Parties provide information on indirect greenhouse gases (GHGs) such as carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs) and sulphur oxides (SO_x) in the National Inventory Report (NIR).

Aerosols are liquid, solid, or mixed particles suspended in the atmosphere. Aerosol particles are either emitted directly to the atmosphere or produced in the atmosphere from precursor gases. While these gases do not have a direct global warming effect, they either influence the creation and destruction of tropospheric and stratospheric ozone (O_3) or affect terrestrial radiation absorption, as in the case of SO_x. These gases can impact the climate by acting as short-lived GHGs, alter atmospheric lifetimes of other GHGs and quickly react to form GHGs, as in the case of CO reacting with a hydroxyl radical (OH), an oxidation reaction, to form carbon dioxide (CO_2) in the atmosphere—hence the label "indirect GHGs." Emissions from these precursors are produced by a number of sources, such as fossil fuel combustion in the energy and transportation sectors, industrial production, and biomass combustion.

Information on ozone and aerosol precursor emissions in Canada, including CO, NO_x, NMVOCs, and SO_x, is available in Canada's Air Pollutant Emissions Inventory Report.[3]

Canada also reports indirect CO_2 emissions that result from the atmospheric oxidation of CO emitted from biomass burned on site after forest harvest and from forest conversion activities. These emissions are reported in the Land Use, Land-use Change, and Forestry (LULUCF) sector within Table 6 of the Common Reporting Tables[4] (CRT). National totals are presented in CRT Table 10 and Summary 2 with and without these indirect CO_2 emissions in accordance with paragraph 52 of the MPGs. Details on the source of these emissions can be found in Chapter 6 and Annex 3.5 of this report.

1 Adopted through Decision 24/CP.19 (2014), see paragraph 29 for information on precursor gases, available at https://unfccc.int/sites/default/files/resource/docs/2013/cop19/eng/10a01.pdf.

2 Adopted through Decision 18/CMA.1 (2018), see paragraph 51 for information on indirect GHGs, available at https://unfccc.int/resource/tet/0/00mpg.pdf.

3 Canada's Air Pollutant Emissions Inventory Report can be found at canada.ca/apei.

4 More information on the NIR submissions (consisting of a report and CRTs) can be found at https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review/reporting-and-review-under-the-paris-agreement/national-inventory-reports, while the complete CRTs submitted by Canada can be found on the National Inventory Submissions page, accessible through the same link.

ANNEX 6

EMISSION FACTORS

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This annex summarizes the development and selection of emission factors (EFs) used to estimate Canada's annual greenhouse gas (GHG) inventory. Annex 6 tables are available in Excel (.xlsx) format on the Government of Canada's Open Data website.[1] Details on sector-specific methodological use of these factors are presented in Annex 3.

A6.1. Fuel Combustion

A6.1.1. Natural Gas and Natural Gas Liquids

A6.1.1.1. Carbon Dioxide (CO_2)

CO_2 emission factors for fossil fuel combustion depend primarily on fuel properties such as carbon content, density and heating value and, to a lesser extent, on the combustion technology.

For natural gas, there are two principal types combusted in Canada: marketable fuel (processed for commercial sale) and non-marketable fuel (unprocessed, for internal use). There are regional variations in marketable and non-marketable natural gas use, with nine regions consuming marketable fuel and seven regions consuming non-marketable fuel.

For the period 1990 to 1998, provincial and territorial emission factors for marketable natural gas (Table A6.1–1) were developed using data from the chemical analysis of representative natural gas samples collected in 1998 (McCann, 2000). Both imported and domestic natural gas were included, where applicable, in the mix of gas samples used for chemical analysis.

For the period 2005 to 2018, an industry expert was contracted to work with the natural gas transmission and distribution industry to define provincial natural gas flow networks and to collect historical data. Over 500 000 data points were collected for these years at key points, such as transmission lines, interprovincial transfer locations, storage locations, import and export sites, and consumer distribution networks, where volumetric flow and composition data were measured and available. Using this data, the emission factors and energy content values of marketable natural gas were updated for the years 2005 to 2024 (Table A6.1–1) to reflect a gradual increase in complex hydrocarbons in the natural gas stream that offset the approximately 2% decrease in methane over the same time period. Data collected by the contractor underwent further analysis (ECCC, 2021) and this showed that since it was last measured in 1998 the percent methane composition in the natural gas stream had changed in the period from 1999 to 2004. This resulted in a step change in natural gas parameters and emissions from 2004 to 2005. To minimize the effect of this step change, ECCC revised the natural gas parameters for these intermediate years, 1999 to 2004, using a simple linear interpolation.

1 https://data-donnees.az.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/

Non-marketable natural gas emission factors for Alberta (Table A6.1–2) were updated using over 400 000 raw gas samples, ranging in date from 1913 to 2016, obtained from the Alberta Energy Regulator (AER) by the Energy and Emissions Research Laboratory (EERL) of Carleton University (EERL, 2020). EERL compiled and analysed the data to provide average gas compositions by township. Gas composition data by township were weighted by township-level fuel gas consumption volumes obtained from Petrinex (2010–2024), to produce annual average CO_2 emission factors for the province.

Emission factors for non-marketable natural gas in British Columbia were developed by ECCC from sample analysis data taken from thousands of wells in the province (BCER, n.d. [a]). Following the procedure set out by EERL (2020) , the gas sample data was used to estimate the composition of natural gas produced from each well in British Columbia. Well-level gas production data (BCER, n.d. [b]) was linked to the final natural gas composition dataset and used to develop production-weighted average compositions for 1990–2024, which were then used to calculate annual average CO_2 emission factors.

Non-marketable natural gas is produced and consumed at oil and gas facilities offshore of Newfoundland and Labrador. Non-marketable natural gas CO_2 emission factors for these offshore facilities were derived using emissions data reported to the GHG Reporting Program (ECCC, 2025) and fuel and flare volumes reported by facilities to the Canada-Newfoundland and Labrador Offshore Energy Regulator (C-NLOER, n.d.).

Generally, non-marketable natural gas emission factors (Table A6.1–2) are higher than those of marketable natural gas (Table A6.1–1) because of their raw/unprocessed nature where complex hydrocarbons are not removed prior to usage. In addition to methane, the composition of marketable and non-marketable natural gas includes ethane, propane, butane, and other more complex hydrocarbons.

CO_2 emission factors (Table A6.1–3) for natural gas liquids (NGL), such as ethane, propane and butane, were developed based on chemical analysis data for marketable fuels (McCann, 2000).

A6.1.1.2. Methane (CH_4)

Emissions of CH_4 from fuel combustion are technology-dependent. Sectoral emission factors (Table A6.1–3, Table A6.1–4, and Table A6.1–5) have been developed based on technologies typically used in Canada. For most sources, the factors were developed based on a broad review of emission factors for combustion technologies (SGA Energy, 2000). The generic emission factor for producer consumption of natural gas in Table A6.1–4 was developed based on a technology split for the upstream oil and gas industry (CAPP, 1999) and technology-specific emission factors from the U.S. EPA report AP 42 (U.S. EPA, 1996). Province-specific values in Table A6.1–5 were calculated using the same approach, but the fuel volumes used to weight the emissions factors were updated to reflect the annual distribution of producer consumption within the upstream oil and gas industry.

A6.1.1.3. Nitrous Oxide (N_2O)

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors (Table A6.1–3 and Table A6.1–4) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

Table A6.1–1 CO_2 Emission Factors for Marketable Natural Gas

Year	EF (g/m^3)[a]													
	Canada	BC	AB	SK	MB	QC	ON	NB	NS	PE	NL	YT	NT[b]	NU
1990	1 899	1 926	1 928	1 829	1 886	1 887	1 888	1 901	1 901	1 901	1 901	1 901	2 466	NO
1995	1 899	1 926	1 928	1 829	1 886	1 887	1 888	1 901	1 901	1 901	1 901	1 901	2 466	NO
2000	1 895	1 918	1 923	1 839	1 880	1 880	1 881	1 884	1 884	1 884	1 884	1 900	2 466	1 900
2005	1 883	1 898	1 911	1 864	1 864	1 864	1 865	1 864	1 864	1 864	1 867	1 898	2 466	1 898
2006	1 878	1 896	1 917	1 855	1 855	1 854	1 855	1 855	1 855	1 855	1 862	1 896	2 466	1 896
2007	1 881	1 901	1 910	1 857	1 857	1 858	1 859	1 858	1 858	1 858	1 856	1 901	2 466	1 901
2008	1 887	1 906	1 910	1 863	1 863	1 865	1 865	1 864	1 864	1 864	1 860	1 906	2 466	1 906
2009	1 889	1 900	1 920	1 861	1 861	1 865	1 863	1 862	1 862	1 862	1 865	1 900	2 466	1 900
2010	1 891	1 902	1 923	1 860	1 862	1 868	1 869	1 865	1 865	1 865	1 864	1 902	2 466	1 902
2011	1 893	1 900	1 921	1 866	1 866	1 870	1 871	1 869	1 869	1 869	1 869	1 900	2 466	1 900
2012	1 905	1 899	1 931	1 874	1 873	1 882	1 888	1 880	1 880	1 880	1 873	1 899	1 899	1 899
2013	1 910	1 909	1 933	1 875	1 873	1 884	1 896	1 887	1 887	1 887	1 886	1 909	1 909	1 909
2014	1 912	1 912	1 930	1 878	1 875	1 882	1 896	1 887	1 887	1 887	1 892	1 912	1 912	1 912
2015	1 924	1 939	1 943	1 881	1 905	1 911	1 911	1 912	1 912	1 912	1 900	1 939	1 939	1 939
2016	1 932	1 941	1 954	1 897	1 896	1 907	1 915	1 908	1 908	1 908	1 914	1 941	1 941	1 941
2017	1 936	1 955	1 955	1 900	1 903	1 915	1 916	1 910	1 910	1 910	1 914	1 955	1 955	1 955
2018	1 944	1 966	1 962	1 920	1 915	1 926	1 921	1 919	1 919	1 919	1 918	1 966	1 966	1 966
2019	1 944	1 966	1 962	1 920	1 915	1 926	1 921	1 919	1 919	1 919	1 921	1 966	1 966	1 966
2020	1 944	1 966	1 962	1 920	1 915	1 926	1 921	1 919	1 919	1 919	1 921	1 966	1 966	1 966
2021	1 944	1 966	1 962	1 920	1 915	1 926	1 921	1 919	1 919	1 919	1 921	1 966	1 966	1 966
2022	1 944	1 966	1 962	1 920	1 915	1 926	1 921	1 919	1 919	1 919	1 921	1 966	1 966	1 966
2023	1 944	1 966	1 962	1 920	1 915	1 926	1 921	1 919	1 919	1 919	1 921	1 966	1 966	1 966
2024	1 944	1 966	1 962	1 920	1 915	1 926	1 921	1 919	1 919	1 919	1 919	1 966	1 966	1 966

Notes:
The term "marketable" applies to fuel consumed by the Utility, Industry, Residential, Commercial, and Transport subsectors.
NO = Not occurring
a. Years 1990–1998, McCann (2000). Years 1999–2024, ECCC (2021).
b. Prior to 2012, natural gas consumption was regional non-marketable natural gas. Since 2012, marketable natural gas has been imported from BC.

Table A6.1–2 CO_2 Emission Factors for Non-Marketable Natural Gas

Year	EF (g/m^3)												
	BC[a]	AB[b]	SK	MB	QC	ON	NB	NS	PE	NL[c]	YT	NT	NU
1990	1 946	2 080	2 441	2 401	NO	2 401	2 401	2 494	NO	NO	2 401	2 466	NO
1995	1 960	2 080	2 441	2 401	NO	2 401	2 401	2 494	NO	NO	2 401	2 466	NO
2000	1 980	2 080	2 441	2 401	NO	2 401	2 401	2 494	NO	C	2 401	2 466	NO
2005	1 940	2 080	2 441	2 401	NO	2 401	2 401	2 494	NO	2 299	2 401	2 466	NO
2006	1 942	2 080	2 441	2 401	NO	2 401	2 401	2 494	NO	2 298	2 401	2 466	NO
2007	1 943	2 080	2 441	2 401	NO	2 401	2 401	2 494	NO	2 294	2 401	2 466	NO
2008	1 938	2 080	2 441	2 401	NO	2 401	2 401	2 494	NO	2 327	2 401	2 466	NO
2009	1 939	2 080	2 441	2 401	NO	2 401	2 401	2 494	NO	2 309	2 401	2 466	NO
2010	1 941	2 054	2 441	2 401	NO	2 401	2 401	2 494	NO	2 276	2 401	2 466	NO
2011	1 941	2 062	2 441	2 401	NO	2 401	2 401	2 494	NO	2 220	2 401	2 466	NO
2012	1 956	2 068	2 441	2 401	NO	2 401	2 401	2 494	NO	2 281	2 401	2 466	NO
2013	1 973	2 071	2 441	2 401	NO	2 401	2 401	2 494	NO	2 272	2 401	2 466	NO
2014	1 998	2 075	2 441	2 401	NO	2 401	2 401	2 494	NO	2 263	2 401	2 466	NO
2015	2 017	2 081	2 441	2 401	NO	2 401	2 401	2 494	NO	2 260	2 401	2 466	NO
2016	2 052	2 089	2 441	2 401	NO	2 401	2 401	2 494	NO	2 261	2 401	2 466	NO
2017	2 070	2 093	2 441	2 401	NO	2 401	2 401	2 494	NO	2 250	2 401	2 466	NO
2018	2 109	2 101	2 441	2 401	NO	2 401	2 401	2 494	NO	2 191	2 401	2 466	NO
2019	2 128	2 106	2 441	2 401	NO	2 401	2 401	2 494	NO	2 218	2 401	2 466	NO
2020	2 144	2 109	2 441	2 401	NO	2 401	2 401	2 494	NO	2 274	2 401	2 466	NO
2021	2 164	2 109	2 441	2 401	NO	2 401	2 401	2 494	NO	2 210	2 401	2 466	NO
2022	2 172	2 112	2 441	2 401	NO	2 401	2 401	2 494	NO	2 340	2 401	2 466	NO
2023	2 177	2 112	2 441	2 401	NO	2 401	2 401	2 494	NO	2 260	2 401	2 466	NO
2024	2 199	2 115	2 441	2 401	NO	2 401	2 401	2 494	NO	2 290	2 401	2 466	NO

Notes:
The term "non-marketable" applies to raw/unprocessed gas consumption, mainly by natural gas producers.
NO = Not occurring
C = confidential
a. Derived by ECCC from well-level gas samples and production data reported to the provincial regulator (BCER, n.d. [b]; [c]).
b. Adapted from EERL (2020) using Petrinex (2010–) annual volumetric data
c. Derived using ECCC (2025) and C-NLOER (n.d.)
All other provinces/territories from McCann (2000)

Table A6.1–3 Emission Factors for Natural Gas Liquids

Source	EF (g/L)		
	CO_2	CH_4	N_2O
Propane			
Residential	1 515[a]	0.027[b]	0.108[b]
All Other Uses	1 515[a]	0.024[b]	0.108[b]
Ethane	986[a]	0.024[b]	0.108[b]
Butane	1 747[a]	0.024[b]	0.108[b]

Notes:
a. McCann (2000)
b. SGA Energy (2000)

Table A6.1–4 CH_4 and N_2O Emission Factors for Natural Gas

Source	EF (g/m^3)[a]	
	CH_4	N_2O
Electric Utilities	0.490	0.049
Industrial	0.037	0.033
Producer Consumption (Non-marketable)	6.4[b]	0.060
Producer Consumption (Non-marketable) – Newfoundland and Labrador	0.490	0.060
Pipelines	1.9	0.050
Cement	0.037	0.034
Manufacturing Industries	0.037	0.033
Residential, Construction, Commercial/Institutional, Agriculture	0.037	0.035

Notes:
a. SGA Energy (2000).
b. Adapted from U.S. EPA (1996) and CAPP (1999). Not applicable in British Columbia, Alberta, and Saskatchewan.

Table A6.1–5 CH_4 Emission Factors for Natural Gas Producer Consumption in Western Provinces

Year	EF (g/m^3)						
	BC[a]	AB[b]	SK[c]	Year	BC[a]	AB[b]	SK[c]
1990	8.85	6.40	6.02	2008	9.04	8.55	4.55
1991	8.85	6.40	6.42	2009	9.03	8.51	4.44
1992	8.85	6.40	6.29	2010	8.91	8.52	4.10
1993	8.85	6.40	5.99	2011	8.80	8.58	3.80
1994	8.85	6.40	5.71	2012	8.66	8.32	3.60
1995	8.85	6.40	5.54	2013	8.59	8.33	3.44
1996	8.85	6.62	5.30	2014	8.61	8.32	4.04
1997	8.85	6.85	5.18	2015	8.41	8.22	3.81
1998	8.85	7.07	5.29	2016	8.47	8.32	3.89
1999	8.85	7.29	5.19	2017	8.39	8.39	3.89
2000	8.85	7.52	5.04	2018	8.41	8.25	4.16
2001	8.85	7.74	5.26	2019	8.44	8.16	4.55
2002	8.87	7.96	5.44	2020	8.59	8.23	4.82
2003	8.79	8.19	5.78	2021	8.73	8.08	4.49
2004	9.15	8.41	4.90	2022	8.83	8.21	4.09
2005	9.15	8.51	4.66	2023	9.20	8.22	4.21
2006	9.15	8.50	4.77	2024	9.35	8.14	4.10
2007	9.15	8.52	4.67				

Notes:
All EFs adapted from U.S. EPA (1996) and CAPP (1999) and weighted using annual fuel gas volumes taken from the following sources and grouped to align with CAPP (1999).
a. Years 2019–2024, BCER (n.d. [c]). Years 2001–2018, BC (2019). Years 1990–2000, constant.
b. Years 2010–2024, Petrinex (2010–). Years 2004–2009, AER (2003–). Years 1996–2003, linear interpolation. Years 1990–1995, CAPP (1999).
c. Years 2013–2024, Petrinex (2013–). Years 1990–2012, SK MER (2012–).

A6.1.2. Refined Petroleum Products

A6.1.2.1. CO_2

CO_2 emission factors for fossil fuel combustion are dependent primarily on fuel properties and, to a lesser extent, on the combustion technology.

Emission factors (Table A6.1–6) have been developed for each major class of refined petroleum products (RPP) based on their heating value, carbon content and density (McCann, 2000), to ensure consistency with the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006).

