NATIONAL INVENTORY REPORT 1990–2022: GREENHOUSE GAS SOURCES AND SINKS IN CANADA

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

PART 1

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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 Article 13 of the Paris Agreement, national inventories of sources and sinks of greenhouse gases (GHGs) must be submitted to the UNFCCC anually. This report is part of Canada's annual inventory submission under the Paris Agreement.

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. Canada's 2024 national GHG inventory complies for the first year with the the modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement (MPGs) (see 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 2023. 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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The Pollutant Inventories and Reporting Division (PIRD) of Environment and Climate Change Canada wishes to acknowledge the many individuals and organizations that contributed to the annual submission of Canada's official greenhouse gas inventory: National Inventory Report (NIR) and data reporting tables. Although the list of all researchers, government employees and consultants who provided technical support is too long to include here, the Division would like to highlight the contributions of the following authors and reviewers of the *National Inventory Report 1990–2022: Greenhouse Gas Sources and Sinks in Canada*, whose work helped to improve this year's report.

Executive Summary

Tatyana Abou-Chaker, Sean Angel, Alice Au, Warren Baker, Nicholas Bishop, Ana Blondel, Alessia Czerwinski, Corey Flemming, Brandon Greenlaw, Jordon Kay, Emil Laurin, Geneviève Leblanc-Power, Catherine Lee, Chang Liang, Douglas MacDonald, Kristen Obeda, Raphaëlle Pelland St-Pierre, Lindsay Pratt, Catherine Robert, Duane Smith, Steve Smyth, Kristine Tracey, Brittany Sullivan, Brett Taylor, Arumugam Thiagarajan, Amy Vallières, and Melanie Vanderpol.

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Chapter 5: Agriculture

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Chapter 6: Land Use, Land-Use Change and Forestry

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Annexes

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Sean Angel (Annexes 1, 2, 3, 6, 8, 9, 10, 11 and 12)

Alice Au (Annexes 1, 2, 3, 6, 8, 9, 10, 11 and 12)

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Owen Barrigar (Annexes 2, 3, 9, 10, 11 and 12)

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Ana Blondel (Annexes 1, 2, 3, 6, 7, 8 and 9)

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Dominic Cyr (Annex 3)

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Amy Vallières (Annexes 6 and 7)

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Overall coordination of Canada's National Inventory Report was led by Raphaëlle Pelland St-Pierre. Centralized data compilation and the generation of comprehensive emission tables were led by Amélie Amiot. Compilation of uncertainty estimates as well as key category analyses were led by Pegah Baratzadeh and Amélie Amiot. Compilation and layout of the National Inventory Report for publication were led by Marida Waters with the support of Bruna Sunye. Editing and translation services were provided by the Translation Bureau of Public Services and Procurement Canada (PSPC) with the support of Katryn Lamoureux and Sara Gagnon-Calestagne. Special thanks to Jorge Aranda Fernandez for the development of webpages related to this publication. The compilation and coordination of the data reporting tables was managed by Catherine Robert.

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Readers' Comments

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Abbreviations

AR4 .... Fourth Assessment Report of the Intergovernmental Panel on Climate Change

AR5 .... Fifth Assessment Report of the Intergovernmental Panel on Climate Change

BCER .... British Columbia Energy Regulator

BCOGC .... British Columbia Oil and Gas Commission

CAC .... criteria air contaminant

CANSIM .... Statistics Canada's key socioeconomic database

CAPP .... Canadian Association of Petroleum Producers

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

CRF .... Common Reporting Format

DOC .... dissolved organic carbon

ECCC .... Environment and Climate Change Canada

EF .... emission factor

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

IEA .... International Energy Agency

IPCC .... Intergovernmental Panel on Climate Change

IPPU .... Industrial Processes and Product Use

LDAR .... light detection and repair

LTO .... landing and takeoff

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

MMV .... Measurement, Monitoring and Verification

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

MSW .... municipal solid waste

N/A .... not available

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*

StatCan .... Statistics Canada

UOG .... upstream oil and gas

VKT .... vehicle kilometres travelled

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

Chemical Formulas

Al .... aluminium

$CaCO_3$ .... calcium carbonate; limestone

$CaMg(CO_3)_2$ .... dolomite

CaO .... lime; quicklime; calcined limestone

CF_4 .... carbon tetrafluoride

C_2F_6 .... carbon hexafluoride

CH_3OH .... methanol

CH_4 .... methane

C_2H_6 .... ethane

C_3H_8 .... propane

C_4H_{10} .... butane

C_2H_4 .... ethylene

CO_2 .... carbon dioxide

CO_2 eq .... carbon dioxide equivalent

H_2O .... water

H_2S .... hydrogen sulphide

HNO_3 .... nitric acid

Mg .... magnesium

$MgCO_3$ .... magnesite; magnesium carbonate

MgO .... magnesia; dolomitic lime

N .... nitrogen

Na_2CO_3 .... sodium carbonate; soda ash
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 .... nitric oxide
NO_2 .... nitrogen dioxide
NO_3- .... nitrate
NO_x .... nitrogen oxides
O_2 .... oxygen
SF_6 .... sulphur hexafluoride
SiC .... silicon carbide

Notation Keys

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

Units

g .... gram
Gg .... gigagram
Gt .... gigatonne
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