The composition of petroleum coke is process-specific. Factors have been developed for both refinery (catalytic cracker) derived cokes and coke used in upgrading facilities. These factors (Table A6.1–7) have been developed using emissions and energy content data provided by industry to the Canadian Energy and Emissions Data Centre (CEEDC).[2] The bulk of the coke consumed by refineries is catalytic cracker-derived, and the emission factor is a weighted average of petroleum coke and catalytic cracker coke emission factors. In the electricity generation sector in New Brunswick, petroleum coke is imported and mixed with coal prior to combustion. Carbon content data specific to this imported petroleum coke was used to develop a sector-specific petroleum emission factor, used only in New Brunswick. Since the data is facility-specific, the petroleum coke emission factor provided in Table A6.1–6 is a weighted emission factor for Canada.

Emission factors for still gas (Table A6.1–7) from refining operations and upgrading facilities were also derived from data provided by industry and reported by CEEDC.

A6.1.2.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors were developed (Table A6.1–6) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

The emission factor for petroleum coke was assumed to be the same for both catalytic cracker-derived cokes and coke used in upgrading facilities.

The emission factor for still gas from upgraders (Table A6.1–6) was based on the 2006 IPCC default emission factor and was adapted using energy conversion factors provided by CEEDC. The still gas emission factors for refineries and other industries (Table A6.1–9) were based on the 2006 IPCC default emission factor, which was calculated on an annual basis using energy conversion factors provided by CEEDC.

A6.1.2.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for RPP, except for petroleum coke, have been developed (Table A6.1–6) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

Emission factors for petroleum coke (Table A6.1–8) were based on 2006 IPCC default emission factors and were calculated on an annual basis using energy conversion factors provided by Statistics Canada (n.d.) and CEEDC.

2 Griffin, B. 2025. Personal communication (email from Griffin B., CEEDC to Kay J., Physical Scientist, PIRD dated October 2, 2025). Canadian Energy and Emissions Data Centre (CEEDC).

Table A6.1–6 Emission Factors for Refined Petroleum Products

Source	EF (g/L)		
	CO_2[a]	CH_4[b]	N_2O[c]
Light Fuel Oil			
Electric Utilities	2 753	0.18	0.031
Industrial	2 753	0.006	0.031
Producer Consumption	2 670	0.006	0.031
Residential	2 753	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 753	0.026	0.031
Heavy Fuel Oil			
Electric Utilities	3 156	0.034	0.064
Industrial	3 156	0.12	0.064
Producer Consumption	3 190	0.12	0.064
Residential, Forestry, Construction, Public Administration and Commercial/Institutional	3 156	0.057	0.064
Kerosene			
Electric Utilities	2 560[c]	0.006	0.031
Industrial	2 560[c]	0.006	0.031
Producer Consumption	2 560[c]	0.006	0.031
Residential	2 560[c]	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 560[c]	0.026	0.031
Diesel – Refineries and Others[d]	2 681	0.078	0.022
Diesel – Upgraders[d]	2 681	0.078	0.022
Petroleum Coke	See Table A6.1–7	0.12	See Table A6.1–8
Still Gas – Refineries and Others	See Table A6.1–7	See Table A6.1–9	0.00002
Still Gas – Upgraders	See Table A6.1–7	0.000039	0.00002
Motor Gasoline[e]	2 307	0.100	0.02

Notes:
a. McCann (2000); except Kerosene, Diesel and Motor Gasoline
b. SGA Energy (2000); except Diesel and Motor Gasoline
c. Assumed McCann (2000) aviation turbo-fuel EF
d. CO_2 from ECCC (2017); CH_4 and N_2O from Oak Leaf Environmental Inc. (2017)
e. CO_2 from ECCC (2017); CH_4 and N_2O adapted from IPCC (2006)

Table A6.1–7 **CO_2 Emission Factors for Petroleum Coke and Still Gas**

Year	EF			
	Petroleum Coke (g/L)		Still Gas (g/m³)	
	Upgrading Facilities[a]	Refineries and Others[b]	Upgrading Facilities[a]	Refineries and Others[c]
1990	2 965	3 140	2 310	1 740
1995	2 961	3 160	2 090	1 800
2000	2 903	3 090	2 120	1 680
2005	2 837	3 141	2 140	1 707
2006	2 813	3 150	2 140	1 741
2007	2 800	3 174	2 140	1 749
2008	2 813	3 193	2 140	1 690
2009	2 792	3 199	2 140	1 711
2010	2 817	3 261	2 140	1 825
2011	2 820	3 234	2 140	1 818
2012	2 802	3 240	2 140	1 718
2013	2 765	3 220	2 140	1 738
2014	2 794	3 227	2 140	1 741
2015	2 795	3 232	2 140	1 762
2016	2 781	3 236	2 140	1 781
2017	2 800	3 253	2 140	1 796
2018	2 769	3 235	2 140	1 847
2019	2 771	3 258	2 140	1 849
2020	2 769	3 246	2 140	1 770
2021	2 744	3 250	2 140	1 764
2022	2 729	3 199	2 140	1 773
2023	2 717	3 256	2 140	1 773
2024	2 703	3 319	2 140	1 790

Notes:

a. CEEDC (2003)

b. Weighted EF based on Griffin B. 2025. Personal communication (email from Griffin B to Kay J, Physical Scientist, Pollutant Inventories and Reporting Division, dated October 2, 2025). Canadian Emissions and Energy Data Centre, and Samms J. 2020 Personal Communication (email from Samms J to Tracey K, Senior Program Engineer, Pollutant Inventories and Reporting Division, dated December 8, 2020).

c. Griffin B. 2025. Personal communication (email from Griffin B to Kay J, Physical Scientist, Pollutant Inventories and Reporting Division, dated October 2, 2025). Canadian Emissions and Energy Data Centre.

Table A6.1–8 **N_2O Emission Factors for Petroleum Coke**

Year	EF	
	Petroleum Coke (g/m^3)	
	Upgrading Facilities[a, b]	Refineries and Others[a, c]
1990	18.2	21.9
1995	18.9	22.9
2000	20.1	23.5
2005	19.5	23.0
2006	19.4	23.1
2007	19.3	23.1
2008	19.4	23.1
2009	19.2	23.2
2010	19.4	23.2
2011	19.4	23.2
2012	19.3	23.4
2013	19.0	23.4
2014	19.2	23.4
2015	19.2	23.6
2016	19.1	23.5
2017	19.3	23.6
2018	19.1	23.5
2019	19.1	23.6
2020	19.1	23.6
2021	18.9	23.6
2022	18.8	23.3
2023	18.7	23.6
2024	18.6	23.4

Notes:
a. Adapted from IPCC (2006)
b. Energy content from Statistics Canada (n.d.)
c. Energy content from Griffin B. 2025. Personal communication (email from Griffin B to Kay J, Physical Scientist, Pollutant Inventories and Reporting Division, dated October 2, 2025). Canadian Emissions and Energy Data Centre.

Table A6.1–9 **CH_4 Emission Factors for Still Gas (Refineries and Others)**

Year	EF[a]
	g/m³
1990–96	0.033
1997	0.032
1998	0.031
1999	0.033
2000	0.034
2001	0.034
2002	0.033
2003	0.033
2004	0.033
2005	0.032
2006	0.032
2007	0.032
2008	0.032
2009	0.032
2010	0.032
2011	0.033
2012	0.031
2013	0.031
2014	0.031
2015	0.033
2016	0.032
2017	0.033
2018	0.034
2019	0.035
2020	0.032
2021	0.033
2022	0.032
2023	0.033
2024	0.033

Note:
a. Adapted from IPCC (2006) using energy content taken from Griffin B. 2025. Personal communication (email from Griffin B to Kay J, Physical Scientist, Pollutant Inventories and Reporting Division, dated October 2, 2025. Canadian Emissions and Energy Data Centre.

A6.1.3. Coal and Coal Products

A6.1.3.1. CO_2

CO_2 emission factors for coal combustion depend largely on the properties of the fuel and, to a lesser extent, on the combustion technology. Coal emission factors (Table A6.1–10) were developed for each province based on the rank of the coal and the region of supply. Emission factors were based on data from chemical analysis of coal samples for electric utilities, which account for most of the coal consumption.

ECCC has been developing coal emission factors over time, starting in 2012 with the analysis of over 3000 analytical samples for a variety of coal types and producing/consuming regions. The analysis and uncertainty calculations were conducted using the @Risk software package. The coal emission factors are presented with uncertainty estimates since the supply and quality of coal can vary over time. The average coal carbon and moisture content for each coal type were used to develop CO_2 emission factors.

In 2015, an additional study to determine country-specific coal oxidation factors and further investigate the carbon content of coal burned at electric generation facilities was conducted for ECCC by GHD Limited. In 2021, ECCC collected further carbon content coal data from electric generation facilities that did not participate in the 2015 study. Based on an analysis of the data collected since 2012, ECCC has developed rank and region-specific emission and oxidation factors as well as uncertainty estimates for all but anthracite (ECCC, 2023).

Factors for anthracite imported from the United States are from a study done for Environment Canada (EC) on CO_2 emission factors, based on data collected on coal consumption in Canada in 1998 (McCann, 2000). All coal emission factors in Table A6.1–10 now incorporate Canada-specific oxidation factors (ECCC, 2023).

Coke and coke oven gas emission factors are presented in Table A6.1–11. The coke emission factor was developed from an iron and steel industry study completed in 2014 (CRA, 2014). It is representative of coke use in the cement, non-ferrous metal and other manufacturing industries. The coke oven gas emission-factor value is from McCann (2000) and represents use in the iron and steel industry.

Table A6.1–10 CO_2 Emission Factors for Coal

Province	Coal Type	Source	EF (kg CO_2 / tonne)[a, b]			Oxidation Factor[b] (%)	Moisture (wt %)
			Mean	Uncertainty (95% CI)[c]			
				Low	High		
NL, NS, PE, QC (Prior to 2000)	Canadian Bituminous	NS	2 344	-33%	22%	98.78	3.2
NL, NS, PE, QC (2000 onward)	Canadian Bituminous	AB	2 212	-26%	26%	98.78	7.7
NB (Prior to 2010)	Canadian Bituminous	NB	2 333	-14%	14%	98.78	3.2
NB (2010 onward)	Canadian Bituminous	AB	2 212	-26%	26%	98.78	7.7
AB, BC, MB, ON, SK	Canadian Bituminous	AB	2 212	-26%	26%	98.78	7.7
NB, NS, PE and NL	Foreign Bituminous	Non-U.S.	2 571	-7%	7%	98.78	8.3
MB	Foreign Bituminous	U.S. (Pennsylvania)	2 651	-7%	7%	98.78	N/A
ON	Foreign Bituminous	U.S. (Pennsylvania)	2 651	-7%	7%	98.38	N/A
QC, AB, BC	Foreign Bituminous	U.S. (Pennsylvania)	2 662	-7%	7%	98.78	N/A
All Provinces and Territories, except SK	Lignite	SK	1 463	-13%	13%	99.92	24
SK	Lignite	SK	1 463	-13%	13%	99.61	36
QC, ON, MB	Sub-bituminous	Foreign	1 865	-8%	8%	99.84	24
NS, PE	Sub-bituminous	Foreign	1 743	-8%	8%	99.84	24
AB, SK, BC	Sub-bituminous	AB	1 775	-11%	11%	99.36	21
NB (2010, 2011, 2013, 2014)	Sub-bituminous	Foreign	2 189	-2%	2%	99.84	19
NB (2012, 2015 onward)	Sub-bituminous	Foreign	2 352	-2%	2%	99.84	12
All Provinces and Territories	Anthracite	--	3 097	-6%	6%	98.78	N/A

Notes:
CI = confidence interval
N/A = Not available
a. Factors presented on a "wet basis." Moisture content shown is that for the "weighted average" EF.
b. ECCC (2023)
c. 95% Confidence Intervals, which were determined through statistical analysis of Canadian coal data.

Table A6.1–11 CO_2 Emission Factors for Coke Oven Gas and Coke

Coal Product – Fuel Type	EF
Coke Oven Gas[a]	687 g/m^3
Coke[b]	3 173 g/kg

Notes:
a. McCann (2000)
b. CRA (2014)

A6.1.3.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors for sectors (Table A6.1–12) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

A6.1.3.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for sectors (Table A6.1–12) have been developed based on technologies typically used in Canada. The emission factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

Table A6.1–12 CH_4 and N_2O Emission Factors for Coal, Coke and Coke Oven Gas

Source	EF	
	CH_4	N_2O
	g/kg	
Coal		
Electric Utilities	0.02	0.03
Industry and Heat & Steam Plants	0.03	0.02
Residential, Public Administration	4.00	0.02
Coke	0.03	0.02
	g/m^3	
Coke Oven Gas	0.04	0.04

Note:
Source: SGA Energy (2000)

A6.1.4. Fugitive Emission Factors for Coal Mining

The factors in Table A6.1–13 are for fugitive emissions from coal mining only. Although derived from measurements at individual mines or coal seams, these emission factors are aggregated and weighted, province-wide averages for a given mine type. These weighted emission factors are updated yearly to account for the change in production of coal types, at individual mines. They should only be applied to total provincial gross (not net) production quantities of coal mined which includes small quantities of minerals, stone and other inert materials mined with the coal, but later removed before sale or consumption.

Table A6.1–13 **Provincially Weighted Coal Mining Fugitive Emission Factors (t CH_4/kt coal mined)**

	Surface Coal Mines				
	Bituminous			Sub-bituminous	Lignite
Year	AB	BC	NS	AB	SK
1990	0.58	0.82	C	0.18	0.07
1995	0.58	0.82	0.07	0.21	0.07
2000	0.59	0.82	0.07	0.21	0.07
2005	0.51	0.87	0.07	0.21	0.07
2006	0.48	0.86	0.07	0.21	0.07
2007	0.47	0.87	C	0.21	0.07
2008	0.47	0.85	C	0.21	0.07
2009	0.43	0.85	C	0.20	0.07
2010	0.44	0.86	C	0.20	0.07
2011	0.42	0.84	C	0.21	0.07
2012	0.45	0.85	C	0.21	0.07
2013	0.46	0.84	C	0.22	0.07
2014	0.52	0.84	C	0.20	0.07
2015	0.55	0.86	C	0.20	0.07
2016	C	0.87	C	0.21	0.07
2017	C	0.86	C	0.22	0.07
2018	0.51	0.92	C	0.23	0.07
2019	0.47	0.93	C	0.24	0.07
2020	0.36	0.93	C	0.21	0.07
2021	C	0.93	C	0.15	0.07
2022	0.31	0.92	C	0.15	0.07
2023	0.31	0.92	C	0.15	0.07
2024	0.31	0.91	C	0.43[a]	0.07

Notes:
C = Confidential
a. Alberta's 2024 weighted sub-bituminous EF reflects a larger contribution from more GHG intensive mines than previous years due to the closure of a less GHG intensive operation.
Adapted from King (1994), and Cheminfo and Clearstone Engineering Ltd (2014).
Weighted EFs for underground coal mines in Nova Scotia, Alberta, and British Columbia are either confidential or there are no mines operating due to closures.

A6.1.5. Other Fuels

A6.1.5.1. CO_2

Alternative fuels such as tires, shingles, plastics, refuse, and waste oil, solvents and other fossil-based wastes, along with dried sewage sludge, paper, animal meal, animal fat and other biogenic wastes are used in the cement industry to offset combustion of purchased fuels like coal, oil or natural gas. CO_2 emissions associated with the stationary combustion of fossil-based waste fuels are included in the National Inventory Report where data are available. Fuel use data reported by the cement industry, using CO_2 accounting and reporting standards developed by the World Business Council for Sustainable Development (WBSCD, 2005), were used to generate the emission factors in Table A6.1–14 from 1990 to 2016. From 2017 onwards, fuel use data and emissions were reported by cement facilities through the Greenhouse Gas Reporting Program (GHGRP) (ECCC, 2025). An annual weighted average EF was developed based on reported data. CO_2 emissions associated with the stationary combustion of biogenic waste fuels are reported as a memo item in the common reporting tables (CRT) of the Energy sector. See section A6.6.1 for the emission factor associated with biogenic waste fuels.

Some municipal solid wastes and medical wastes are combusted in waste-to-energy facilities. See section A6.7.2 for the emission factors associated with these other fuels.

A6.1.5.2. CH_4

CH_4 emission factors for fossil-based alternative fuels (Table A6.1–14) were adapted from the 2006 IPCC Guidelines (IPCC, 2006). See section A6.6.2 for the emission factors associated with bio-based alternative fuels.

Some municipal solid wastes and medical wastes are combusted in waste-to-energy facilities. See section A6.7.2 for the emission factors associated with these other fuels.

A6.1.5.3. N_2O

N_2O emission factors for fossil-based alternative fuels (Table A6.1–14) were adapted from the 2006 IPCC Guidelines (IPCC, 2006). See section A6.6.3 for the emission factors associated with bio-based alternative fuels.

Some municipal solid wastes and medical wastes are combusted in waste-to-energy facilities. See section A6.7.2 for the emission factors associated with these other fuels.

Table A6.1–14 **Emission Factors for Alternative Fuels**

Year	EF (kg/GJ)		
	Cement Industry Waste Fuel		
	CO_2[a]	CH_4[b]	N_2O[b]
1990	78.8	0.03	0.004
1995	77.6	0.03	0.004
2000	77.6	0.03	0.004
2005	81.1	0.03	0.004
2006	79.4	0.03	0.004
2007	80.1	0.03	0.004
2008	79.5	0.03	0.004
2009	78.2	0.03	0.004
2010	79.3	0.03	0.004
2011	79.1	0.03	0.004
2012	79.1	0.03	0.004
2013	79.1	0.03	0.004
2014	79.1	0.03	0.004
2015	79.1	0.03	0.004
2016	79.1	0.03	0.004
2017	80.1	0.03	0.004
2018	84.1	0.03	0.004
2019	86.0	0.03	0.004
2020	68.5	0.03	0.004
2021	84.3	0.03	0.004
2022	75.8	0.03	0.004
2023	79.8	0.03	0.004
2024	73.0	0.03	0.004

Notes:
a. Years 1990–2016 adapted from WBSCD (2005). Years 2017–2024 adapted from ECCC (2025).
b. Adapted from IPCC (2006)

A6.1.6. Mobile Combustion

A6.1.6.1. CO_2

CO_2 emission factors for mobile combustion are dependent on fuel properties and are generally the same as those used for stationary combustion fuels.

A6.1.6.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Mode-specific CH_4 emission factors have been developed based on technologies typically used in Canada, and are summarized in Table A6.1–15. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies. A number of on-road CH_4 emission factors were subsequently refined with updated Canadian and U.S. emissions test results (Environment Canada, 2006, 2009; Graham et al., 2008). Light-duty on-road trucks and vehicles of model year 2017 and newer are associated with Tier 3 emissions standards. CH_4 emission factors for Tier 3 vehicles were established using MOVES3-based results (Oak Leaf Environmental Inc., 2022). The CH_4 emission factor applicable to off-road gasoline two-stroke engines was parsed into gasoline and lubricating oil components based on relative proportions of energy in the gasoline-lubricating oil blend (ECCC, 2022c).

Over 50 aircraft-specific aviation turbo fuel CH_4 emission factors from the 2006 IPCC Guidelines (IPCC, 2006) are used in the Tier 3 civil aviation model (Aviation Greenhouse Gas Emission Model—AGEM). Table A6.1–15 displays a national overall average implied emission factor (refer to section A3.4.2.3 for more information on AGEM).

A6.1.6.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Mode-specific N_2O emission factors have been developed based on technologies typically used in Canada. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies. Several on-road N_2O emission factors were subsequently refined with updated Canadian and U.S. emissions test results (Environment Canada, 2006, 2009; Graham et al., 2008, 2009). Light-duty on-road trucks and vehicles of model year 2017 and newer are associated with Tier 3 emissions standards. N_2O emission factors for Tier 3 vehicles were established using certification-based results (Oak Leaf Environmental Inc., 2022).

The N_2O emission factor applicable to off-road gasoline two-stroke engines was parsed into gasoline and lubricating oil components based on relative proportions of energy in the gasoline-lubricating oil blend (ECCC, 2022c).

In particular, the updated test data highlighted the effect of high-sulphur gasoline on N_2O emission factors. Vehicles fuelled with high-sulphur gasoline for most of their useful lives generally emitted higher levels of N_2O than those run on low-sulphur gasoline (Environment Canada, 2009).

Table A6.1–15 Emission Factors for Energy Mobile Combustion Sources

Mode†	EF (g/L fuel)		
	CO_2	CH_4	N_2O
Road Transport			
Gasoline Vehicles			
Light-duty Gasoline Vehicles (LDGVs)			
Tier 3	2 307.3 [a]	0.111 [r]	0.007 [r]
Tier 2	2 307.3 [a]	0.14 [c]	0.022 [d]
Tier 1	2 307.3 [a]	0.23 [e]	0.47 [e]
Tier 0	2 307.3 [a]	0.32 [f]	0.66 [g]
Oxidation Catalyst	2 307.3 [a]	0.52 [h]	0.20 [f]
Non-catalytic Controlled	2 307.3 [a]	0.46 [h]	0.028 [f]
Light-duty Gasoline Trucks (LDGTs)			
Tier 3	2 307.3 [a]	0.111 [r]	0.007 [r]
Tier 2	2 307.3 [a]	0.14 [c]	0.022 [d]
Tier 1	2 307.3 [a]	0.24 [e]	0.58 [e]
Tier 0	2 307.3 [a]	0.21 [h]	0.66 [g]
Oxidation Catalyst	2 307.3 [a]	0.43 [h]	0.20 [f]
Non-catalytic Controlled	2 307.3 [a]	0.56 [f]	0.028 [f]
Heavy-duty Gasoline Vehicles (HDGVs)			
Three-way Catalyst	2 307.3 [a]	0.068 [h]	0.20 [h]
Non-catalytic Controlled	2 307.3 [a]	0.29 [f]	0.047 [f]
Uncontrolled	2 307.3 [a]	0.49 [f]	0.084 [f]
Motorcycles			
Non-catalytic Controlled	2 307.3 [a]	0.77 [c]	0.041 [c]
Uncontrolled	2 307.3 [a]	2.3 [f]	0.048 [f]
Diesel Vehicles			
Light-duty Diesel Vehicles (LDDVs)			
Advanced Control*	2 680.50 [a]	0.051 [f]	0.22 [f]
Moderate Control	2 680.50 [a]	0.068 [f]	0.21 [f]
Uncontrolled	2 680.50 [a]	0.10 [f]	0.16 [f]
Light-duty Diesel Trucks (LDDTs)			
Advanced Control*	2 680.50 [a]	0.068 [f]	0.22 [f]
Moderate Control	2 680.50 [a]	0.068 [f]	0.21 [f]
Uncontrolled	2 680.50 [a]	0.085 [f]	0.16 [f]
Heavy-duty Diesel Vehicles (HDDVs)			
Advanced Control	2 680.50 [a]	0.11 [i]	0.151 [i]
Moderate Control	2 680.50 [a]	0.14 [f]	0.082 [f]
Uncontrolled	2 680.50 [a]	0.15 [f]	0.075 [f]
Natural Gas Vehicles	1.9 [b]	0.0088 [f]	0.00006 [f]
Propane Vehicles	1 515 [b]	0.64 [f]	0.028 [f]
Off-road			
Off-road Gasoline 2-stroke	2 307.3 [a]	10.56 [q]	0.013 [q]
Off-road Gasoline 4-stroke	2 307.3 [a]	5.08 [l]	0.064 [m]
Off-road Diesel < 19kW	2 680.50 [a]	0.073 [l]	0.022 [l]
Off-road Diesel ≥ 19kW, Tier 1 - 3	2 680.50 [a]	0.073 [l]	0.022 [l]
Off-road Diesel ≥ 19kW, Tier 4	2 680.50 [a]	0.073 [l]	0.227 [l]
Off-road Lubricating Oil 2-stroke	2 705.0 [q]	12.69 [q]	0.016 [q]
Off-road Natural Gas	1.9 [b]	0.0088 [f]	0.00006 [f]
Off-road Propane	1 515 [b]	0.64 [f]	0.087 [l]
Railways			
Diesel Train	2 680.50 [a]	0.149 [m]	1.029 [m]
Marine			
Gasoline	2 307.3 [a]	0.21931 [m]	0.06266 [m]
Diesel	2 680.50 [a]	0.25193 [m]	0.07198 [m]
Light Fuel Oil	2 753 [b]	0.2555 [m]	0.073 [m]
Heavy Fuel Oil	3 156 [b]	0.2856 [m]	0.0816 [m]
Kerosene	2 559.70 [n]	0.2471 [m]	0.0706 [m]
Aviation			
Aviation Gasoline	2 325.40 [j]	2.19 [j]	0.23 [j]
Aviation Turbo Fuel	2 559.70 [b]	0.018 [k]	0.0711 [m]
Renewable Fuels			
Ethanol	1 508.04 [a, o]	**	**
Biodiesel	2 472.2 [a, o, p]	***	***

Notes:
† In the context of Transportation Modes, Tiers refer to increasingly stringent emission standards, enabled through advancements in emission control technologies. It should not be confused with IPCC GHG estimation methodologies.
* Advanced control diesel EFs are used for Tier 2 diesel vehicle populations.
** Gasoline CH_4 and N_2O EFs (by mode and technology) are used for ethanol.
*** Diesel CH_4 and N_2O EFs (by mode and technology) are used for biodiesel.

a. ECCC (2017)
b. McCann (2000)
c. Adapted from Environment Canada (2006)
d. Adapted from Environment Canada (2006) and Graham et al. (2009)
e. Adapted from Environment Canada (2009)
f. SGA Energy (2000)
g. Adapted from Barton & Simpson (1994)
h. ICF Consulting (2004)
i. Graham et al. (2008)
j. Jaques (1992)
k. National overall average EF for the whole time series based on 2006 IPCC Guidelines (IPCC 2006). Refer to section A3.1.4.2.3 of Annex 3.1 for further information.
l. Oak Leaf Environmental Inc (2017)
m. IPCC (2006) Converted into g/L using gross calorific value where necessary.
n. Assumed McCann (2000) aviation turbo-fuel EF.
o. Refer to section 3.5.1 Chapter 3 for further information.
p. BioMer (2005)
q. ECCC (2022)
r. Oak Leaf Environemental Inc. (2022)

A6.2. Industrial Processes

A6.2.1. Mineral Products

Emission factors used to estimate emissions from the production and use of mineral products are listed in Table A6.2–1.

Table A6.2–1 Range of CO_2 Emission Factors for Mineral Products

Category	Mineral Product	EF ($g\ CO_2$ / kg of mineral product)
Cement Production	Clinker	493–533[a]
	Total Organic Carbon (TOC)	10.3–13.1[a]
Lime Production	High-Calcium Lime	751–759[b]
	Dolomitic lime	865–889[b]
Other Limestone and Dolomite Use	Limestone	418–453[c]
	Dolomite	445–468[c]
Other Uses of Soda Ash	Soda Ash	415[c]
Non-Metallurgical Magnesia Production	Magnesite	522[c]

Notes:
a. Range of year-specific EFs provided by the Cement Association of Canada (2015) and ECCC (2025).
b. Range of year-specific EFs developed based on information from ECCC (2025) and Kenefick W. 2008. Personal communication (email from Kenefick W to Shen A, Environment Canada, dated October 7, 2008). Canadian Lime Institute.
c. Range of year-specific EFs from AMEC Earth & Environmental (2006) and ECCC (2025).

A6.2.2. Chemical Industry

Table A6.2–2, Table A6.2–3, Table A6.2–4 and Table A6.2–5 present the emission factors used for categories included under the Chemical Industry subsector, as well as the sources from which these factors were obtained.

Table A6.2–2 Emission Factors for Ammonia Production

	Average Ammonia-to-Feed Fuel Factor[a] (m^3 natural gas / tonne of NH_3)	CO_2 EF ($g\ CO_2$ / m^3 of natural gas)	Emission Recovery Factor ($g\ CO_2$ / kg of urea)
Ammonia Production	671	Marketable natural gas emission factors found in NIR Table A6.1–1 are used.	733

Note:
a. Facility-specific fuel factors are used and these are confidential.

Table A6.2–3 N_2O Emission Factors for Nitric Acid and Adipic Acid Production

Category	Process Description	N_2O EF (kg N_2O / t product)
Nitric Acid Production[a]	Sector-wide weighted average in 2024	0.534
Adipic Acid Production	Oxidation reaction of cyclohexanone and cyclohexanol mixture without N_2O abatement	300[b]

Notes:
a. Emission factors for nitric acid production process types and abatement technologies are confidential, or could expose confidential activity data.
b. IPCC (2000)

Table A6.2–4 **Emission Factors for Petrochemical Products**

Petrochemical Product	EF	Type
Silicon Carbide	11.6 kg CH_4 / t (tonne) product	IPCC default[a]
Calcium Carbide	4.8 kg CH_4 / t product	Derived from CH_4 EF for silicon carbide and the ratio of IPCC default Calcium Carbide CO_2 EF to IPCC default Silicon Carbide CO_2 EF (i.e. 11.6 (kg CH_4 / t SiC) * (1.09 tCO_2 / $tCaC_2$ / 2.62 tCO_2 / tSiC))
Carbon Black	1.29 kg CH_4 / t product	Sector-wide weighted average[b]
	0.032 kg N_2O / t product	Sector-wide weighted average[b]
Ethylene	0.039 kg CH_4 / t product	Sector-wide weighted average[b]
	0.0055 kg N_2O / t product	Sector-wide weighted average[b]
	0.411 t CO_2 / t product	Sector-wide weighted average[c]
Ethylene Dichloride	0.0142 kg CH_4 / t product	IPCC default[d]
Ethylene Oxide	0.663 t CO_2 / t product	IPCC default for the oxygen process[d]
	1.79 kg CH_4 / t product	IPCC default[d]
Styrene	4 kg CH4 / t product	IPCC default[a]
Methanol	0.105 kg CH_4 / t product	Average of sector-wide weighted data[b] (1990-2006) and facility reported data (2011-2021)
	0.010 kg N_2O / t product	Average of sector-wide weighted data[b] (1990-2006) and facility reported data (2011-2021)
	0.754 t CO_2 / t product	Average of sector-wide weighted data[c] (1990-2006) and facility reported data (2011-2021)
Other Uses of Urea	0.733 t CO_2 / t product use	IPCC default[d]

Notes:
a. Default value from IPCC/OECD/IEA (1997)
b. Cheminfo Services (2010)
c. Cheminfo Services (2015); EFs may vary if changes are made to the composition of feed.
d. IPCC (2006)

Table A6.2–5 **Emission Factor for By-Product Emissions from Fluorochemical Production**

Process	EF
HCFC-22 production	0.04 t HFC-23 emitted / t HCFC-22 produced[a]

Note:
a. IPCC (2006)

A6.2.3. Metal Production

The emission factors used for categories included under the Metal Production subsector are presented in Table A6.2–6, Table A6.2–7, Table A6.2–8, Table A6.2–9 and Table A6.2–10. The range of the metallurgical coke emission factors and other parameters used for estimating emissions from Iron and Steel Production are found in Table A6.2–6, and Table A6.2–7.

Table A6.2–6 **Range of CO_2 Emission Factors for the Iron and Steel Industry**

Parameter	EF	Unit
Iron ore reduction with coke	3.1–3.3[a]	t CO_2 / t (tonne) coke used
Electrode consumption in electric arc furnaces	4.5–7.7[b]	kg CO_2 / t steel
Emissions from basic oxide furnaces	0.14–0.23[b]	kg CO_2 / t steel
Iron ore pellet production	0.03[c]	t CO_2/ t pellet
Limestone use	418–453[d]	CO_2 / kg $CaCO_3$
Dolomite use	445–468[d]	CO_2 / kg $MgCO_3$

Notes:
a. Range of year-specific emission factors provided in Cheminfo Services (2010) and ECCC (2025).
b. Provided by the Canadian Steel Producers Association and ECCC (2022). Chan K. (2009). Personal communication (email from Chan K to Pagé M, Environment Canada, dated July 21, 2009). Canadian Steel Producers Association.
c. IPCC (2006)
d. Range of year-specific emission factors from AMEC Earth & Environmental (2006) and ECCC (2025).

Table A6.2–7 **Range of Carbon Contents for the Iron and Steel Industry**	
Parameter	Carbon Contents (%)[a]
Pig iron (production of pig iron) from BFs	4.4–4.8
Pig iron (includes hot metal, cold iron, DRI and pig iron) for steel making	3.4–3.9
Crude steel produced in BOF	0.06–0.13
Crude steel produced in EAF	0.14–0.26
Scrap steel	0.1–1.2

Note:
a. Range of values from CSPA (2009) and ECCC (2025)

Tier 1-type emission factors for the category of Aluminium Production and the sources from which these emission factors were obtained are shown in Table A6.2–8.

Table A6.2–8 **Tier 1 Emission Factors for Aluminium Production**			
Cell Technology Type	EF (kg / t product)		
	CO_2	Carbon Tetrafluoride (CF_4)	Carbon Hexafluoride (C_2F_6)
Side-worked pre-baked	1 600	1.6	0.4
Centre-worked pre-baked	1 600	0.4	0.04
Horizontal stud Söderberg	1 700	0.4	0.03
Vertical stud Söderberg	1 700	0.8	0.04

Note:
Data Source: International Aluminium Institute (IAI) (2006)

Tier 1 CO_2 emission factors for the Magnesium Production category and shown in Table A6.2–9.

Table A6.2–9 **Tier 1 CO_2 Emission Factors for Magnesium Production**	
Carbonate Raw-Material used in Mg Production	EF (tonnes CO_2 emission/tonne primary Mg produced)[a]
Dolomite	5.13
Magnesite	2.83

Note:
a. IPCC (2006)

Emission factors for the Rare Earths Production category and their sources are shown in Table A6.2–10.

Table A6.2–10 **Emission Factors for Rare Earths Production**		
GHG	Emission Factor	Unit
CO_2	0.564[a]	t CO_2/t metal produced
CF_4	35.8[b]	g CF_4/t metal produced
$C2F_6$	5.2[b]	g C_2F_6/t metal produced
$C3F_8$	0.21[b]	g C_3F_8/t metal produced

Notes:
a. The CO_2 emission factor is the IPCC default emission factor of 0.56 multiplied by an emission correction factor to account for the atomic weight of the produced alloy (IPCC, 2019). The composition of the produced alloy was gathered from a facility brochure (Saskatchewan Research Council, 2024). The atomic weight of the produced alloy was estimated to be 143.33 g/mol, and the emission correction factor was estimated to be 1.006.
b. IPCC (2019)

A6.2.4. Non-Energy Products from Fuels and Solvent Use

The use of fossil fuels as feedstock or for other non-energy use (NEU) may result in emissions during the life of manufactured products. To estimate CO_2 emissions from NEU of natural gas, an emission factor of 38 g CO_2/m^3 was used. This emission factor excludes the feedstock use of natural gas to produce ammonia, and it is derived from the NEU of natural gas data found in the 2005 Cheminfo Study (Cheminfo Services, 2005).

Table A6.2–11 shows the emission factors used to develop CO_2 emission estimates for non-energy applications of natural gas liquids and petroleum products, respectively. The emission factors for NEU petroleum coke are found in Table A6.1–7. The 2011 emission factor value for Upgrading Facilities in Table A6.1–7 has been used for Ontario across the time series. For the other provinces, the 2011 emission factor value for Refineries and Others is used across the time series. The emission factors associated with NEU of coal are referenced in Table A6.1–10.

Table A6.2–11 CO_2 Emission Factors for Non-Energy Use of Natural Gas Liquids and Petroleum Products

Product	Fraction of Carbon Stored in Product	CO_2 EF (g CO_2 / L)
Natural Gas Liquids		
Propane	0.8[a]	303[b]
Butane	0.8[a]	349[b]
Ethane	0.8[a]	197[b]
Petroleum Products		
Petrochemical Feedstocks[c]	0.8[a]	500[d]
Naphthas[e]	0.75[a]	625[d]
Lubricating Oils and Greases[f]	0.2[g]	2 260[d]
Petroleum Used for Other Products[h]	0.5[a]	1 450[d]

Notes:
a. IPCC/OECD/IEA (1997)
b. McCann (2000)
c. Carbon factor for Petrochemical Feedstocks is 680 g of carbon per litre (C/L) (Jaques 1992).
d. The resulting CO_2 EF is calculated by multiplying the carbon factor for each product by the molecular weight ratio between CO_2 and carbon (44/12) and by (1-fraction of carbon stored in product).
e. Carbon factor for Napthas is 680 g C/L (Jaques 1992).
f. Carbon factor for Lubricating Oils and Greases is 770 g C/L (Jaques 1992).
g. IPCC (2006)
h. Carbon factor for Petroleum Used in Other Products is 790 g C/L (Jaques 1992).