ES.1. Key Points

- In 2022, Canada's greenhouse gas (GHG) emissions were 708 megatonnes of carbon dioxide equivalent (Mt CO_2 eq), a decrease of 54 Mt (7.1%) from 2005, the base year for Canada's 2030 GHG emission reduction target, and an increase of 9.3 Mt (1.3%) from 2021, while remaining 44 Mt (5.9%) below pre-pandemic (2019) emission levels.
- Notable changes between 2021 and 2022 include Transport, and commercial, institutional and residential combustion emission increases of 7.8 Mt (4.2%) and 3.8 Mt (5.3%), respectively, while emissions from Public Electricity and Heat Production and Fugitive Sources from oil and gas decreased by 4.3 Mt (7.0%) and 2.1 Mt (2.8%), respectively.
- The emissions intensity for the entire Canadian economy (GHG per gross domestic product [GDP]) has continued to decline; in 2022 it had declined by 42% since 1990 and by 30% since 2005.
- While the COVID-19 pandemic undoubtedly impacted recent year emissions, the sustained decline in emission intensities over time can be attributed to factors such as fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.
- Significant methodological improvements were implemented in the upstream oil and gas and managed forest land sectors, among others, along with the implementation of the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5) Global Warming Potential (GWP) values. Overall, this edition of the inventory incorporates upward revisions of 29 Mt in 2005 and 28 Mt in 2021, relative to the previously (2023) published inventory. The 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 National Inventory Report (NIR) is a scientific report which, along with other publications such as Canada's Eighth National Communication and Fifth Biennial Report to the United Nations Framework Convention on Climate Change (UNFCCC) and Canada's 2030 Emissions Reduction Plan, informs and supports decision-making to reduce Canada's GHG emissions and combat climate change.

ES

ES.2. Introduction

The 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 December 1992, and the Convention came into force in March 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 target.

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 National Greenhouse Gas 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.[1] The annual inventory submission consists of the NIR and data reporting tables. This is the first year Parties will be reporting under the Paris Agreement, including Canada.

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 IPCC *2006 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, Inventory Improvements).

In 2021, Canada formally submitted its enhanced Nationally Determined Contribution (NDC) to the United Nations, committing to cut its GHG emissions to 40%–45% below 2005 levels by 2030 (see The NIR: Scientific Evidence for Decision Makers box that follows).

In keeping with the MPGs, the GHG inventory reports annual emissions from 1990 up to and including the year ending 16 ½ months prior to its submission (e.g., 2022 for the 2024 edition of the inventory). 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.

Section ES.3 of this Executive Summary provides an overview of the latest information on Canada's net anthropogenic GHG emissions in recent years 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 2005–2022 period.

For the purposes of analyzing economic trends and policies, it is useful to allocate emissions 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.[2] 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 details GHG emissions for Canada's 13 sub-national jurisdictions. Section ES.7 gives an overview of the key category analysis and results. Finally, section ES.9 provides some detail on the components of this submission and outlines key elements of its preparation.

1 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.

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

ES

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 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, and setting Canada on a path to reaching net-zero emissions by 2050.

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

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 our scientific understanding improves.

Thus Canada's National GHG Inventory, along with other regular publications such as the greenhouse gas and air pollutant emissions projections, 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 (1990–2022)

Canada accounts for approximately 1.5% of global GHG emissions (Climate Watch, 2024 for the year 2020), 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 18 t CO_2 eq/capita in 2022 (StatCan, n.d.[a]).[3]

Emission Breakdown by Sector (2022)

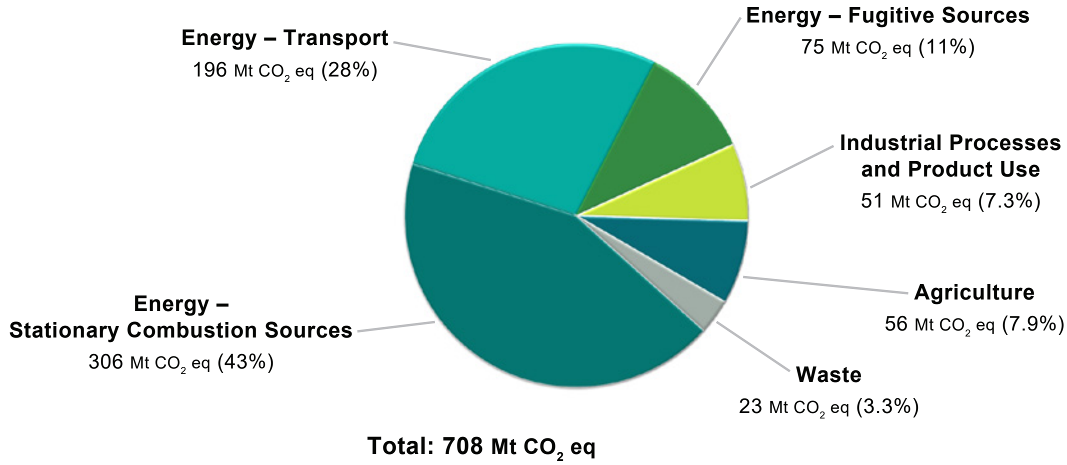
In 2022, Canada's GHG emissions were 708 Mt CO_2 eq.[4] The Energy sector (consisting of Stationary Combustion Sources [306 Mt], Transport [196 Mt] and Fugitive Sources [75 Mt]) emitted 577 Mt, or 82% of Canada's total GHG emissions (Figure ES–1). The remaining emissions were largely generated by the Agriculture and IPPU sectors (7.9% and 7.3%, respectively), with contributions from the Waste sector (3.3%). When included with emissions from other sectors, LULUCF sector emissions corresponded to 7.3% of the national total.[5]