A6.2.5. Electronics Industry

The use of perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) in integrated circuit or semiconductor manufacturing, electrical environmental testing, gross leak testing and thermal shock testing creates GHG emissions of their respective source gases. The use of PFCs and NF_3 in the integrated circuit or semiconductor manufacturing industry can also lead to by-product PFC emissions. The emission factors for the use of PFCs, SF_6 and NF_3 in the electronics industry are summarized in Table A6.2–12.

Table A6.2–12 Emission Factors for the use of PFCs, SF_6 and NF_3 in the Electronics Industry

Application	GHG Source	IPCC Tier	Emission Rate (%)[a]	By-Product Emission Rate
Integrated Circuit or Semiconductor Manufacturing[b]	CF_4	T2A	90	N/A
	CF_4	T2B – CVD	90	N/A
	CF_4	T2B – Etching	70	N/A
	C_2F_6	T2A	60	0.2 kg CF_4 / kg $C2F_6$
	C_2F_6	T2B – CVD	60	0.1 kg CF_4 / kg $C2F_6$
	C_2F_6	T2B – Etching	40	0.4 kg CF_4 / kg $C2F_6$
	$c\text{-}C_4F_8$	T2A	10	0.1 kg CF_4 / kg $c\text{-}C4F_8$, 0.1 kg $C2F_6$ / kg $c\text{-}C4F_8$
	$c\text{-}C_4F_8$	T2B – Etching	20	0.2 kg CF_4 / kg $c\text{-}C4F_8$, 0.2 kg $C2F_6$ / kg $c\text{-}C4F_8$
	SF_6	T2A	20	N/A
	NF_3	T2A	20	0.09 kg CF_4 / kg NF_3
	NF_3	T2B – Etching	20	N/A
Other Emissive Applications	PFCs	T2	50% first year / 50% second year	N/A

Notes:
N/A = Not available
a. IPCC (2006)
b. When available, confidential company/gas/process-specific values are used for the fraction of gas volume fed into process types with emission control technology and the fraction of gas destroyed by the emission control technology (respectively, ai and di in the IPCC Guidelines).

A6.2.6. Product Uses as Substitutes for Ozone Depleting Substances

The use of halocarbons in various applications, such as air conditioning (AC), refrigeration, aerosols, foam blowing, solvents and fire extinguishing, result in hydrofluorocarbon (HFC) and PFC emissions.

Table A6.2–13 and Table A6.2–14 summarize emission rates used to estimate HFC and PFC emissions, respectively.

Table A6.2–13 **HFCs as Ozone Depleting Substance (ODS) Substitutes – Assembly, In-Service and End-of-Life Emission Factors (%)**

Application/Sub-Application	Assembly[a]	In-Service[b]	End-of-Life[c]	Life Time (years)
Aerosols[d]	-	50% first year / 50% second year	-	2
Blowing agent in foams[d]				
Open-cell foam	100	-	-	-
Closed-cell foam	10	4.5	100	23
Air conditioning (equipment manufactured in Canada)[e]				
Air conditioner units in motor vehicles	0.5	10	75	13
Chillers (specify centrifugal or reciprocating)	1	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	1	4	20	17
Air conditioning (manufactured elsewhere)[e]				
Air conditioner units in motor vehicles	-	10	75	13
Chillers (specify centrifugal or reciprocating)	-	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	-	4	20	17
Refrigeration (equipment manufactured in Canada)[e]				
Commercial transport	1	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	1	10	30	17
Industrial (warehouses, process equipment, etc.)	1	10	30	17
Residential (freezers, refrigerators)	0.6	0.5	30	15
Other equipment (specify)	1.0	10.8	30	15
Refrigeration (manufactured elsewhere)[e]				
Commercial transport	-	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	-	10	30	17
Industrial (warehouses, processes, etc.)	-	10	30	17
Residential (refrigerators, freezers, etc.)	-	0.5	30	15
Other equipment (specify)	-	10.1	30	15
Solvent[d]	-	50% first year / 50% second year	-	2
Fire suppression/extinguishing systems[d]				
Portable (mobile) systems	-	4	5	18
Total flooding (fixed) systems	-	2	5	18
Miscellaneous[d] (Hospital / institutional sterilizing and leak testing)	-	50% first year / 50% second year	-	2
Other (specify)[d]	-	50% first year / 50% second year	-	2

Notes:
a. Percentage of losses of the HFC charged into new equipement.
b. Release percentage of HFC bank (by application) during operation.
c. Release percentage of HFC bank (by application) during disposal.
d. IPCC (2006)
e. ECCC (2015)

Table A6.2–14 **PFCs as Ozone Depleting Substance (ODS) Substitutes – Assembly, In-Service and End-of-Life Emission Factors (%)**

Application/Sub-Application	Assembly[a]	In-Service[b]	End-of-Life[c]	Life Time (years)
Air Conditioning				
Mobile A/C	0.35	15	100	12
Residential and Commercial A/C, including Heat Pumps	0.6	5.5	100	15
Foam Blowing Agents				
Closed-Cell Foam	45	0.75% of original charge	100 (43.75% of original charge)	15
Refrigeration				
Industrial Refrigeration including Food Processing and Cold Storage	1.75	16	100	15
Medium and Large Commercial Refrigeration	1.75	22.5	100	15
Solvents	-	50% first year / 50% second year	-	2

Notes:
a. Percentage of losses of the PFC charged into new equipment.
b. Annual release percentage of PFC bank (by application) during operation.
c. Release percentage of PFC bank (by application) during disposal.
Source: IPCC (2006)

A6.3. Other Product Manufacture and Use

The uses of N_2O as an anaesthetic and as a propellant result in N_2O emissions. The emission factors used are shown in Table A6.3–1.

Table A6.3–1 **Emission Factors for N_2O Usage (Medical and Propellant)**

Product	Application	N_2O Emission Rate (%)
N_2O Use	Anaesthetic Usage	100
	Propellant Usage	100

Note: Source: IPCC (2006)

The use of perfluorocarbons (PFCs) in contained applications (such as use as an electrical insulator or as a dielectric coolant) results in PFC emissions. The emission factors used for contained applications are shown in Table A6.3–2.

Table A6.3–2 **Emission Factor for PFC Emissions from Other Contained Product Uses**

Process	PFC Emissions from Other Contained Sources
Assembly	1% of charge
Annual Leakage Rate	2% of stock
Disposal	100% of remaining stock
Product Lifespan	15 years

Note: Source: IPCC (2000)

The use of urea-based diesel exhaust fluid (DEF) in diesel vehicles equipped with selective catalytic reduction (SCR) systems results in CO_2 emissions, the rate of which is dependent on the purity factor of urea in DEF as well as the dosing rate of urea to diesel consumption as per Table A6.3–3.

Table A6.3–3 **Emission Factors for Use of Urea in SCR Vehicles**

Product	DEF Purity	Dosing Rate
Urea use in SCR Vehicles	32.50%	2% of diesel consumption

Note: Source: IPCC (2006)

A6.4. Agriculture

The sources of agricultural GHGs are enteric fermentation, manure management, field burning of crop residues, agricultural soils (including nitrous oxide emissions from mineralization/immobilization associated with loss/gain of soil organic matter), and agricultural use of lime, urea and other carbon-containing fertilizers. The most significant sources use country-specific Tier 2 methodologies. Carbon dioxide emissions from liming, urea application and other carbon-containing fertilizers are calculated based on the total quantity of carbon (C) contained in these products. Ammonia emissions from synthetic nitrogen (N) application are estimated using a country-specific modelling method as noted in Annex 3.4. Finally, indirect emissions from ammonia volatilization and nitrogen leaching are calculated based on the IPCC default emission factors provided in Table A6.4–27.

Those emission factors for agriculture calculated based on country-specific methodologies are described in detail in Annex 3.4. In most cases, annual emission factors by gas presented in this annex represent an overall weighted average, which includes a number of underlying factors that influence regional emission rates. Emission estimates are developed using more detailed emission factors, as described in Annex 3.4. For enteric fermentation emissions from cattle, weighted national emission factors and the methodology for generating emission factors are detailed in section A3.4.2.1. In the case of manure management CH_4, the methodology for generating emission factors is described in A3.4.3, and weighted national emission factors are presented in A3.4.3.5. For manure management N_2O emissions, the methodologies for calculating direct and indirect N_2O emissions are described in sections A3.4.4.1 and A3.4.4.2, respectively. Finally, the methodologies for generating N_2O emission factors for direct emissions from agricultural soils and pasture, range and paddock (PRP), are described in A3.4.5.1. Cattle are described using an approach consistent with common reporting tables (CRT).[3] For enteric fermentation, Dairy Cattle includes only dairy cows, while for manure management and PRP, Dairy Cattle includes dairy cows and dairy heifers.

A compilation of emission factors for agriculture is provided here in Table A6.4–1 to Table A6.4–29.

A6.4.1. Enteric Fermentation

Table A6.4–1 **CH_4 Emission Factors for Enteric Fermentation in Cattle, for Selected Years from 1990 to 2024**

Year	$EF_{(EF)T}$ (kg CH_4 $head^{-1}$ yr^{-1})[a]							
	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	115.4	79.4	108.0	105.9	82.5	44.7	41.4	43.8
2005	125.0	77.2	119.9	114.4	87.0	52.8	46.0	43.6
2018	139.6	76.7	125.5	120.6	91.4	54.0	48.7	43.9
2019	142.1	76.7	124.2	120.4	91.2	54.2	49.3	43.8
2020	142.9	76.7	124.2	120.5	91.3	54.2	49.6	43.9
2021	145.3	76.7	127.6	120.0	90.9	54.2	49.7	43.9
2022	145.8	76.7	123.2	120.7	91.4	54.6	49.9	43.9
2023	145.6	76.7	124.6	121.5	91.8	54.4	49.6	44.0
2024	147.4	76.7	126.6	124.7	93.9	57.1	50.1	44.0

Notes:
a. Enteric EFs are derived from Boadi et al. (2004), modified to take account of trends in milk production in dairy cows and carcass weights for several beef cattle categories.
b. Reported as kg $head^{-1}$ yr^{-1}; however, emissions are calculated based on time to slaughter.

3 Canada's 2024 CRT tables are available online at: https://unfccc.int/ghg-inventories-annex-i-parties/2024.

Table A6.4–2 **Methane Emission Factors (EF) for Enteric Fermentation for Non-Cattle Animals**

Non-cattle Animal Category	Enteric Fermentation EF (kg CH_4 $head^{-1}$ yr^{-1})
Pigs	
Boars	1.5
Sows	1.5
Pigs < 20 kg	1.5
Pigs 20–60 kg	1.5
Pigs > 60 kg	1.5
Other Livestock	
Sheep	8
Lambs	8
Goats	5
Horses	18
Bison	55
Llamas & Alpacas	8
Elk & Deer	20
Wild Boars	1.5
Fox	N/A
Mink	N/A
Rabbits	N/A
Mules and Asses	10
Poultry	
Chickens	N/A
Hens	N/A
Turkeys	N/A

Notes:
N/A = Not available
Data source: IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.10)

A6.4.2. Manure Management

Table A6.4–3 **Maximum Methane-Producing Potential (B_0) by Animal Category**

Animal Category	Maximum CH_4-Producing Potential (B_0) (m^3 kg^{-1} VS)
Dairy Cattle[a]	0.24
Non-dairy Cattle[b]	0.19
Sheep	0.19
Goats	0.18
Horses	0.3
Swine	0.48
Hens	0.39
Broilers	0.36
Turkeys	0.36

Notes:
VS = Volatile solids
a. Dairy cattle include dairy cows and dairy heifers.
b. The non-dairy cattle value is also used for bison.
Data source: IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, tables 10A-5 to 10A-9)

Table A6.4–4 Methane Conversion Factors (MCF) by Animal Category and Manure Management System

Animal Categories	Liquid Systems (MCF_L)	Solid Storage and Drylot (MCF_{SSD})	Pasture, Range and Paddock (MCF_{PRP})	Other Systems (MCF_O)
Non-dairy Cattle[a]	0.2	0.02	0.01	0.01
Poultry	0.2	0.015	0.015	0.015
Horses	NA	0.01	0.01	0.01
Goats	NA	0.01	0.01	NA
Sheep	0.2	0.01	0.01	0.01
Lambs	0.2	0.01	0.01	0.01

Notes:
NA = Not applicable
a. Non-dairy cattle values are also used for bison.
Source: IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, tables 10A-5 to 10A-9 – cool climate, average annual temperature 12°C)

Table A6.4–5 Methane Conversion Factors (MCF) for Dairy Cattle and Swine

Manure Management System	Manure Management Subsystem	Crust Formation	MCF
Dairy			
Liquid	Earthen Basin	No crust	0.17
	Earthen Basin	Crust	0.13
	Tank	No crust	0.17
	Tank	Crust	0.13
	Slatted floor	N/A	0.17
Swine			
Liquid	Earthen Basin	No crust	0.22
	Earthen Basin	Crust	0.11
	Tank	No crust	0.22
	Tank	Crust	0.11
	Slatted floor	N/A	0.22
Dairy and Swine			
Solid[a]	Exercise Yard	N/A	0.01
	Pack	N/A	0.01
	Pile	N/A	0.02
Compost[a]		N/A	0.005
Pasture, Range, Paddock[a]		N/A	0.01
		N/A	0.01

Notes:
N/A = Not available
a. Source: IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.17 – cool climate, average annual temperature 12°C)

Table A6.4–6 Emission Factors for Estimating CH_4 Emissions from Manure Management for Cattle by Subcategory, from 1990 to 2024

Year	$EF_{(MM)T}$ (kg CH_4 $head^{-1}$ yr^{-1})							
	Dairy Cows	Dairy Heifers[a]	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	13	9	4.5	4.1	3.2	1.9	1.8	2.2
2005	28	13	4.6	4.3	3.1	2.1	1.9	2.4
2018	40	18	4.8	4.5	3.2	2.2	2.0	2.9
2019	41	18	4.7	4.5	3.2	2.2	2.0	2.9
2020	41	18	4.7	4.5	3.2	2.2	2.0	2.9
2021	42	18	4.9	4.5	3.2	2.2	2.0	2.9
2022	42	18	4.7	4.5	3.2	2.2	2.0	2.9
2023	42	18	4.7	4.5	3.2	2.2	2.0	2.9
2024	42	18	4.8	4.6	3.3	2.3	2.0	2.9

Notes:
a. For dairy heifers, EFs were estimated using the same B_0, MCF and manure management systems as for dairy cows.
b. Reported as kg $head^{-1}$ yr^{-1}, but emissions are calculated based on time to slaughter.

Table A6.4–7 **Emission Factors for Estimating CH_4 Emissions from Manure Management for Swine by Subcategory, from 1990 to 2024**

Year	$EF_{(MM)T}$ (kg CH_4 $head^{-1}$ yr^{-1})				
	Boars	Sows	Pigs (< 20 kg)	Pigs (20–60 kg)	Pigs (> 60 kg)
1990	7.0	7.3	2.2	4.5	8.3
2005	7.0	7.1	2.2	4.4	8.5
2018	7.0	7.0	2.1	4.3	9.1
2019	7.0	7.0	2.2	4.3	9.2
2020	7.0	7.0	2.2	4.3	9.3
2021	7.0	7.0	2.1	4.3	9.4
2022	7.0	7.0	2.2	4.2	9.4
2023	7.0	7.0	2.2	4.3	9.5
2024	7.0	7.0	2.2	4.2	9.5

Table A6.4–8 **2024 CH_4 Emission Factors for Manure Management for All Other Livestock**

Non-Cattle Animal Categories	Manure Management Emission Factors $EF_{(MM)}$ (kg CH_4 $head^{-1}$ yr^{-1})
Other livestock	
Sheep	0.33
Lambs	0.22
Goats	0.32
Horses	2.6
Bison	2.1
Elk and deer	0.22
Wild boars[a]	0.56
Foxes	0.68
Mink	0.68
Rabbits	0.08
Mules and asses	0.76
Poultry	
Chickens	0.03
Hens	0.11
Turkeys	0.10

Note:
a. EF based on swine VS, assuming 100% solid manure.

Table A6.4–9 **Dairy Cattle and Swine Emission Factors for Manure Nitrogen (N) Lost as N_2O-N by Animal Waste Management Systems**

Manure Management System	Manure Management Subsystem	Crust Formation	EF
Liquid	Earthen Basin	No crust	0
	Earthen Basin	Crust	0.005
	Tank	No crust	0
	Tank	Crust	0.005
	Slatted floor	NA	0.002
Solid	Exercise Yard	NA	0.02
	Pack	NA	0.02
	Pile	NA	0.005
Other	Compost	NA	0.01

Notes:
NA = Not applicable
Source: IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.21)

Table A6.4–10 **Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O-N by Animal Category and Animal Waste Management Systems**

	Liquid Systems (EF_L)	Solid Storage and Drylot (EF_{SSD})	Other Systems (EF_O)
Non-dairy Cattle	0.001	0.02	0.005
Poultry	0.001	0.02	0.005
Sheep and Lambs	0.001	0.02	0.005
Goats	0.001	0.02	0.005
Horses	0.001	0.02	0.005
Mules and Asses	0.001	0.02	0.005
Buffalo	0.001	0.02	0.005

Note:
Source: IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.21)

Table A6.4–11 Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O During Storage of Cattle and Swine Manure

Year	EF (g N_2O $head^{-1}$ yr^{-1})				
	1990	2005	2015	2020	2024
Cattle[a]					
Dairy Cows[b]	1 268	1 128	930	917	896
Beef Cows	862	999	1 093	1 102	1 169
Bulls	1 305	1 495	1 641	1 575	1 615
Dairy Heifers[b]	938	906	745	751	751
Beef Heifers	680	769	838	843	894
Heifers for Slaughter	320	425	458	467	475
Steers	336	426	468	481	501
Calves	382	383	382	382	384
Swine[c]					
Sows	74	29	24	24	24
Boars	95	58	58	57	59
Pigs (<20 kg)	6	2	2	2	2
Pigs (20–60 kg)	26	12	10	9	9
Pigs (>60 kg)	52	25	22	22	23

Notes:
a. EFs are derived from information in Boadi et al. (2004), Marinier et al. (2004) and (2005), and default factors in the 2006 IPCC Guidelines. Derivation of the Tier 2 EFs is explained in NIR Annex 3.4.
b. For dairy cows and heifers, nitrogen excretion rates are derived from feed intake information from Lactanet, and manure storage practices are taken from farm management surveys, as described in NIR Annex 3.4.
c. For swine, nitrogen excretion rates are calculated using default IPCC parameters and country-specific animal mass time series, and manure storage practices are taken from farm management surveys, as described in NIR Annex 3.4.