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

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

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

Figure ES–1 **Breakdown of Canada's Emissions by Intergovernmental Panel on Climate Change Sector (2022)**

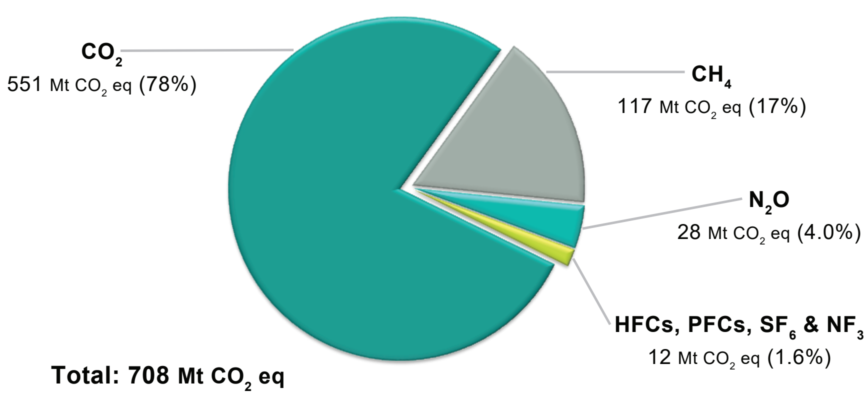


Note: Totals may not add up due to rounding.

Emission Breakdown by GHG (2022)

Canada's emissions profile is similar to most industrialized countries, in that CO_2 is the largest contributor to total emissions, accounting for 551 Mt or 78% of total emissions in 2022, 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 2022 amounted to 117 Mt or 17% of Canada's total and is the second largest contributor. These emissions consist largely of fugitive emissions from oil and natural gas systems (56 Mt), agriculture (31 Mt) and landfills (19 Mt). Emissions of N_2O mostly arise from agricultural soil management, accounting for 28 Mt or 4.0% of Canada's emissions in 2022. 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 (2022)**

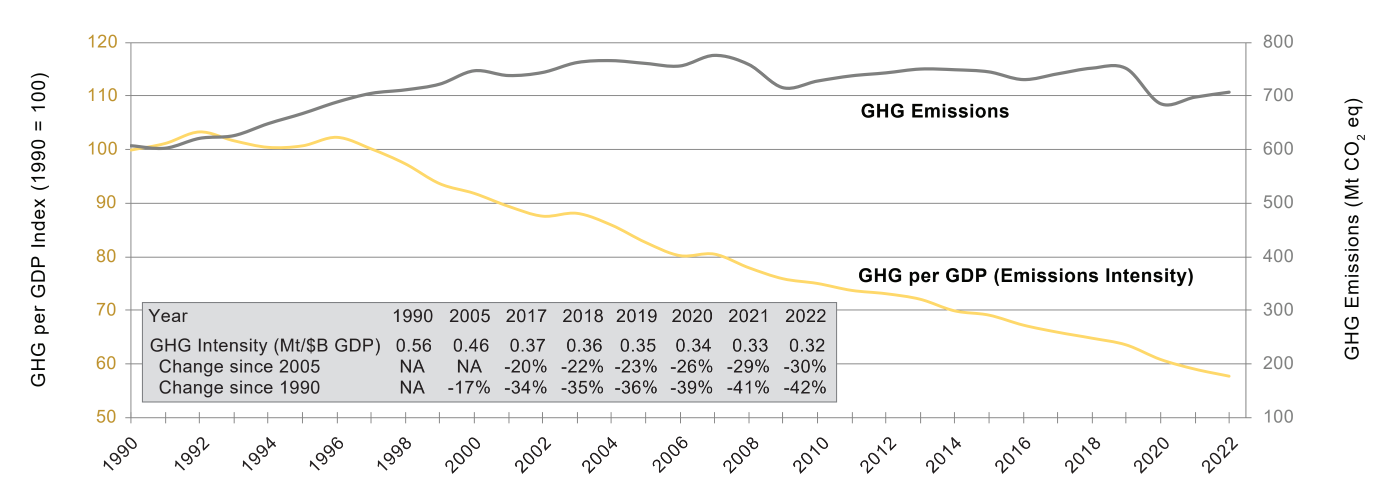


Note: Totals may not add up due to rounding.

Changes in Total Emissions (1990–2022)

After fluctuations in recent years, Canada's GHG emissions in 2022 decreased by 54 Mt or 7.1% from 2005 emissions. 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 2022 it had declined by 42% since 1990 and by 30% 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.

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



Year	1990	2005	2017	2018	2019	2020	2021	2022
GHG Intensity (Mt/$B GDP)	0.56	0.46	0.37	0.36	0.35	0.34	0.33	0.32
Change since 2005	NA	NA	-20%	-22%	-23%	-26%	-29%	-30%
Change since 1990	NA	-17%	-34%	-35%	-36%	-39%	-41%	-42%

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

Recent emission fluctuations (2019–2022) are described here, while the remainder of this Executive Summary focus on 2005 to 2022 trends and their drivers.