Table A6.4–12 2024 Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O During Storage of Non-Cattle and Non-Swine Manure

Livestock Category	EF[a] (g N_2O $head^{-1}$ yr^{-1})
Poultry	
Turkey	54
Hens	13
Pullets	6
Broiler	11
Other Livestock	
Sheep	44
Goat	135
Buffalo	990
Horse	486
Llama and alpacas	163
Lamb	41
Deer	222
Elk	210
Wild boars	280
Rabbit	149
Mink	95
Fox	250
Mules and Asses	265

Note:
a. EFs are derived from information in Marinier et al. (2004) and (2005), and default factors in the 2006 IPCC Guidelines. Derivation of the Tier 2 EFs is explained in NIR Annex 3.4.

Table A6.4–13 **Emission Factors (EF) for Cattle and Swine Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching During Storage**

	EF (g N_2O $head^{-1}$ yr^{-1})				
	1990	2005	2015	2020	2024
Volatilization[a]					
Dairy Cow	261	263	217	214	207
Beef Cow	98	105	113	112	118
Bull	162	162	173	162	164
Dairy Heifers	197	187	152	151	150
Beef Heifers	86	83	88	87	92
Heifers for Slaughter	48	48	54	54	54
Steer	49	58	59	59	63
Calf	46	43	42	41	41
Sow	63	58	49	48	48
Boar	60	54	45	42	43
Pig (<20 kg)	5	5	4	4	4
Pig (20–60 kg)	21	20	17	17	17
Pig (>60 kg)	43	42	38	40	41
Leaching[b]					
Dairy Cow	23	15	10	9	9
Beef Cow	0	0	0	0	0
Bull	0	0	0	0	0
Dairy Heifers	16	12	9	9	9
Beef Heifers	0	0	0	0	0
Heifers for Slaughter	0	0	0	0	0
Steer	0	0	0	0	0
Calf	0	0	0	0	0
Sow	1.2	0.2	0.1	0.1	0.1
Boar	1.6	0.7	0.7	0.7	0.7
Pig (<20 kg)	0.10	0.02	0.01	0.01	0.01
Pig (20–60 kg)	0.5	0.1	0.1	0.1	0.1
Pig (>60 kg)	0.9	0.3	0.2	0.2	0.2

Notes:

a. Indirect N_2O from volatilization is calculated using the climate-specific EF_4 values from Table 11.3 in Volume 4, Chapter 11 of the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019). Volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016). Derivation of the Tier 2 EFs is explained in NIR Annex 3.4.

b. A Tier 2 method for the calculation of swine and dairy cattle leaching is based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016). Derivation of the Tier 2 EFs is explained in NIR Annex 3.4.

Table A6.4–14 Annual Emission Factors (EF) for Cattle and Swine Manure Nitrogen (N) Lost as NH_3 Due to Volatilization During Storage

	EF (kg NH_3 head^{-1} year^{-1})				
	1990	2005	2015	2020	2024
Cattle					
Dairy Cow	22	17	13	13	13
Beef Cow	39	67	50	51	50
Bull	3.7	5.3	4.4	4.3	4.2
Dairy Heifers	7.6	6.0	4.3	4.2	4.1
Beef Heifers	5.7	7.1	6.1	6.5	6.0
Heifers for Slaughter	2.3	6.1	5.2	4.7	4.8
Steer	4.7	7.6	8.5	8.4	9.1
Calf	18	26	18	18	17
Swine					
Sow	4.6	7.1	4.7	4.8	4.8
Boar	0.29	0.15	0.074	0.064	0.061
Pig (<20 kg)	1.1	1.7	1.6	1.7	1.7
Pig (20-60 kg)	4.7	7.0	3.7	3.8	3.8
Pig (>60 kg)	9.0	14	12	14	14

Note: Volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016). Derivation of the emission factors is explained in NIR Annex 3.4.

Table A6.4–15 2024 Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching During Storage

Livestock Category	Volatilization EF[a] (g N_2O head^{-1} yr^{-1})	Leaching EF[b] (g N_2O head^{-1} yr^{-1})
Poultry		
Turkey	16	0
Hens	4.5	0
Pullets	2.3	0
Broiler	3.3	0
Other Livestock		
Sheep	3.2	0
Goat	10	0
Buffalo	85	0
Horse	29	0
Llama and alpacas	12	0
Lamb	3.0	0
Deer	41	0
Elk	20	0
Wild boars	46	0
Rabbit	31	0
Mink	7.7	0
Fox	21	0
Mules and Asses	16	0

Notes:

a. Indirect N_2O from volatilization is calculated using the climate-specific EF_4 values from Table 11.3 in Volume 4, Chapter 11 of the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019). Derivation of the volatilization EFs is explained in NIR Annex 3.4.

b. Leaching is not calculated as there are no Tier 1 leaching factors available in the 2006 IPCC Guidelines (IPCC, 2006).

Table A6.4–16 **2024 Emission Factors (EF) for Manure Nitrogen (N) Lost as NH_3 Due to Volatilization During Storage**

Livestock Category	EF (kg NH_3 $head^{-1}$ yr^{-1})
Poultry	
Turkey	1.0
Hens	0.3
Pullets	0.1
Broiler	0.2
Other Livestock	
Sheep	0.2
Goat	0.6
Buffalo	12
Horse	2.4
Llama and alpacas	0.8
Lamb	0.2
Deer	2.6
Elk	2.6
Wild boars	3.2
Rabbit	1.7
Mink	0.4
Fox	1.2
Mules and Asses	1.3

Note: Volatilization factors are taken from default parameters in the 2006 IPCC Guidelines (IPCC, 2006). Derivation of the EFs is explained in NIR Annex 3.4.

A6.4.3. Pasture, Range and Paddock

Table A6.4–17 **Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O From Deposition of Cattle Manure on Pasture, Range and Paddock**

Year	EF (g N_2O kg^{-1} N yr^{-1})[a, b, c, d]									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.68	0.68	0.68	8.8	9.5	8.8	9.7	7.5	9.4	0.68
2005	0.68	0.68	0.68	8.8	9.6	8.8	9.7	7.6	9.4	0.68
2020	0.68	0.68	0.68	8.8	9.6	8.9	9.6	7.5	9.4	0.68
2024	0.68	0.68	0.68	8.7	9.5	8.8	9.6	7.5	9.4	0.68

Notes:
a. EFs are derived from Rochette et al. (2014) for eastern Canada, and Lemke et al. (2012) for western Canada.
b. The proportion of excreted manure deposited on pasture is taken from Marinier et al. (2005), for all livestock except dairy cows and heifers.
c. The proportion of excreted manure deposited on pasture by dairy cows and heifers is based on a farm size relationship derived from Sheppard et al. (2011a), as described in NIR Annex Annex 3.4.
d. Derivation of the Tier 2 EFs is explained in NIR Annex 3.4.

Table A6.4–18 Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching of Manure Deposited on Pasture, Range and Paddock

	EF (g N_2O kg^{-1} N yr^{-1})									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
Volatilization[a]										
1990	1.6	1.8	1.6	2.9	2.3	2.9	3.0	2.7	2.3	1.6
2005	1.6	1.8	1.6	3.1	2.2	3.2	3.4	3.1	2.8	1.6
2015	1.6	1.7	1.6	3.0	1.9	3.0	3.3	2.7	2.6	1.6
2020	1.6	1.7	1.6	2.8	2.1	2.9	3.3	2.7	2.4	1.6
2024	1.6	1.6	1.6	2.9	2.2	2.9	3.3	2.7	2.4	1.6
Leaching[b]										
1990	1.9	1.7	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2005	1.8	1.7	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2015	1.8	1.7	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2020	1.8	1.7	2.1	3.5	3.6	3.5	3.1	3.5	3.4	1.5
2024	1.8	1.7	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.5

Notes:

a. For dairy cattle, volatilization is calculated based on Sheppard et al. (2011b) and Chai et al. (2016), and the default climate-specific indirect N_2O EFs from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019) are used. For all other livestock the IPCC Tier 1 methodology is used to estimate indirect N_2O EFs from volatilization. Default parameters are used from the 2006 IPCC Guidelines (IPCC, 2006) as described in NIR Annex 3.4.

b. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in NIR Annex 3.4.

Table A6.4–19 Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as NH_3 Due to Volatilization of Manure Deposited on Pasture, Range and Paddock

Year	EF (kg NH_3 kg^{-1} N yr^{-1})									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.20	0.18	0.19	0.13	0.10	0.13	0.14	0.12	0.10	0.20
2005	0.21	0.19	0.20	0.14	0.10	0.14	0.16	0.14	0.13	0.21
2020	0.21	0.19	0.20	0.13	0.09	0.13	0.15	0.12	0.11	0.21
2024	0.21	0.19	0.20	0.13	0.10	0.13	0.15	0.12	0.11	0.21

Note: For dairy cattle, volatilization is calculated based on Sheppard et al. (2011b) and Chai et al. (2016). For all livestock except dairy cattle, the IPCC Tier 1 methodology is used to estimate volatilization. Further detail can be found in NIR Annex 3.4.

Table A6.4–20 **Emission Factors (EF) for Crop Residue, Organic and Inorganic Fertilizer Nitrogen (N) Lost as N_2O Following Application to Agricultural Soils**

	EF (g N_2O kg^{-1} N yr^{-1})						
	AB	BC	MB	ATL[a]	ON	QC	SK
Organic N							
1990	8.1	6.9	9.0	7.6	15	17	5.0
2005	7.5	7.2	8.4	8.2	16	20	4.2
2015	7.8	8.2	8.8	9.0	16	22	4.1
2020	8.1	8.2	9.6	9.2	16	22	4.0
2022	8.2	8.2	9.9	9.2	16	22	4.0
2023	8.1	8.1	9.9	9.4	16	22	4.0
2024	8.1	8.0	10	9.6	16	22	4.0
Inorganic N							
1990	10	5.6	11	12	19	24	7.8
2005	8.7	4.8	11	13	19	28	6.8
2015	8.8	5.1	11	14	20	30	6.5
2020	8.9	4.9	10	14	20	30	6.5
2022	9.0	4.7	10	14	20	29	6.5
2023	9.0	4.7	10	14	20	29	6.5
2024	9.0	4.6	10	14	20	29	6.5
Crop Residue N							
1990	8.2	4.8	8.6	8.5	13	15	6.5
2005	8.0	5.3	8.1	9.2	15	21	5.7
2015	8.2	6.0	8.9	11	16	23	5.6
2020	8.4	5.0	8.7	11	17	25	5.6
2022	8.4	5.2	8.5	11	17	23	5.6
2023	8.5	5.7	8.6	11	17	24	5.6
2024	8.5	5.5	8.5	11	17	24	5.6

Notes:
Country-specific Tier 2 soil N_2O emission factors are calculated as described in NIR Annex 3.4.
a. ATL = Atlantic Canada (NB, NL, NS, PE)

Table A6.4–21 **Emission Factors (EF) for Manure Nitrogen (N) Lost as NH_3 from Agricultural Soils**

Year	EF (g NH_3 kg^{-1} N yr^{-1})									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	235	214	228	295	266	294	254	293	267	239
2005	236	204	196	264	253	258	242	277	256	236
2020	235	199	181	250	250	249	237	265	252	236
2024	233	201	176	259	261	244	236	263	252	234

Notes:
For dairy cattle and swine, volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016).
For all other livestock the IPCC Tier 1 methodology is used to estimate volatilization. Further detail can be found in NIR Annex 3.4.

Table A6.4–22 Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching of Manure Applied to Agricultural Soils

	EF (g N_2O kg^{-1} N applied yr^{-1})									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
Volatilization[a]										
1990	1.5	2.7	1.6	5.3	4.8	5.3	5.3	4.6	4.8	1.5
2005	1.5	2.4	1.3	4.8	4.6	4.7	5.0	4.4	4.6	1.5
2020	1.5	2.4	1.2	4.5	4.5	4.5	4.8	4.3	4.6	1.5
2024	1.5	2.4	1.2	4.6	4.5	4.4	4.8	4.3	4.6	1.5
Leaching[b]										
1990	1.9	2.3	2.1	3.5	3.5	3.5	3.5	3.1	3.5	1.6
2005	1.8	2.3	2.1	3.5	3.5	3.5	3.5	3.1	3.5	1.6
2020	1.8	2.3	2.1	3.5	3.5	3.5	3.5	3.1	3.5	1.5
2024	1.8	2.3	2.1	3.5	3.5	3.5	3.5	3.1	3.5	1.5

Notes:
a. For dairy cattle and swine, volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016) and the climate-specific default IPCC indirect N_2O EFs from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019) are used. For all other livestock the IPCC Tier 1 methodology is used to estimate volatilization. Default parameters are used from the 2006 IPCC Guidelines and 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019; 2006) as described in NIR Annex 3.4.
b. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in NIR Annex 3.4.

Table A6.4–23 Fraction of N Volatilized ($FRAC_{GASM}$) as Ammonia Resulting from the Application of Biosolid N to Agricultural Soils

IPCC default EF, $FRAC_{GASM}$	0.21 kg NH_3-N volatilized kg^{-1} N applied

Note:
Source: IPCC (2019)

Table A6.4–24 N_2O Emission Factor for Mid-latitude Cultivation of Organic Soils

	Annual crops	Perennial crops
IPCC default EF for mid-latitude cultivation of organic soils	13.0 kg N_2O-N ha^{-1} yr^{-1}	9.5 kg N_2O-N ha^{-1} yr^{-1}

Note:
Source: IPCC (2014)

Table A6.4–25 Emission Factors (EF) for Biosolid Nitrogen (N) Lost Indirectly as N_2O Due to Leaching of Biosolids Applied to Agricultural Soils

Year	EF (g N_2O kg^{-1} N applied)						
	AB	BC	MB	ATL[a]	ON	QC	SK
1990	2.0	1.9	2.1	3.5	3.1	3.4	1.5
2005	2.0	2.0	2.1	3.5	3.0	3.4	1.5
2020	2.0	2.0	2.1	3.5	3.0	3.4	1.5
2024	2.0	2.1	2.1	3.5	3.0	3.4	1.5

Notes:
A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in NIR Annex 3.4.
a. ATL = Atlantic Canada (NB, NL, NS, PE)

Table A6.4–26 **Fractions of N Volatilized ($FRAC_{GASF}$) as Ammonia Resulting from the Application of Inorganic N Fertilizer, from Select Years, 1990–2024, at a Provincial Scale**										
Year	Implied EF (kg NH_3-N volatilized kg^{-1} inorganic fertilizer N applied)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.05	0.07	0.05	0.05	0.06	0.06	0.07	0.05	0.07	0.05
2005	0.05	0.08	0.06	0.05	0.06	0.06	0.07	0.05	0.06	0.05
2020	0.05	0.08	0.05	0.05	0.00	0.06	0.06	0.05	0.06	0.05
2024	0.05	0.07	0.05	0.06	0.08	0.07	0.06	0.06	0.06	0.05

Table A6.4–27 **Indirect N_2O Emissions from Agricultural Soils**	
EF due to volatilization and redeposition of Nitrogen[a]	Wet climate: 0.014 kg N_2O-N kg^{-1} N Dry climate: 0.005 kg N_2O-N kg^{-1} N
EF due to leaching/runoff[b]	0.0075 kg N_2O-N kg^{-1} N

Notes:
a. Source: IPCC (2019)
b. Source: IPCC (2006)

A6.4.5. Other Sources

Table A6.4–28 **CH_4 and N_2O Emissions from Field Burning of Agricultural Residues**	
CH_4 EF	2.7 g CH_4 kg^{-1} dry matter burnt
N_2O EF	0.07 g N_2O kg^{-1} dry matter burnt

Note:
Source: IPCC (2006)

Table A6.4–29 **CO_2 Emissions from Liming and Urea Fertilization**	
Dolomite EF	0.12 Mg C / Mg dolomite applied
Limestone EF	0.11 Mg C / Mg limestone applied
Urea EF	0.20 Mg C / Mg urea

Note:
Source: IPCC (2006)

A6.5. Land Use, Land-Use Change and Forestry

The IPCC Tier 2 and Tier 3 methods and country-specific parameters are used for generating estimates for most of the Land Use, Land-Use Change and Forestry (LULUCF) sector. The Carbon Budget Model of the Canadian Forest Sector or CBM-CFS3 model[4] is used for estimating growth, litter fall, tree mortality and decomposition, as well as the effects of natural disturbances for Forest Land and the emissions due to forest conversion to other land uses. For Cropland, a process model (CENTURY[5]) is used for estimating CO_2 emissions and removals as influenced by management activities, based on the National Soil Database of the Canadian Soil Information System.[6] More details on methods for Forest Land, forest conversion and Cropland are provided in Annex 3.5 of this report, specifically in sections A3.5.2 and A3.5.4.

A country-specific model, the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP),[7] is used to estimate the emissions from the use and disposal of wood products reported under the Harvested Wood Products category. For details on the methods used, see section A3.5.3.

Emissions due to the conversion and management of peatlands for peat extraction, the creation of flooded lands (reservoirs), and resource extraction on areas with no evidence of forest clearing and from the conversion of grasslands to Settlements, are estimated using IPCC Tier 2 methods and country-specific parameters (see sections A3.5.6.1, A3.5.6.2 and A3.5.7.3). Net CO_2 removals from the growth of urban trees are estimated using an IPCC Tier 2A approach (see section A3.5.7.1). In addition, emissions due to the occasional burning of grassland are estimated using an IPCC Tier 1 method and default emission factors (see section A3.5.5.1).

A compilation of emission factors and other parameters used to develop and report the LULUCF estimates is provided in this annex (see Figure A6.5–1 and Table A6.5–1 to Table A6.5–13).