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 66 Mt (8.7%) in total GHG emissions between 2019 and 2020. These changes occurred in numerous subsectors between 2019 and 2020, most notably in Transport (-31 Mt or -15%), Stationary Combustion Sources (-23 Mt or -7.2%) and Fugitive Sources (-9.4 Mt or -11%). The year after, between 2020 and 2021, emissions increased slightly by 12 Mt (1.8%). Finally, in the latest year, between 2021 and 2022, they continued to increase by 9.3 Mt (1.3%), while remaining below their 2019 pre-pandemic levels.

Some emission sources contributed significantly to these recent emission changes. Specifically, Transport emissions are down by 14 Mt (6.7%) between 2019 and 2022 as travel demand decreased because of the pandemic and has yet to return to pre-pandemic levels. Within the Transport subsector, between 2019 and 2020, first year of the pandemic, these emissions included a decrease in Light-Duty Gasoline Vehicles and Trucks (-15 Mt or -17%) and Domestic Aviation (-3.8 Mt or -45%). Between 2020 and 2022, Road Transportation (9.3 Mt or 8.4%) was responsible for most of the emissions increase in Transport (17 Mt or 9.7%) as vehicle travel continued to return to pre-pandemic levels.

For Fuel Combustion Sources (excluding Transport), emissions are down by 23 Mt (6.1%) between 2019 and 2022. Between 2019 and 2020, decreases in Public Electricity and Heat Production (-7.6 Mt or -11%) were due to reduced coal consumption partially offset by an increase in natural gas consumption. Plant closures during the pandemic can partially explain decreases in Manufacturing Industries (-3.8 Mt or -8.7%). Between 2020 and 2021, second year of the pandemic, combustion emissions from Oil and Gas Extraction increased by 3.7 Mt (3.6%), consistent with a rise in crude bitumen (13%), synthetic crude oil (6%) from oil sands and natural gas (4%) production. Contributing to the 2021-2022 overall increase, Commercial and Institutional, and Residential combustion emissions increased by 3.8 Mt (5.3%), consistent with a 6% increase in heating degree days, indicating a colder winter and therefore longer heating season in 2022. In contrast, Public Electricity and Heat Production decreased by 4.3 Mt (7.0%) during the same period, due to further reductions in coal consumption.

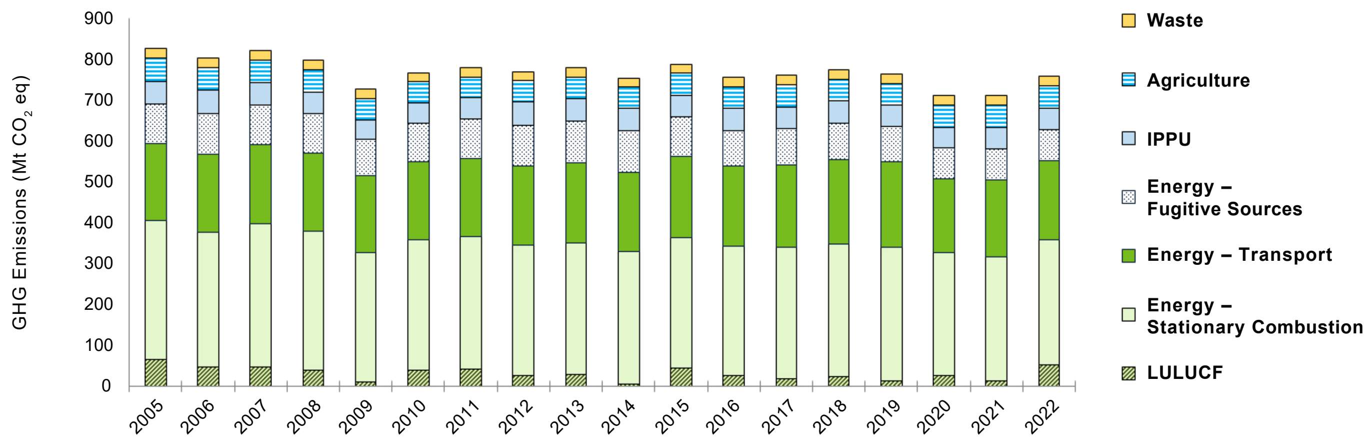
For Fugitive Sources, emissions decreased by 11 Mt (13%) between 2019 and 2022. In the first year, emission decreases between 2019 and 2020 included venting (-9.0 Mt or -15%), and leaks from oil (-0.4 Mt or -4.5%) and natural gas production and processing facilities (-0.4 Mt or -3.6%). In the latest year, Fugitive Sources from oil and natural gas systems continued to decrease by 2.1 Mt (2.8%) between 2021 and 2022, mainly due to decreased venting in Alberta and Saskatchewan.

Between 2019 and 2022, IPPU sector emissions are down by 1.0 Mt (1.9%). Temporary plant shutdowns during the first pandemic year can partially explain the decrease between 2019 and 2020 in this sector (-2.6 Mt or -5.0%). Between 2020 and 2022, the IPPU sector emissions increased by 1.6 Mt (3.3%) overall, most notably, from the use of fuels for non-energy purposes (1.8 Mt or 18%), which is in line with the increase in fuel quantities reported to Statistics Canada for this use.

Finally, Agriculture emissions increased by 1.6 Mt between 2019 and 2022 (3.0%), mainly due to increased inorganic nitrogen use between 2019 and 2020, and subsequently emissions of nitrous oxide that resulted from the loss of soil organic carbon as a result of drought on the prairies between 2020 and 2022.