4 Carbon Budget Model of the Canadian Forest Sector: https://www.nrcan.gc.ca/climate-change/climate-change-impacts-forests/carbon-accounting/carbon-budget-model/13107

5 CENTURY Soil Organic Matter Model Environment: https://www2.nrel.colostate.edu/projects/irc/public/Documents/Software/Century5/Reference/html/Century/cent5-overview.htm

6 The National Soil Database: https://sis.agr.gc.ca/cansis/nsdb/index.html

7 Canada's forest carbon reporting system: https://natural-resources.canada.ca/climate-change/forest-carbon/canada-s-forest-carbon-reporting-system

Figure A6.5–1 **Disturbance Matrix Parameters for Carbon Modelling (Selected Examples)**

Disturbance Matrix Simulating the Carbon Transfers Associated with Clear-Cut Harvesting and Salvage Logging Applicable in all Ecozones Except Those in Alberta and Quebec

	13	14	15	16	17	18	19	24	25	Products
1. Softwood merchantable					0.15					0.85
2. Softwood foliage	1									
3. Softwood others			1							
4. Softwood sub-merchantable			1							
5. Softwood coarse roots			0.5	0.5						
6. Softwood fine roots	0.5	0.5								
7. Hardwood merchantable					0.15					0.85
8. Hardwood foliage	1									
9. Hardwood other			1							
10. Hardwood sub-merchantable			1							
11. Hardwood coarse roots			0.5	0.5						
12. Hardwood fine roots	0.5	0.5								
13. Above-ground very fast soil C	1									
14. Below-ground very fast soil C		1								
15. Above-ground fast soil C			1							
16. Below-ground fast soil C				1						
17. Medium soil C					1					
18. Above-ground slow soil C						1				
19. Below-ground slow soil C							1			
20. Softwood stem snag					0.5					0.5
21. Softwood branch snag			1							
22. Hardwood stem snag					0.5					0.5
23. Hardwood branch snag			1							
24. Black C								1		
25. Peat									1	

Disturbance Matrix Simulating the Carbon Transfers Associated with Firewood Collection from Hardwood applicable in Atlantic Maritime and Mixewood Plains Ecozones

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Products
1. Softwood merchantable	1																									
2. Softwood foliage		1																								
3. Softwood others			1																							
4. Softwood sub-merch				1																						
5. Softwood coarse roots					1																					
6. Softwood fine roots						1																				
7. Hardwood merch							0.7																			0.3
8. Hardwood foliage								0.7					0.3													
9. Hardwood other									0.7						0.1											0.2
10. Hardwood submerch										0.7													0.3			
11. Hardwood coarse roots											0.7				0.15	0.15										
12. Hardwood fine roots												0.7	0.15	0.15												
13. Above-ground very fast soil C													1													
14. Below-ground very fast soil C														1												
15. Above-ground fast soil C															1											
16. Below-ground fast soil C																1										
17. Medium soil C																	1									
18. Above-ground slow soil C																		1								
19. Below-ground slow soil C																			1							
20. Softwood stem snag																				1						
21. Softwood branch snag																					1					
22. Hardwood stem snag																						0.5				0.5
23. Hardwood branch snag																							0.5			0.5
24. Black C																								1		
25. Peat																									1	

A6.5.2. Harvested Wood Products

Table A6.5–1 Default Parameter Values Used in Harvested Wood Products Analysis

Description	Units	Value
Bark expansion factor, Softwoods	dimensionless	1.11[a]
Bark expansion factor, Hardwoods	dimensionless	1.15[a]
Bark expansion factor, Mixedwoods	dimensionless	1.13[a]
C content of wood	tonnes C od tonne^{-1}, [b]	0.5[c]

Notes:
a. IPCC (2006) (Vol. 4, Table 12.5)
b. Tonnes carbon per oven dry tonne (od tonne) of wood material.
c. IPCC (2006) (Vol. 4, Table 12.4)

Table A6.5–2 Wood Densities of Commodities

Country/Countries	Description	Units	Value
Canada	Species-weighted average density, Roundwood	od tonne m^{-3}	0.386 [a]
Canada	Species-weighted average density, Sawnwood	od tonne m^{-3}	0.481 [a]
Canada	Species-weighted average density, Other industrial roundwood	od tonne m^{-3}	0.583 [a]
Canada	Species-weighted average density, Panels	od tonne m^{-3}	0.643 [b]
Canada	Species-weighted average density, Bioenergy	od tonne m^{-3}	0.523 [c]
U.S.	Coniferous (C) roundwood	od tonne green m^{-3}	0.46 [d]
U.S.	Nonconiferous (NC) roundwood	od tonne green m^{-3}	0.53 [d]
U.S.	C+NC roundwood	od tonne green m^{-3}	0.47 [d]
U.S.	Hardwood (HW) plywood & veneer	tonnes C m^{-3}	0.28 [e]
U.S.	Softwood (SW) lumber	tonnes C m^{-3}	0.22 [e]
U.S.	HW lumber	tonnes C m^{-3}	0.26 [e]
U.S.	Particle board	tonnes C m^{-3}	0.29 [e]
U.S.	Hardboard	tonnes C m^{-3}	0.42 [e]
U.S.	Medium density fibreboard	tonnes C m^{-3}	0.32 [e]
U.S.	Fibreboard, compressed	tonnes C m^{-3}	0.37 [a]
U.S.	Pulp, paper & board	tonnes C ad tonne^{-1}	0.42 [e]
U.S.	Insulating board	tonnes C m^{-3}	0.45 [e]
All	Sawnwood – C	od tonne m^{-3}	0.45 [f]
All	Sawnwood – NC	od tonne m^{-3}	0.45 [f]
All	Panels, structural	od tonne m^{-3}	0.63 [f]
All	Panels, non-structural	od tonne m^{-3}	0.63 [f]
All	Paper	od tonne ad tonne^{-1}	0.9 [f]
All	Wood pulp	od tonne ad tonne^{-1}	0.9 [f]

Notes:
od tonne = Oven dry tonne of wood material
ad tonne = Air dry tonne of product
a. Country-specific values derived from internal analysis of Canada's forest management levels carried out in 2011–2012.
b. Derived from Briggs D (1994)
c. Average of the values for roundwood, sawnwood, other industrial roundwood and panels.
d. FAO (2010)
e. Skog (2008)
f. IPCC (2006) (Vol. 4, Table 12.4)

Table A6.5–3 **Half-Life Parameters (Years) of Harvested Wood Products In-Use**

Country/Countries	Description[a]	Value
Canada	Sawnwood	35[b]
Canada	Wood panels	25[c]
Canada	Pulp and paper	2[b]
Canada	Other industrial roundwood	35[b]
U.S.	Sawnwood	40[b]
U.S.	Wood panels	27.04[c]
U.S.	Pulp and paper	3.25[c]
U.S.	Other industrial roundwood	40[b]
Rest of world	Sawnwood	35[b]
Rest of world	Wood panels	25[c]
Rest of world	Pulp and paper	2[b]
Rest of world	Other industrial roundwood	35[b]

Notes:
a. Firewood and mill residue assumed to be burned for the former, or disposed of for the latter, in the year of harvest.
b. IPCC (2003) (Appendix 3a.1, Table 3a.1.3)
c. Derived from IPCC (2003) (Appendix 3a.1, Table 3a.1.3)

A6.5.3. Cropland

Table A6.5–4 **Coefficients of Agricultural Area-based Soil Organic Carbon factors by Land Management Change (LMC)**

Zone[a, e]	LMC[b, c]	k yr^{-1}	ΔC_{LMCmax} (Mg ha^{-1})	Final Year of Effect after LMC[d]	Mean Annual Linear Coefficient over Duration of Effect of LMC (Mg $ha^{-1}yr^{-1}$)	Mean Annual Linear Coefficient over First 20 Years after LMC (Mg/ha per year)
East Atlantic	IT to NT	0.0216	3.5	52	0.05	0.06
	IT to RT	0.0251	2.4	36	0.04	0.05
	RT to NT	0.0233	1.1	1	0.03	0
	Increase perennial	0.0217	43.4	167	0.25	0.77
East Central	IT to NT	0.025	5	65	0.06	0.1
	IT to RT	0.0261	1.9	25	0.04	0.04
	RT to NT	0.0255	3.2	46	0.05	0.06
	Increase perennial	0.0247	38.2	147	0.25	0.74
Parkland	IT to NT	0.0286	6.5	70	0.08	0.14
	IT to RT	0.0242	2.8	41	0.04	0.05
	RT to NT	0.0263	3.7	51	0.05	0.07
	Increase perennial	0.0233	29.4	142	0.2	0.55
Semi-arid Prairies	IT to NT	0.0261	4.9	63	0.06	0.1
	IT to RT	0.0188	2.3	30	0.03	0.04
	RT to NT	0.0222	2.5	37	0.04	0.05
	Increase perennial	0.0281	26.1	120	0.21	0.56
West	IT to NT	0.0122	4.8	69	0.04	0.05
	IT to RT	0.0116	0.8	0	0	0
	RT to NT	0.0119	3.9	53	0.03	0.04
	Increase perennial	0.0155	34.4	198	0.17	0.46

Notes:
Effective Linear Coefficients of SOC were generated using $F_{LMC(t)} = \Delta C_{LMCmax} \times [1 - \exp(-k \times t)]$.
a. Area-weighted summary: East Atlantic is the Atlantic Maritime reporting zone plus the Boreal Shield reporting zone in Newfoundland and Labrador; East Central is the Mixedwood Plains reporting zone plus the Boreal Shield East reporting zone in Ontario and Quebec; Parkland is the Subhumid Prairies, Boreal Shield West and Boreal Plains reporting zones plus those parts of the Montane Cordillera reporting zone with agricultural activity contiguous to agricultural activity within the rest of the Parkland zone; and West is the Pacific Maritime reporting zone plus the Montane Cordillera reporting zone excepting that portion of the latter that is included in the Parkland zone as described above.
b. For LMCs in the opposite direction to that listed, the F_{LMC}max will be the negative of the value listed.
c. IT = intensive tillage, RT = reduced tillage, NT = no-till
d. No further C changes once the absolute value of the rate of change is less than 25 kg C ha^{-1} yr^{-1}.
e. Factors estimated from changes to yield, and as a consequence, carbon inputs to soils cannot be summarized by single regional factors, alternative approaches to presenting simplified factors are under development.

Table A6.5–5 C:N Ratios of Applied Manure from Major Livestock Types and Manure Management Systems on Agricultural Soils

Livestock	Manure Type	C:N Ratio[a]
Dairy Cattle	Liquid	15.0 (±7.3)[b]
	Solid	13.1 (±1.4)[c]
Beef Cattle	Solid	14.1 (±4.7)[d]
Swine	Liquid	10.5 (±2.4)[e]
Poultry	Solid	5.0 (±0.4)[f]

Notes:
a. Numbers in the parentheses are standard deviations.
b. Bhandral et al. (2009); Rochette et al. (2008); Pelster et al. (2012); Lynch et al. (2005); Maillard et al. (2015); Maillard et al. (2016); Aoyama et al. (1999)
c. Rochette et al. (2008)
d. Hao et al. (2003); Sommerfeldt et al. (1988); Izaurralde et al. (2001); Grant et al. (2001); Pare et al. (1999); Larney and Janzen (1996)
e. Pelster et al. (2012); Chantigny et al. (2000); Chantigny et al. (2007); Chantigny et al. (2010); Chantigny et al. (2012)
f. Pelster et al. (2012); Forge et al. (2016); Rees et al. (2014); Larney and Janzen (1996)

Table A6.5–6 Manure-induced C Retention in Soils under annual crop production from Manure Application

Manure Type	Manure-induced C Retention %
Solid Swine and Cattle Manure	26 (±1.4a)
Composted Swine Manure	36 (±2.2)
Liquid Swine and Cattle Manure	4.7 (±3.6)

Note:
a. Standard errors
Data source: Liang et al. (2021)

Table A6.5–7 Soil CO_2 Loss Factor for Mid-Latitude Cultivation of Organic Soils

	Annual crops	Perennial crops
IPCC default emission factor for mid-latitude cultivation of organic soils	7.9 Mg CO_2-C ha^{-1} yr^{-1}	5.7 Mg CO_2-C ha^{-1} yr^{-1}

Note:
Source: IPCC (2014)

Table A6.5–8 **Parameters and Emission Factors (EF) for Estimating Emissions from Peat Extraction**

EF/Parameter	Unit[a]	Value
Biomass Clearing		
Forest land biomass cleared	t C ha^{-1}	19.2[b]
Other land biomass cleared	t C ha^{-1}	2.8[b]
Drainage, Active Extraction, and Unrestored		
CO_2 from drained, actively extracted, and unrestored areas	t CO_2 ha^{-1} yr^{-1}	9.42[c]
CO_2 -DOC from drained, actively extracted, and unrestored areas	t CO_2 ha^{-1} yr^{-1}	1.38[d]
CH_4 from drained, actively extracted, and unrestored areas	t CH_4 ha^{-1} yr^{-1}	0.020[e]
N_2O from drained, actively extracted, and unrestored areas	t N_2O ha^{-1} yr^{-1}	0.00047[f]
Peat Stockpiling and Product Production		
Amount of stockpiled peat	t C ha^{-1}	50[g]
Exponential decay constant, stockpiled peat		0.05[g]
Carbon fraction of peat products	t C t air-dry $peat^{-1}$	0.26[h]
Natural Regeneration/Reclamation		
CO_2 natural regeneration after block-cut	t CO_2 ha^{-1} yr^{-1}	8.7[i]
CH_4 natural regeneration after block-cut	t CH_4 ha^{-1} yr^{-1}	0.012[j]
CO_2 natural regeneration after vacuum	t CO_2 ha^{-1} yr^{-1}	7.6[k]
CH_4 natural regeneration after vacuum	t CH_4 ha^{-1} yr^{-1}	0.043[l]
CO_2 -DOC natural regeneration	t CO_2 ha^{-1} yr^{-1}	0.33[m]
CO_2 tree plantation peat efflux	t CO_2 ha^{-1} yr^{-1}	14.6[n]
Rewetting and Restoration		
CO_2 MLTT restored ≤12 years	t CO_2 ha^{-1} yr^{-1}	7.89[o]
CO_2 MLTT restored >12 years	t CO_2 ha^{-1} yr^{-1}	-3.29[p]
CH_4 MLTT restored	t CH_4 ha^{-1} yr^{-1}	0.03[q]
CO_2 active rewetting	t CO_2 ha^{-1} yr^{-1}	-4.50[r]
CH_4 active rewetting	t CH_4 ha^{-1} yr^{-1}	0.19[r]
CO_2-DOC from restored/rewetted Areas	t CO_2 ha^{-1} yr^{-1}	0.33[m]
N_2O from MLTT restored/rewetted Areas	t N_2O ha^{-1} yr^{-1}	N/A[s]

Notes:
MLTT = Moss Layer Transfer Technique
N/A = Non applicable

a. All units where the greenhouse gas (GHG) is specified use units of the relevant GHG (CO_2, CH_4 or N_2O) instead of carbon (C) or nitrogen (N).
b. Hayne and Verbicki (2011)
c. Moore et al. 2002, as cited in Cleary 2003; Glatzel et al. 2003; Waddington et al. 2010; Strack & Zuback 2013; Strack et al. 2014; Nugent et al. 2019; Rankin et al. 2018; Clark et al. 2023; Turmel-Courchesne et al. 2023; Hunter et al. 2024
d. Waddington et al. (2008), Strack and Zuback (2013)
e. Moore et al. (2002) (unpublished data) as cited in Cleary (2003); Waddington and Day (2007); Strack and Zuback (2013); Strack et al. (2014); Rankin et al. (2018); Nugent et al. (2019); Turmel-Courchesne et al. (2023); Clark et al. (2023); Hunter et al. (2024)
f. IPCC, 2014 (Table 2.5, Default value for Boreal & Temperate climate zone)
g. Cleary (2003); Hayne et al. (2014); Sharma et al. (2024)
h. Hayne et al. (2014)
i. Waddington and Price (2000); Waddington et al. (2002); Waddington and Warner (2001); McNeil and Waddington (2003); Cagampan and Waddington (2008)
j. Waddington and Price (2000)
k. Moore et al. (2002) as cited in Cleary (2003); Petrone et al. (2001); Petrone et al. (2003); Waddington et al. (2010); Strack and Zuback (2013); Strack et al. (2014)
l. Moore et al. (2002) as cited in Cleary (2003); Waddington and Day (2007); Strack and Zuback (2013); Strack et al., (2014)
m. Waddington et al. (2008); Strack and Zuback (2013); Nugent et al. (2018); D'Acuna et al., (2019)
n. Garcia Bravo et al. (2018)
o. Moore et al. (2002) (unpublished data) as cited in Cleary (2003); Petrone et al. (2001); Petrone et al. (2003); Waddington et al. (2010); Strack & Zuback (2013); Strack et al. (2014); Nugent et al. (2019); Lazcano et al. (2018)
p. Nugent et al.(2018)
q. Moore et al. (2002) (unpublished data) as cited in Cleary (2003); Waddington and Day (2007); Strack and Zuback (2013); Strack et al. (2014); Nugent et al. (2018); Nugent et al. (2019); Lazcano et al. (2018)
r. Turmel-Courchesne et al. (2023); Lee et al. (2017); D'Acunha et al. (2019)
s. IPCC 2014 Wetlands Supplement, Default assumption of no N_2O emissions from rewetted/restored areas

Table A6.5–9 **Average Reservoir Emission Factors (EF) per Reconciliation Unit (RU)**

Reconciliation Unit	CO_2 Diffusive flux (g CO_2-C m^{-2} yr^{-1})	CO_2 Baseline flux (g CO_2-C m^{-2} yr^{-1})	CH_4 Diffusive flux (g CH_4 m^{-2} yr^{-1})	CH_4 Ebullitive flux (g CH_4 m^{-2} yr^{-1})	CH_4 Degassing flux (g CH_4 m^{-2} yr^{-1})
1 NL – Boreal Shield East	131	29	0.5	0.015	0.0010
3 NL – Taiga Shield East	160	35	6.3	0.31	0.11
4 NL – Boreal Shield East	125	27	0.8	0.0083	0.0038
5 NS – Atlantic Maritime	119	26	6.1	1.2	0.13
7 NB – Atlantic Maritime	198	43	3.2	0.24	0.26
11 QC – Atlantic Maritime	173	38	5.0	0.65	0.74
12 QC – Mixedwood Plains	174	38	6.0	0.55	1.1
13 QC – Hudson Plains	143	31	1.3	0.026	0.019
14 QC – Taiga Shield East	141	31	0.5	0.0082	0.0058
15 QC – Boreal Shield East	151	33	3.5	0.28	0.45
16 ON – Boreal Shield West	162	36	0.6	0.029	0.044
17 ON – Mixedwood Plains	221	48	6.5	1.4	0.053
19 ON – Boreal Shield East	171	37	4.3	0.47	0.31
21 MB – Taiga Shield West	186	41	3.8	0.13	0.68
22 MB – Boreal Shield West	225	49	1.8	0.063	0.18
23 MB – Boreal Plains	417	91	5.6	0.54	0.095
24 MB – Subhumid Prairies	437	96	6.8	0.76	0.048
25 MB – Hudson Plains	226	50	3.8	0.13	0.68
26 SK – Taiga Shield West	186	41	3.8	0.13	0.68
27 SK – Boreal Shield West	186	41	3.8	0.13	0.68
28 SK – Boreal Plains	375	82	5.4	0.52	0.40
29 SK – Subhumid Prairies	416	91	6.5	0.83	0.032
30 SK – Semiarid Prairies	289	63	5.4	0.70	0.028
31 AB – Taiga Plains	215	47	3.1	0.26	0.54
34 AB – Boreal Plains	167	36	2.9	0.30	0.037
35 AB – Subhumid Prairies	217	47	5.0	0.72	0.081
36 Ab – Montane Cordillera	162	35	2.8	0.30	0.074
37 AB – Semiarid Prairies	290	63	6.0	0.94	0.028
39 AB – Boreal Plains	150	33	3.1	0.26	0.54
40 BA – Boreal Cordillera	159	35	2.0	0.73	0.35
41 BC – Pacific Maritime	124	27	2.6	3.3	0.076
42 BC – Montane Cordillera	159	35	2.0	0.73	0.35
46 YT – Boreal Cordillera	187	41	5.8	0.28	0.048
51 NU – Taiga Shield West	186	41	3.8	0.13	0.68

Notes:
Refer to A3.5.6.2 for the equations and proxy approach.
For CO_2 emission factors, RU40 used RU42 as a proxy, and RU51 used RU26.
For CH_4 emission factors, RU21, RU26, RU27, and RU51 used RU26 as a proxy, while RU31 used RU39.