Notwithstanding the 2019–2020 abrupt decrease and recent year changes, the general breakdown of emissions by IPCC sector has not substantially changed over time (Figure ES–4).

Figure ES–4 **Trends in Canadian GHG Emissions by Intergovernmental Panel on Climate Change Sector (2005–2022)**



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

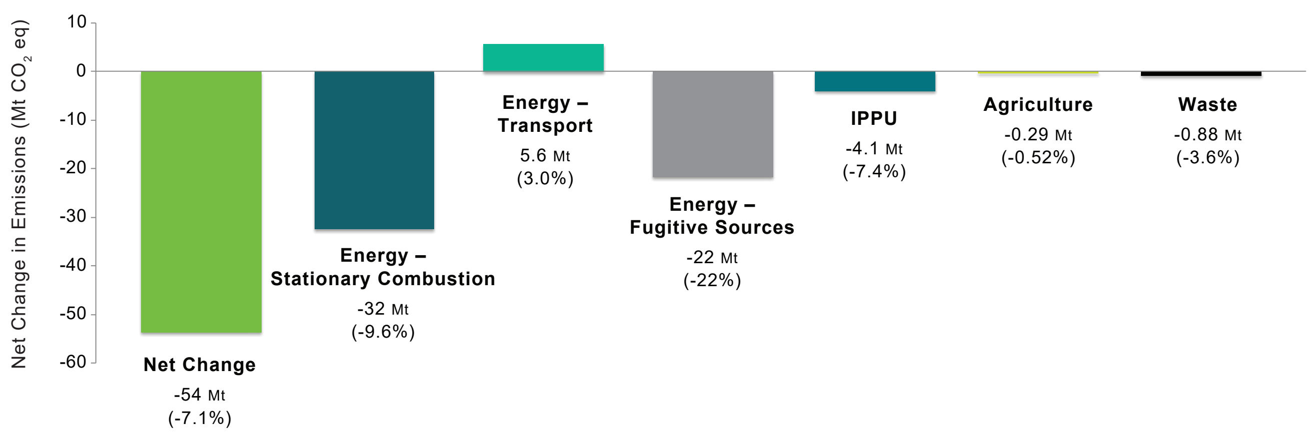
Trends in Emissions (2005-2022)

Over the 2005–2022 period, total emissions are down by 54 Mt or 7.1%. The Energy sector dominated, with emission decreases of 27 Mt (5%) from Fuel Combustion Sources and 22 Mt (22%) from Fugitive Sources (Table ES–1). Transport associated fuel combustion emissions increased by 5.6 Mt (3.0%). Over the same period, emissions are down by 4.1 Mt (7.4%) in the IPPU sector and 0.88 Mt (3.7%) in the Waste sector. The Agriculture sector emissions have remained relatively stable with a 0.29 Mt or 0.5% decrease (Figure ES–5).

Chapter 2 provides more information on GHG emissions trends since 1990 and 2005 and their drivers.[6] Further breakdowns of emissions and a complete time series can be found at open.canada.ca.

6 The complete NIR can be accessed here: http://www.publications.gc.ca/site/eng/9.506002/publication.html.

Figure ES–5 **Changes in Emissions by IPCC Sector (2005–2022)**



Energy – 2022 GHG Emissions (577 Mt)

In 2022, GHG emissions from the IPCC Energy sector (577 Mt) were 7.7% lower than in 2005 (626 Mt). Within the Energy sector, emissions increased by 46 Mt (73%) from Oil and Gas Extraction and 6.7 Mt (14%) from Other Transportation. These emissions were offset by decreases of 67 Mt (54%) from Public Electricity and Heat Production, 22 Mt (22%) from Fugitive Sources, 6.6 Mt (14%) from Manufacturing Industries, 5.8 Mt (29%) from Petroleum Refining, 4.3 Mt (10%) from the Residential sector, and 2.2 Mt (1.8%) from Road Transportation.

Stationary Combustion Sources (306 Mt)

Decreasing electricity generation from coal and refined petroleum product (RPP) usage (by 74% and 75%, respectively) and an increase in the amount of low-emitting generation in the mix[7] were the largest drivers of the 67 Mt (54%) decrease in emissions associated with Public Electricity and Heat Production between 2005 and 2022.

Since 2005, reduced consumption of more GHG-intensive fossil fuels, such as coal and RPPs, accounted for 32% of the decrease in emissions from Public Electricity and Heat Production. Significant reductions in GHG-intensive fossil fuels occurred in Ontario (99%), Manitoba (92%), Alberta (81%), New Brunswick (54%), Nova Scotia (54%), and Saskatchewan (28%). 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 59% of the decrease in emissions.

The 46 Mt increase in emissions from stationary fuel consumption in Oil and Gas Extraction is consistent with a 240% rise in crude bitumen and synthetic crude oil production from Canada's oil sands operations since 2005.

GHG emissions from fuel consumption in Manufacturing Industries decreased by 6.6 Mt (14%) between 2005 and 2022, consistent with a 15% decrease in energy use (StatCan, n.d.[c]). The decrease occurred in Other Manufacturing (-3.1 Mt or -19%), Pulp and Paper (-1.7 Mt or -20%), Cement (-1.6 Mt or -30%), Non-Ferrous Metals (-0.60 Mt or -16%), and Iron and Steel (-0.62 Mt or -11%), in contrast with an increase in Chemicals (0.95 Mt or 12%).

Since 2005, four petroleum refineries have permanently closed or converted to terminal facilities including one in Ontario (2005), Quebec (2010), Nova Scotia (2013), and Newfoundland and Labrador (2020) contributing to the decrease of 5.8 Mt (29%) in Petroleum Refining Industries emissions.

The 4.3 Mt (10%) decrease in emissions in the Residential category between 2005 and 2022 is largely driven by energy efficiency improvements, with smaller decreases due to warmer weather and reduced consumption of light fuel oil.

7 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.

Transport (196 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 using more fuel and therefore generating greater emissions. Despite a reduction in kilometres driven per vehicle, the total vehicle fleet in 2022 had increased by 27% since 2005, most notably for trucks (both light- and heavy-duty), leading to more kilometres driven overall.

From 2005 to 2019, emissions from Transport have generally increased. From 2019 to 2020, the start of the COVID-19 pandemic, Transport emissions were down as travel from aircraft and light-duty on-road vehicles decreased. By 2021, Transport emissions were below 2005 levels. From 2021 to 2022, as travel demand began to return to pre-pandemic level, Transport emissions increased by 7.8 Mt, bringing them 5.6 Mt above 2005 levels.

Fugitive Sources (75 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 215,000 oil and gas wells have been drilled and the number of producing wells has increased by 5%. Crude oil and natural gas production has also increased by 43%, mostly due to Canada's Oil Sands. Even with the increased output and activity, Fugitive Sources emissions have decreased by 22 Mt (22%). This includes a 6% increase from 97 Mt in 2005 to a peak in 2014 of 103 Mt. Since 2014, emissions have decreased by 28 Mt (27%) 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).

Carbon Capture and Storage (0.64 kt)

Carbon capture involves the collection of anthropogenic CO_2 emissions from industrial processes or fuel combustion. 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 2016, and in 2022 approximately 1.1 Mt of captured CO_2 was placed in geological formations for LTS. EOR use began in 2000, and in 2022 about 3.3 Mt of captured CO_2 was injected to support EOR operations, of which approximately 1.6 Mt was imported from the United States. As of 2022, there has been a total of 7.2 Mt of captured CO_2 placed in LTS and 47.8 Mt injected for EOR.

Due to the large increase in activity associated with this category, fugitive emissions from CO_2 capture, transport, use and storage increased by 650%, from 0.09 kt in 2005 to 0.64 kt in 2022.

See Chapter 3, section 3.4, for more details on carbon capture and storage volumes and associated emissions.

Industrial Processes and Product Use – 2022 GHG Emissions (51 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 51 Mt (7.3%) to Canada's 2022 emissions.

Between 2005 and 2022, process emissions from most IPPU categories decreased. Metal Production emissions have decreased by 6.2 Mt (31%) since 2005.Emissions from the Iron and Steel Industry, decreased by 2.5 Mt (24%) during the period because of the closure of an iron and steel producing facility in 2013. The Aluminium Industry also saw a reduction in its process emissions by 2.6 Mt (32%) since 2005, largely due to the implementation of technological improvements to mitigate PFC emissions and the shutdown of older smelters using Søderberg technology, the last of which was closed in 2015. Finally, the closure of primary magnesium plants in 2007 and 2008 also accounted for 1.1 Mt (89%) of the overall process emission drop seen in Metal Production between 2005 and 2022.

The overall decrease of 4.2 Mt (42%) of GHG emissions from the Chemical Industry since 2005 is primarily the result of the 2009 closure of the sole Canadian adipic acid plant located in Ontario. In addition, emissions from Mineral Products decreased by 1.9 Mt (18%) from 2005 to 2022, largely due to decreased cement and lime production, with closures or indefinite idling of three cement facilities (2008, 2016, and 2018) and three lime facilities (2008, 2015, and 2016) occurring during this period.

A notable exception to the overall decrease in IPPU emissions is the 5.8 Mt (120%) increase in emissions from the use of HFCs to replace chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) since 2005. However, since 2018, HFC emissions have been decreasing, primarily due to a reduction in HFC imports, coinciding with the implementation of federal regulations gradually phasing down HFCs.[8]

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

Agriculture – 2022 GHG Emissions (56 Mt)

The Agriculture sector covers non-energy GHG emissions related to the production of crops and livestock. In 2022, emissions from Agriculture accounted for 56 Mt, or 7.9% of total GHG emissions for Canada, including 27% 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 79%, while major livestock populations peaked in 2005, then decreased sharply until 2011. As a result, emissions in 2022 are roughly equivalent to 2005, though the contribution of emissions from crop production has increased relative to the livestock sector. In 2022, emissions from livestock feed consumption and digestion (enteric fermentation) accounted for 48% of total agricultural emissions, and the application of inorganic nitrogen fertilizers accounted for 19% of total agricultural emissions. Emissions from the decomposition of soil organic carbon increased by 1.0 Mt (28%) from 2021 to 2022, as losses of carbon in soils occurred in 2022 as a result of the drought conditions on the Canadian prairies in 2021.

Waste – 2022 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 2022.

The primary sources of emissions in 2022 for the Waste sector are Solid Waste Disposal (Landfills) (19 Mt or 83% of total emissions from this sector), including municipal solid waste (MSW), and Wastewater Treatment and Discharge (2.5 Mt or 11%). Other sources include Industrial Wood Waste landfills (3.3%), Biological Treatment of Solid Waste (composting) (2.0%), and Incineration and Open Burning of Waste (0.7%). More generally, landfills (including MSW and industrial wood waste) accounted for most of Waste emissions (87%).