Table A6.5–10 **Residual Emission Factor Parameters for Wetland Land-Use Change and Management in the Oil Sands Region of Alberta Canada**

Generic Disturbance Type	Regeneration Scenario	Biomass Treatment	Peatland Class	Residual Emission Parameters			
				a	b	c	d
Covered or Capped	No vegetation regeneration	burned	open bog	4.47	-0.03	0	0
			open fen	9.91	-0.048	0	0
			treed bog	9.34	-0.034	0	0
			treed fen	15.31	-0.039	0	0
		intact/mulched	open bog	4.47	-0.03	0	0
			open fen	9.91	-0.048	0	0
			treed bog	13.03	-0.046	0	0
			treed fen	17.87	-0.044	0	0
Excavated and Drained	No vegetation regeneration	burned	open bog	52.11	-0.033	0	0
			open fen	65.71	-0.028	0	0
			treed bog	56.83	-0.033	0	0
			treed fen	73.83	-0.029	0	0
		intact/mulched	open bog	52.17	-0.033	0	0
			open fen	66.19	-0.028	0	0
			treed bog	58.99	-0.033	0	0
			treed fen	75.68	-0.029	0	0
High-Impact Vegetation Clearing	Regeneration of understory (non-tree) vegetation only	intact/mulched	open bog	10.16	-0.398	0.036	-6.41
			open fen	2.99	-0.714	0.048	-8.83
			treed bog	15.25	-0.227	-0.002	-2.49
			treed fen	8.72	-0.201	0.031	-7.59
	Full regeneration	intact/mulched	open bog	10.16	-0.398	0.036	-6.41
			open fen	2.99	-0.714	0.048	-8.83
			treed bog	18.53	-0.18	0.029	-5.89
			treed fen	14.04	-0.153	0.062	-11.83
Low-Impact Vegetation Clearing	Regeneration of understory (non-tree) vegetation only	intact/mulched	open bog	10.12	-0.398	0.036	-6.41
			open fen	2.92	-0.711	0.048	-8.83
			treed bog	15.28	-0.227	-0.002	-2.49
			treed fen	8.75	-0.201	0.031	-7.59
	Full regeneration	intact/mulched	open bog	10.12	-0.398	0.036	-6.41
			open fen	2.92	-0.711	0.048	-8.83
			treed bog	18.51	-0.18	0.029	-5.89
			treed fen	14.02	-0.153	0.062	-11.83

Notes:
Refer to A3.5.6.3 for the equations and proxy approach.
Some parameters are repeated for transparency. Woody biomass is absent in open peatlands, so emissions are the same for all biomass treatments. Intact and mulched treatments are aggregated because only small, non-merchantable trees are included, and both decay in the model's "fine woody debris" pool.

A6.5.5. Settlements

Table A6.5–11 Carbon Storage and Sequestration in Urban Trees

Reconcilliation Unit (RU)	Carbon Storage ($t\ C\ ha^{-1}$)	Net Carbon Sequestration ($t\ C\ ha^{-1}\ yr^{-1}$)
1 NL – Boreal Shield East	40	3.0
5 NS – Atlantic Maritime	62	3.4
6 PE – Atlantic Maritime	62	3.4
7 NB – Atlantic Maritime	62	3.4
11 QC – Atlantic Maritime	62	3.4
12 QC – Mixedwood Plains	58	2.4
15 QC – Boreal Shield East	40	3.0
16 ON – Boreal Shield West	40	3.0
17 ON – Mixedwood Plains	58	2.4
19 ON – Boreal Shield East	40	3.0
24 MB – Subhumid Prairies	55	2.9
28 SK – Boreal Plains	40	3.0
30 SK – Semiarid Prairies	55	2.9
34 AB – Boreal Plains	40	3.0
35 AB – Subhumid Prairies	55	2.9
37 AB – Semiarid Prairies	55	2.9
41 BC – Pacific Maritime	97	6.9
42 BC – Montane Cordillera	23	1.4

Note:
Source: Steenberg et al. (2023)

A6.5.6. Forest Conversion

Table A6.5–12 Soil Organic Carbon in Forest and Agricultural Land (0- to 30-cm soil depth)

Soil Texture	Soil Organic Carbon ($Mg\ C\ ha^{-1}$)		Difference (%)
	Forested Land[a]	Cropland[a]	
Eastern Canada			
Coarse	85 (26)	68 (42)	-20
Medium	99 (38)	77 (35)	-22
Fine	99 (58)	78 (36)	-21
Western Canada			
Coarse	73 (39)	74 (38)	1.4
Medium	66 (30)	73 (30)	11
Fine	74 (38)	77 (25)	4.0

Note:
a. Standard deviation in parentheses.

Table A6.5–13 **Parameters and Emission Factors (EF) for Estimating Emissions from Northern Land-Use Change (NLUC)**

EF/Parameter	Unit	Value
Above-ground Biomass (AGB)		
Landcover of Canada Vegetation Class[a]		
Temperate or sub-polar needleleaf forest	t C ha^{-1}	24[b,c]
Sub-polar taiga needleleaf forest	t C ha^{-1}	17[b,c]
Temperate or sub-polar broadleaf deciduous forest	t C ha^{-1}	24[b,c]
Mixed forest	t C ha^{-1}	24[b,c]
Temperate or sub-polar shrubland	t C ha^{-1}	10[b]
Temperate or sub-polar grassland	t C ha^{-1}	4.8[b]
Sub-polar or polar shrubland-lichen-moss	t C ha^{-1}	8.0[b]
Sub-polar or polar grassland-lichen-moss	t C ha^{-1}	4.8[b]
Sub-polar or polar barren-lichen-moss	t C ha^{-1}	1.5[b, d]
Wetland	t C ha^{-1}	3.8[b]
Below-ground Biomass (BGB)		
Ecozone		
Boreal	BGB:AGB ratio	0.21[e]
Arctic	BGB:AGB ratio	0.69[e]

Notes:
Values are derived from a Delphi expert consultation (Lapointe, 2021) and primary literature (Wulder et al., 2020; Bona et al., 2020), where the average values from matches expert opinion.
a. Latifovic (2019)
b. Lapointe E. (2022)
c. Wulder et al. (2020)
d. Bona et al. (2018)
e. Poorter et al. (2012)

A6.6. Biomass Combustion

A6.6.1. CO_2

Emissions of CO_2 from the combustion of biomass originated from forests or other woodlands (whether for energy use, from prescribed burning or from wildfires) are not included in National Inventory totals. Emissions from prescribed burning and from the combustion of this biomass for energy use are estimated and reported in the Land Use, Land-use Change and Forestry (LULUCF) sector, in common reporting tables (CRT) 4(V) and 4.G respectively. Forest wildfires are considered uncontrollable natural disturbances in the modelling and reporting approach used in the LULUCF sector by which these emissions and subsequent removals are estimated and tracked separately from emissions/removals resulting from commercially managed forest stands, more details on his approach can be found in section A3.5.2.4.

The CO_2 emissions related to the combustion of biomass for energy use are reported as memo items in the CRT of the Energy sector, as required by the modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement (MPGs).

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The CO_2 emission factor (EF) (Table A6.6–1) for industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (one million British thermal units; U.S. EPA, 2003). The U.S. EPA data were converted to kg/tonne at 0% moisture content (m.c.) using a higher heating value (HHV) of 20.44 MJ/kg, which was developed from an internal review of available moisture content and heating value data. The EF for spent pulping liquor is calculated from data collected by the National Council for Air and Stream Improvement (NCASI), based on carbon content assuming a 1% correction for unoxidized carbon (NCASI, 2010). The NCASI EFs were reported in units of kg/GJ HHV, which was converted to kg/tonne at 0% m.c. using a HHV of 13.7 MJ/kg (Tran, 2014). The EF for biogenic waste fuels used in the cement industry is calculated from fuel use data reported by the cement industry, using CO_2 accounting and reporting standards developed by the World Business Council for Sustainable Development (WBSCD, 2005) for years 2001-2016. From 2017 onwards, fuel use data and emissions were reported by cement facilities through the Greenhouse Gas Reporting Program (GHGRP) (ECCC, 2025). An weighted average EF was developed based on reported data.

CO_2 EFs for residential combustion (Table A6.6–1) are based on an ECCC study of emissions from wood burning appliances (ECCC, 2024). The study collected emissions data from residential wood burning appliances that are typical for Canada and represent improvements to pollution control over the time series. The EFs are reported at a 25% m.c., except for the EPA certified pellet stove, which is reported at a 10% m.c.

CO_2 emissions occur during forest wildfires and from controlled burning during forest conversion activities. The carbon emitted as CO_2 (CO_2-C) during forest fires is considered in the forest carbon balance, whereas the CO_2-C emitted during controlled burns is reported under the new land-use categories. There is no unique CO_2 EF applicable to all fires, as the proportion of CO_2-C emitted for each pool can be specific to the pool, the type of forest and disturbance, and the ecological zone (see Annex 3.5).

EFs for gaseous biomass (Table A6.6–2), which includes landfill gas, sludge gas from wastewater treatment and digester gas from centralized anaerobic digesters, are adapted from the IPCC (2006).

Table A6.6–1 **Emission Factors for Biomass**

Source[a]	Description	EF			
		CO_2	CH_4	N_2O	Units
Wood Fuel / Wood Waste	Industrial Combustion	1 715[b]	0.1[c]	0.07[c]	g/kg fuel
Forest Wildfires	Open Combustion	NA	NA[d]	NA[e]	g/kg fuel
Controlled Burning	Open Combustion	NA	NA[d]	NA[e]	g/kg fuel
Spent Pulping Liquor	Industrial Combustion	1 250[f]	0.03[g]	0.005[g]	g/kg fuel
Stoves and Fireplaces	Residential Combustion				
Open Fireplace		1 162[h]	5.04[h]	0.057[h]	g/kg fuel
Conventional Woodstove		1 096[h]	7.85[h]	0.065[h]	g/kg fuel
Fireplace Insert		1 212[h]	5.70[h]	0.062[h]	g/kg fuel
Pre-2020 EPA Certified Woodstove		1 206[h]	4.11[h]	0.067[h]	g/kg fuel
2020 EPA Certified Non-Catalytic Woodstove		1 195[h]	4.28[h]	0.058[h]	g/kg fuel
2020 EPA Certified Catalytic Woodstove		1 203[h]	7.70[h]	0.065[h]	g/kg fuel
EPA Certified Pellet Stove		1 449[h]	1.74[h]	0.069[h]	g/kg fuel
Cement Industry Waste Fuel (biogenic)	Industrial Combustion	86[i]	0.03[j]	0.004[j]	kg/GJ

Notes:
NA = Not applicable
a. CO_2 emissions from biomass combusted for energy or agricultural purposes are not included in inventory totals, whereas CH_4 and N_2O emissions from these sources are inventoried under the Energy Sector. All greenhouse gas (GHG) emissions, including CO_2 emissions from biomass burned in managed forests (wildfires and controlled burning), are reported under Land-Use, Land-use Change and Forestry (LULUCF) and excluded from national inventory totals.
b. Adapted from U.S. EPA (2003)
c. Adapted from U.S. EPA (2003) and NCASI TB998 (2012)
d. Emission ratio for CH_4 is 1/90th CO_2. See NIR Annex 3.4.
e. Emission ratio for N_2O is 0.017% CO_2. See NIR Annex 3.4.
f. Adapted from NCASI (2011)
g. Adapted from NCASI (2012)
h. ECCC (2024)
i. Adapted from WBCSD (2005) and ECCC (2025)
j. Adapted from IPCC (2006)

A6.6.2. CH_4

Emissions of CH_4 from residential combustion of firewood are technology-dependent. The CH_4 EFs are based on an ECCC study of emissions from wood burning appliances (ECCC, 2024). The EFs are reported at a 25% m.c., except for the EPA certified pellet stove, which is reported at a 10% m.c.

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The EF (Table A6.6–1) for CH_4 from industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA, 2003) and collected by the NCASI in units of kg/MMBTU and converted to kg/tonne at 0% m.c. as discussed in section A6.6.1. The EF for CH_4 from spent pulping liquor has been developed using source sampling data from NCASI in units of kg/MMBTU, converted to kg/tonne at 0% m.c. using a HHV of 13.7 MJ/kg as discussed in section A6.6.1. The CH_4 EF for bio-based alternative fuels (Table A6.6–1) was adapted from the 2006 IPCC Guidelines (IPCC, 2006).

EFs from gaseous biomass (Table A6.6–2), which includes landfill gas, sludge gas from wastewater treatment and digester gas from centralized anaerobic digesters, are adapted from the IPCC (2006).

Emissions of carbon as CH_4 (CH_4-C) from wildfires and controlled burning are always equal to 1/90th of CO_2-C emissions.

A6.6.3. N_2O

Emissions of N_2O from residential combustion of firewood are technology-dependent. The N_2O EFs are based on an ECCC study of emissions from wood burning appliances (ECCC, 2024). The EFs are reported at a 25% m.c., except for the EPA certified pellet stove, which is reported at a 10% m.c.

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. EFs (Table A6.6–1) for industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA, 2003) and collected by the National Council for Air and Stream Improvements (NCASI) in units of kg/MMBTU and converted to kg/tonne at 0% m.c. as discussed in section A6.6.1. The EF for N_2O from spent pulping liquor has been developed using source sampling data from NCASI in units of kg/MMBTU, converted to kg/tonne at 0% m.c. using a HHV of 13.7 MJ/kg as discussed in section A6.6.1. The N_2O EF for bio-based alternative fuels (Table A6.6–1) was adapted from the 2006 IPCC Guidelines (IPCC, 2006).

EFs for gaseous biomass (Table A6.6–2), which includes landfill gas, sludge gas from wastewater treatment and digester gas from centralized anaerobic digesters, are adapted from the IPCC (2006).

N_2O emissions from wildfires and controlled burning are equal to 0.017% vol/vol of CO_2 emissions. Since both gases have the same molecular weight, the same ratio can be applied on a mass basis (see section A3.5.2).

Table A6.6–2 **Emission Factors for Gaseous Biomass Combustion**

Source	Description	EF			EF Units
		CO_2	CH_4	N_2O	
Landfill Gas	Industrial Combustion (for Energy)	2 752[a]	0.05[a]	0.005[a]	kg/t CH_4 Utilized for Energy
Sludge Gas	Industrial Combustion (for Energy)	2 752[a]	0.05[a]	0.005[a]	kg/t CH_4 Utilized for Energy
Digester Gas	Industrial Combustion (for Energy)	2 752[a]	0.05[a]	0.005[a]	kg/t CH_4 Utilized for Energy
Landfill Gas	Flaring	NE	3.0[b]	NE	kg/t CH_4 Flared

Notes:
NE = Not estimated
a. Adapted from IPCC (2006) (Vol. 2, Table 2.2)
b. U.S. EPA (1998)

A6.7. Waste

A6.7.1. Municipal Wastewater Treatment and Discharge

A6.7.1.1. CH_4

Emissions from Municipal Wastewater Treatment and Discharge occur in two distinct steps: from the treatment process and from the receiving waterbody as a function of organics remaining in the effluent. Emissions may also occur from anaerobic digestion at the wastewater treatment plant; these are presented in section A6.7.3.

Emission factors (EFs) for CH_4 from Wastewater Treatment and Discharge are the product of the maximum methane producing capacity (B_0) and the methane correction factor (MCF). The B_0 represents the maximum amount of methane that can be generated from a given quantity of organics in the wastewater, measured as BOD_5 (IPCC, 2006). The MCF represents the degree to which the maximum methane producing capacity is realised, and varies by treatment technology and receiving waterbody type for the respective emissions-generating steps.

The IPCC default B_0 value of 0.6 kg CH_4/kg BOD (IPCC, 2006) for BOD_5 was not used; a Canada-specific B_0 value of 0.36 kg CH_4/kg BOD_5 is used instead. A study commissioned by Environment Canada (AECOM, 2011) identified that the IPCC 2006 derivation of B_0 for BOD_5 from the B_0 value for chemical oxygen demand (COD) of 0.25 kg CH_4/kg COD may be erroneous.

The MCF and EF values for CH_4 emissions from wastewater treatment are shown in Table A6.7–1. EF values for CH_4 from discharge to receiving waterbodies are shown in Table A6.7–2. Emission factors are expressed in kg CH_4/kg BOD_5 of the wastewater.