In 2022, emissions from MSW landfills (excluding Industrial Wood Waste Landfills) decreased by 3.6% between 2005 and 2022. Of the 34 Mt CO_2 eq of CH_4 generated by MSW landfills in 2022, 19 Mt CO_2 eq (58%) were emitted to the atmosphere, while 12 Mt CO_2 eq (36%) were captured by landfill gas collection facilities and flared or used for energy (compared to 29% in 2005). The remaining 2.2 Mt (6%) is assumed to be oxidized through landfill cover materials.

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 and Provincial 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. Industrial process emissions reported to the GHGRP are directly incorporated in the NIR's IPPU sector for cement, lime and aluminium production, as are volumes of CO_2 captured, transported, injected and stored in geological reservoirs. Emissions from waste incineration and industrial wastewater are also directly included in the NIR. Work is ongoing to integrate combustion emissions reported by facilities in the cement, iron and steel, pulp and paper manufacturing, electricity generation and petroleum refining sectors. Technical specifications of industrial fuel and raw material reported to the GHGRP are also used to verify and improve the quality of industrial process emissions. More information on the use of GHGRP data is provided in Chapter 1, Table 1–2.

The national energy balance compiled by Canada's statistics agency presents annual energy supply and demands by regions following North American 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 – 2022 (Net GHG Source of 51 Mt)

The LULUCF sector reports anthropogenic GHG fluxes between the atmosphere and Canada's managed lands, including those associated with land-use change and emissions from Harvested Wood Products (HWP), 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 2022, this net flux amounted to a net source of 51 Mt.

Net fluxes from the LULUCF sector over recent years have fluctuated between net emissions of 5.6 Mt and 70 Mt. Fluctuations are driven by the variability in crop yields and by variations in emissions from HWP and removals from Forest Land, which are closely tied to 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—from forest harvest—fluctuated from a net source of 80 Mt in 2005 to a net source of 20 Mt in 2022, as 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. Approximately 33% of HWP emissions in 2022 resulted from long-lived wood products reaching the end of their economic life decades after the wood was harvested while short-lived products made up 67%.

In most years, cropland contributed to net removals ranging from 4.2 Mt (1992) to 45 Mt (2014). Net emissions occurred due to drought in recent years, specifically 2002, 2003 and 2022 that result in low yields and consequently decomposition rates that are 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 including 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 2022 have fluctuated around 13 Mt.

Using Atmospheric 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 have been referred to as "top-down." 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).

Recent research has produced "top-down" estimates of methane (CH_4) emissions from the Canadian oil and gas industry (Atherton et al., 2017; Johnson et al., 2017; Zavala-Araiza et al., 2018; Chan et al., 2020; Mackay et al., 2021; Tyner and Johnson, 2021; Festa-Bianchet et al., 2023; Johnson et al., 2023; Conrad et al., 2023a, b). Results suggest that "bottom-up" inventory methods may underestimate some sources of fugitive methane emissions in oil and gas operations. Despite ongoing data and methodological improvements, this category remains a monitoring challenge with tens of thousands of facilities, hundreds of thousands of wells and millions of components with the potential to emit. Many of these recent studies highlight the significance of "super-emitters," a small number of facilities that contribute disproportionately to total emissions.

Resolving the discrepancies between "bottom-up" and "top-down" approaches to estimate fugitive methane emissions from oil and gas operations requires separating out the contribution of individual sources to total facility emissions; "top-down" approaches have advanced significantly, with the recent publication of source-resolved methane emission inventories based on atmospheric measurements for Canada's major oil and gas producing provinces (Johnson et al., 2023; Conrad et al., 2023a, b).