Table A6.7–1 Methane Correction Factors (MCF) and Emission Factors (EFs) for CH_4 from Wastewater Treatment

Treatment	MCF	EF (kg CH_4/kg BOD_5)[g]
No Treatment	0[a]	0
Primary	0.03[b]	0.0108
Aerobic Lagoon	0[a]	0
Anaerobic Lagoon	0.8[a]	0.288
Facultative Lagoon	0.2[a]	0.072
Other / Unspecified Lagoon	0.2[c]	0.072
Secondary Anaerobic	0.8[a]	0.288
Secondary Activated Sludge	0.03[b]	0.0108
Trickling Filter	0.03[b]	0.0108
Trickling Filter – High Rate	0.03[b]	0.0108
Rotating Biological Contactor	0.03[b]	0.0108
Sequencing Batch Reactor	0.05[d]	0.018
Secondary Biofiltration	0.03[b]	0.0108
Secondary with Biological Nutrient Removal	0.03[b]	0.0108
Septic	0.5[a]	0.18
Septic with Marine Outfall	0.5[a]	0.18
Wetland	0.17[e]	0.0612
Other / Unknown	0.2[f]	0.072

Notes:
a. IPCC (2006), Volume 5, Chapter 6
b. IPCC (2019), Volume 5, Chapter 6
c. Assuming Unspecified lagoon types were assumed to be facultative lagoons
d. Taseli (2018)
e. Mean value of MCFs from IPCC Supplement to 2006 Guidelines for Wetlands (2014) for three wetland types provided in document.
f. Assuming facilities of unknown or other treatment type are facultative lagoon.
g. EF = MCF x B_0 (B_0 = 0.36 kg CH_4/kg BOD_5)

Table A6.7–2 Methane Correction Factors (MCF) and Emission Factors (EFs) for CH_4 from Wastewater Discharge

Receiving Waterbody Type	MCF	EF (kg CH_4/kg BOD_5)[d]
Unpsecified Aquatic Environment	0.11[a]	0.0396
Canal, Aqueduct or Ditch	0.19[b]	0.0684
Reservoir	0.19[a]	0.0684
Lake	0.19[a]	0.0684
Estuary	0.19[a]	0.0684
River	0.035[a]	0.0126
Ocean	0.035[a]	0.0126
Soil	0[c]	0

Notes:
a. IPCC (2019) Volume 5, Chapter 6
b. Assumed slow moving and more similar to lakes/reservoirs than to rivers/creeks
c. IPCC (2019) Volume 4
d. EF = MCF x B_0 (B_0 = 0.36 kg CH_4/kg BOD_5)

A6.7.1.2. N_2O

N_2O emissions from wastewater occur from two distinct steps: from the wastewater treatment and from the receiving waterbody. N_2O emissions from wastewater treatment are highly variable temporally (Daelman et al., 2015). The emission factors represent annual averages and many not reflect shorter-term emissions. The N_2O EFs from the treatment process are a function of the nitrogen in the wastewater stream and the treatment technology employed. EFs from the receiving waterbody are a function of the nitrogen in the wastewater effluent discharged and of the trophic state of the receiving waterbody.

The emission factor for N_2O from wastewater treatment are shown in Table A6.7–3. EFs for N_2O from receiving waterbodies, resulting from discharge of N with wastewater effluent are is shown in Table A6.7–4. The EFs are expressed as both kg N_2O-N/kg N in the wastewater (effectilvey the N portion of N_2O), and as kg N_2O/kg N in the wastewater.

Table A6.7–3 Emission Factors (EFs) for N_2O from Wastewater Treatment

Treatment Category	EF (kg N_2O-N/kg N)	EF (kg N_2O/kg N)[d]
No Treatment	0[a]	0.0251
Primary	0[b]	0.0000
Aerobic Lagoon	0[b]	0.0000
Anaerobic Lagoon	0[a]	0.0000
Facultative Lagoon	0[b]	0.0000
Other / Unspecified Lagoon	0[c]	0.0000
Secondary Anaerobic	0[a]	0.0000
Secondary Activated Sludge	0.016[a]	0.0251
Trickling Filter	0.016[a]	0.0251
Trickling Filter – High Rate	0.016[a]	0.0251
Rotating Biological Contactor	0.016[a]	0.0251
Sequencing Batch Reactor	0.016[a]	0.0251
Secondary Biofiltration	0.016[b]	0.0251
Secondary with Biological Nutrient Removal	0.016[a]	0.0251
Septic	0.0045[a]	0.0071
Septic with Marine Outfall	0[a]	0.0000
Wetland	0[b]	0.0000
Other / Unknown	0.016[c]	0.0251

Notes:
a. IPCC (2019), Volume 5, Chapter 6
b. ECCC estimate
c. Modelled as facultative lagoon
d. To convert N_2O-N to N_2O, multiply by 44/28.

Table A6.7–4 Emission Factors (EFs) for N_2O from Wastewater Discharge to Receiving Waterbodies

Receiving Waterbody Trophic State	EF (kg N_2O-N/kg N)	EF (kg N_2O/kg N)[c]
Unpsecified Aquatic Environment	0.005[a]	0.0079
Nutrient Impacted (Eutrophic) and/or Hypoxic	0.019[a]	0.0299
Non-Nutrient Impacted Freshwater	0.005[a]	0.0079
Non-Nutrient Impacted Estuarine and Marine	0.005[a]	0.0079
Soil	0[b]	0.0000

Notes:
a. IPCC (2019) Volume 5, Chapter 6
b. IPCC (2019) Volume 4
c. $N_2O = N_2O\text{-}N \times 44/28$

A6.7.2. Waste Incineration

The emission factors for CO_2, CH_4, and N_2O for waste incineration are shown in Table A6.7–5.

Table A6.7–5 **Emission Factors for Waste Incineration**

Category	EF (kg / tonne waste)		
	CO_2	CH_4	N_2O
Municipal Solid Waste Incineration – Continuous – Fluidized Bed	3 666.67[a]	0.0002	0.00005
Municipal Solid Waste Incineration – Continuous – Stoker		0	0.00005
Municipal Solid Waste Incineration – Semi-Continuous – Fluidize Bed		0.006	0.00005
Municipal Solid Waste Incineration – Semi-Continuous – Stoker		0.188	0.00005
Municipal Solid Waste Incineration – Batch – Fluidized Bed		0.06	0.00006
Municipal Solid Waste Incineration – Batch – Stoker		0.237	0.00006
Sewage Sludge Incineration	1 650.00	9.70	0.99
Hazardous Waste Incineration	1 650.00	0.17	3.16
Clinical Waste Incineration – Continuous	572.00	0.0002	0.05
Clinical Waste Incineration – Batch		0.06	0.06
Industrial Sludge – Continuous	1 650.00	0.0002	0.45
Industrial Sludge – Batch		0.06	0.45
Fossil Liquid Waste – Continuous	2 933.33	0.0002	0.1
Fossil Liquid Waste – Batch		0.06	0.1
Fossil Liquid Waste – Semi-Continuous		0.0301	0.1
Industrial – Continuous – Stoker	1 650.00	0.0002	0.05
Industrial – Continuous – Fluidized Bed		0	0.05
Industrial – Semi-Continuous – Fluidized Bed		0.006	0.05
Industrial – Semi-Continuous – Stoker		0.188	0.05
Industrial – Batch – Fluidized Bed		0.06	0.06
Industrial – Batch – Stoker		0.237	0.06

Notes:
Source: IPCC (2006)
a. For Municipal Solid Waste, the EF for CO_2 is in units of kg CO_2 / tonne fossil carbon.

A6.7.2.1. Sewage Sludge Incinerators

Emissions from sewage sludge incinerators are estimated from an emission factor obtained from the IPCC 2006 Guidelines, Volume 5, Chapter 5 (IPCC, 2006).

A6.7.2.2. Municipal Solid Waste Incinerators

The emission estimates from municipal solid waste incineration are calculated based on batch or continuous operations, and based on stoker or fluidized bed combustion technology. The emission factors used are from the IPCC 2006 Guidelines, Volume 5, Chapter 2 and 5 (IPCC, 2006). For CO_2 emissions, only the non-biogenic (fossil) portion of the waste is included when calculating emissions.

A6.7.2.3. Hazardous Waste Incinerators

The CO_2 emission factors for hazardous waste incineration are taken from the IPCC 2006 Guidelines, Volume 5, Chapter 5 (IPCC, 2006). The CO_2 emission factor is based on a carbon content of 50% and fossil carbon content of 90% of the carbon content. CH_4 and N_2O emission factors were developed for Canada using emissions from a facility.

A6.7.2.4. Clinical Waste Incinerators

The emission factors for clinical waste incineration are taken from the IPCC 2006 Guidelines, Volume 5, Chapter 5 (IPCC, 2006). The CO_2 emission factor is based on a carbon content of 45%.

A6.7.3. Biological Treatment of Solid Waste

The emission factors for CO_2, CH_4, and N_2O for the biological treatment of solid waste are shown in Table A6.7–6.

Table A6.7–6 Emission Factors for the Biological Treatment of Solid Waste

	Waste of Facility Type	EF			Units
		CO_2	CH_4	N_2O	
Anaerobic Digestion	Off-farm facilities[a]	NA	2.10	NA	% of methane produced in biogas
Composting	Yard Waste[b]	NA	1.72	0.25	g/kg Wet Waste
	Biosolids or Manure[b]	NA	3.54	0.18	g/kg Wet Waste
	Mixture of Wastes[b]	NA	1.09	0.11	g/kg Wet Waste
	Municipal Solid Waste[b]	NA	1.51	0.18	g/kg Wet Waste

Notes:
NA = Not applicable
a. ECCC(2020a)
b. ECCC(2020b)

ELECTRICITY IN CANADA: SUMMARY AND INTENSITY TABLES

This annex presents detailed greenhouse gas (GHG) information related to the generation of electricity by the Public Electricity and Heat Production category (IPCC Category 1.A.1.a), on a national, provincial, and territorial level.

The Canadian electricity generation industry produces electricity by transforming the energy in falling water, coal, natural gas, refined petroleum products (RPPs), other miscellaneous fuels, biomass, nuclear, wind, and solar resources. The process of supplying electricity to the public involves not only power generation at the plant, but also distribution through the electricity grid. The efficiency of the transmission system has an impact on the amount of electricity available to consumers. GHG emission estimates and electricity generation values are therefore based on activities that occur at the generating plant, and efforts have been made to include the impact of the transmission and distribution infrastructure (including sulphur hexafluoride (SF_6) emissions associated with switchgear and other electrical equipment, which is accounted for in the Industrial Processes and Product Use [IPPU] sector).

The electricity generation industry in Canada is composed of entities whose main activity is the production of electricity (main activity producers) and those who generate either partially or wholly for their own use (autoproducers). Main activity producers sell their electricity to the grid, can be either public or private generators, and are reported under North American Industrial Classification System (NAICS) code 22111. Autoproducers are generally private companies that generate electricity either to feed their operations or as a by-product of their operations. They may sell some or all of their electricity to the grid. Any industry that generates electricity, but whose main business is something other than electric power generation, is reported under the NAICS code associated with their primary business activity. However, in some cases, a company may have divided their operations so that the electric power generation is a separate business entity (even if the operations are on the same site). In this case, the electric power generation is included under the Public Electricity and Heat Production category.

The analysis in this section only includes main activity producers. This analysis relies on a variety of data sources; fuel consumption and electricity production data are published by Statistics Canada in the *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada, n.d. [a]), in the publication *Electric Power Generation, Transmission and Distribution* (EPGTD) (Statistics Canada, n.d. [b]) and online via Statistics Canada data tables 25-10-0019-01, 25-10-0020-01, 25-10-0021-01 and 25-10-0084-01 (Statistics Canada, n.d. [c], n.d. [d], n.d. [e], n.d. [f]).

A "generation intensity" indicator is derived to reflect the GHG emissions intensity of electricity as it is delivered to the electricity grid. Electricity generation intensity values were derived for each fuel type using GHG emission estimates and electricity generation data. The methodology used to develop the GHG emissions is discussed in Chapter 3 and Annex 3.1 of this report. GHG emissions are based on the total fuel consumed by the public utility sector, as provided in the RESD,[1] while generation data are from Statistics Canada data tables (2005–2024) and the EPGTD publication (1990–2004).

A "consumption intensity" indicator was also derived to reflect the GHG emissions intensity of electricity as it is delivered to the consumer. Accordingly, electric energy losses (mainly) in transmission and distribution are subtracted from the overall total electricity generation, while SF_6 emissions associated with equipment used in electricity transmission and distribution are added to overall total GHG emissions. The electric energy losses in transmission, distribution and anywhere else are taken to be the utility sector's share of "unallocated energy," as presented in Table A7–1 and calculated from data provided by Statistics Canada (n.d. [e]) or regional electricity system operators. Likewise, the SF_6 emission values are based on the electric utility sector's share of total SF_6 emissions from equipment used in electricity transmission and distribution.

Electricity intensity values (rounded data) for Canada, are provided in Table A7–1. Unrounded data for Canada at the national, provincial and territorial levels are available in Excel (.xlsx) format on the Government of Canada's Open Data website.[2]

1 Occasionally, Statistics Canada revises some of its historic data, which can affect the values provided in Table A7–1.

2 https://data-donnees.az.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/

Table A7–1 Electricity Generation and GHG Emission Details for Canada

	1990	2005	2010	2015	2019	2020	2021	2022	2023	2024[a]
GREENHOUSE GAS EMISSIONS[b]										
	kt CO_2 equivalent									
Combustion	**94 100**	**123 000**	**102 000**	**82 900**	**69 600**	**62 200**	**61 500**	**58 000**	**58 900**	**57 400**
Coal	80 100	97 900	78 500	57 800	42 800	34 600	31 400	24 400	21 700	14 000
Natural Gas	2 720	14 500	18 800	19 900	22 400	24 000	27 000	29 500	34 200	40 000
Other Fuels[c]	11 300	10 600	4 900	5 200	4 340	3 520	3 150	4 170	3 110	3 470
Other Emissions[d]	**–**	**52**	**53**	**87**	**80**	**68**	**72**	**76**	**75**	**77**
OVERALL TOTAL[e, f, g]	**94 100**	**123 000**	**102 000**	**82 900**	**69 600**	**62 300**	**61 600**	**58 100**	**59 000**	**57 500**
ELECTRICITY GENERATION[h, i]										
	GWh									
Combustion[j]	**101 000**	**140 000**	**117 000**	**108 000**	**97 700**	**92 200**	**95 700**	**93 900**	**101 000**	**109 000**
Coal	82 200	93 900	74 300	57 800	44 500	35 900	32 000	24 400	21 800	15 100
Natural Gas	4 140	29 800	34 100	41 500	46 300	49 900	57 500	62 600	73 300	87 900
Other Fuels	14 800	16 600	8 160	8 220	6 880	6 350	6 140	6 860	6 170	6 460
Refined Petroleum Products	14 700	10 800	3 010	3 550	2 400	2 140	2 100	2 710	2 240	2 480
Biomass	14	1 780	2 310	1 980	1 880	2 070	2 240	1 980	2 230	2 390
Other	91	3 990	2 840	2 690	2 590	2 140	1 800	2 170	1 700	1 590
Nuclear	**68 800**	**86 800**	**85 500**	**96 000**	**95 500**	**92 600**	**87 400**	**82 300**	**84 000**	**80 700**
Hydro	**263 000**	**327 000**	**321 000**	**345 000**	**349 000**	**355 000**	**353 000**	**369 000**	**331 000**	**319 000**
Other Renewables[k]	**26**	**1 580**	**8 780**	**27 500**	**33 600**	**36 300**	**38 100**	**41 100**	**44 000**	**52 800**
Other Generation[l, m]	**–**	**32**	**10 100**	**280**	**330**	**500**	**640**	**550**	**570**	**560**
OVERALL TOTAL[f]	**433 000**	**556 000**	**542 000**	**577 000**	**577 000**	**577 000**	**574 000**	**587 000**	**561 000**	**563 000**
GREENHOUSE GAS INTENSITY[n]										
	Generation Intensity (g GHG / kWh electricity generated)									
CO_2 intensity (g CO_2 / kWh)	220	220	190	140	120	110	110	100	100	100
CH_4 intensity (g CH_4 / kWh)	0.004	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
N_2O intensity (g N_2O / kWh)	0.004	0.004	0.004	0.003	0.003	0.002	0.002	0.002	0.002	0.002
GENERATION INTENSITY (g CO_2 eq / kWh)[f]	**220**	**220**	**190**	**140**	**120**	**110**	**110**	**100**	**110**	**100**
	Losses									
Unallocated Energy (GWh)[o, p]	31 000	33 000	40 000	46 000	42 000	44 000	38 000	37 000	37 000	42 000
SF_6 Emissions (kt CO_2 eq)[q]	210	170	190	200	130	160	160	100	100	110
	Consumption Intensity (g GHG / kWh electricity consumed)									
CONSUMPTION INTENSITY (g CO_2 eq / kWh)[r]	**230**	**240**	**200**	**160**	**130**	**120**	**120**	**110**	**110**	**110**

Notes:

Data presented include emissions, generation and intensity for facilities classified under NAICS code 22111 – Electric Power Generation.

a. Preliminary data.
b. Emissions based on data taken from the *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB, Statistics Canada.
c. Includes GHG emissions from the combustion of refined petroleum products (light fuel oil, heavy fuel oil, and diesel), petroleum coke, still gas and other fuels not easily categorized.
d. GHG emissions from on-site combustion of fuel not directly related to electricity generation.
e. GHG emissions from the flooding of land for hydro dams are not included.
f. Totals may not add up to overall total due to rounding.
g. CO_2 from carbon capture and storage has been removed from the total.
h. Taken from StatCan Data Tables 25-10-0019-01 (2005–2019), 25-10-0084-01 (2020–2024), and 25-10-0020-01 (2005–2024).
i. Taken from the *Electric Power Generation, Transmission and Distribution* (EPGTD) publication, Catalogue No. 57-202-XIB, Statistics Canada (for 1990–2004).
j. From 2014 onward, this includes most of the electricity generated from the by-product steam associated with the fuel combustion. Prior to 2014, it was not possible to break this data into the original fuel source, so it was included in Other Generation.
k. Other Renewables – includes electricity generation by wind, tidal and solar.
l. NAICS category 221119, Other Electric Power Generation.
m. Prior to 2014, this includes electricity generation from steam from waste heat. From 2014 onward, most of the electricity generation from steam from waste heat is reported as part of its original fuel source.
n. Intensity values have been rounded to reflect the estimated level of accuracy.
o. Adapted from StatCan Data Table 25-10-0021-001 (2005-2024), Cat. No. 57-202-XIB (1990-2004) or regional electricity system operators.
p. Includes transmission line losses, metering differences and other losses.
q. The electric utility sector's share of emissions from electrical equipment from CRT Category 2.F.viii (Production and Consumption of Halocarbons and SF_6).
r. Consumption intensity values are impacted by unallocated energy and SF_6 transmission emissions.

– Indicates no emissions or no electricity generation

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Annex 3.6, Methodology for Waste Sector

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