These atmospheric measurement-based inventories have been leveraged to improve the accuracy of methane emission estimates for the oil and gas sector in Canada. See Chapters 3 and 8 for discussion of recalculations and Annex 3.2 for more details on the improved methodology. ECCC continues to work with researchers to improve the integration of "bottom-up" inventory methods and atmospheric 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		2005	2017	2018	2019	2020	2021	2022
		Mt CO_2 eq						
TOTAL[a, b]		**761**	**742**	**753**	**752**	**686**	**698**	**708**
ENERGY		**626**	**613**	**622**	**622**	**558**	**569**	**577**
a.	**Stationary Combustion Sources**	**338**	**321**	**324**	**326**	**302**	**304**	**306**
	Public Electricity and Heat Production	124	79	71	69	62	61	56
	Petroleum Refining Industries	20	15	15	16	14	14	14
	Oil and Gas Extraction	63	101	107	108	104	108	109
	Mining	4.3	4.5	6.0	6.0	5.3	6.1	6.2
	Manufacturing Industries	48	43	43	43	39	40	41
	Construction	1.4	1.3	1.4	1.4	1.4	1.5	1.6
	Commercial and Institutional	32	36	37	38	35	33	35
	Residential	43	39	40	41	39	37	39
	Agriculture and Forestry	2.2	3.1	3.2	3.3	3.0	3.1	3.3
b.	**Transport**	**190**	**202**	**209**	**210**	**179**	**188**	**196**
	Aviation	7.7	7.9	8.7	8.6	4.7	5.6	7.7
	Road Transportation	122	129	132	132	111	116	120
	Railways	6.5	7.2	7.3	7.4	6.8	6.8	6.8
	Marine	4.0	3.5	3.5	4.3	3.8	4.4	5.0
	Other Transportation	50	55	58	58	52	55	56
c.	**Fugitive Sources**	**97**	**89**	**89**	**86**	**77**	**77**	**75**
	Coal Mining	1.6	1.4	1.5	1.6	1.3	1.4	1.5
	Oil and Natural Gas	95	88	88	85	75	76	74
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		**55**	**52**	**54**	**52**	**50**	**51**	**51**
a.	**Mineral Products**	**10**	**8.6**	**8.7**	**8.9**	**8.2**	**9.0**	**8.4**
b.	**Chemical Industry**	**10**	**6.3**	**6.4**	**6.2**	**5.9**	**5.7**	**5.8**
c.	**Metal Production**	**20**	**15**	**15**	**14**	**13**	**14**	**14**
d.	**Production and Consumption of Halocarbons, SF_6 and NF_3**	**4.8**	**11**	**12**	**11**	**11**	**11**	**11**
e.	**Non-Energy Products from Fuels and Solvent Use**	**10**	**11**	**11**	**11**	**10**	**11**	**12**
f.	**Other Product Manufacture and Use**	**0.51**	**0.58**	**0.65**	**0.62**	**0.66**	**0.66**	**0.65**
AGRICULTURE		**56**	**53**	**54**	**54**	**56**	**55**	**56**
a.	**Enteric Fermentation**	**35**	**27**	**27**	**27**	**27**	**27**	**27**
b.	**Manure Management**	**8.7**	**7.9**	**7.9**	**7.9**	**7.8**	**7.9**	**7.8**
c.	**Agricultural Soils**	**12**	**15**	**16**	**16**	**18**	**17**	**18**
d.	**Field Burning of Agricultural Residues**	**0.04**	**0.05**	**0.05**	**0.05**	**0.06**	**0.04**	**0.05**
e.	**Liming, Urea Application and Other Carbon-Containing Fertilizers**	**1.4**	**2.4**	**2.6**	**2.7**	**3.0**	**3.1**	**2.9**
WASTE		**24**	**24**	**23**	**24**	**23**	**23**	**23**
a.	**Solid Waste Disposal (Landfills)**	**20**	**20**	**19**	**20**	**19**	**19**	**19**
b.	**Biological Treatment of Solid Waste**	**0.24**	**0.34**	**0.38**	**0.38**	**0.39**	**0.48**	**0.47**
c.	**Wastewater Treatment and Discharge**	**2.2**	**2.5**	**2.6**	**2.5**	**2.5**	**2.5**	**2.5**
d.	**Incineration and Open Burning of Waste**	**0.34**	**0.18**	**0.17**	**0.17**	**0.15**	**0.14**	**0.16**
e.	**Industrial Wood Waste Landfills**	**1.1**	**0.86**	**0.84**	**0.82**	**0.80**	**0.78**	**0.76**
LAND USE, LAND-USE CHANGE AND FORESTRY		**66**	**19**	**23**	**14**	**26**	**14**	**51**
a.	**Forest Land**	**-64**	**-99**	**-99**	**-103**	**-101**	**-104**	**-108**
b.	**Cropland**	**-23**	**-24**	**-23**	**-19**	**-16**	**-19**	**22**
c.	**Grassland**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
d.	**Wetlands**	**3.1**	**3.1**	**2.8**	**3.1**	**3.5**	**3.2**	**3.3**
e.	**Settlements**	**1.8**	**2.4**	**2.3**	**2.2**	**2.3**	**2.2**	**2.2**
f.	**Harvested Wood Products**	**148**	**137**	**139**	**130**	**136**	**131**	**132**

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.

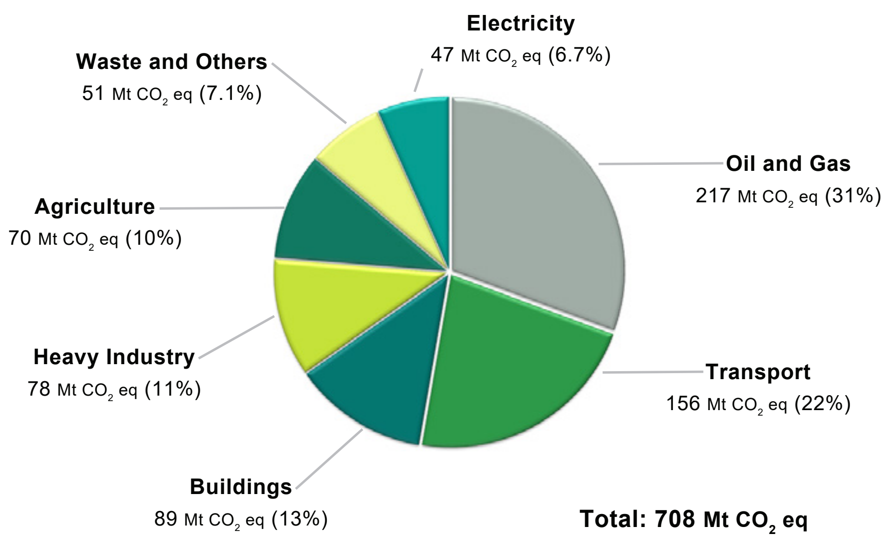
ES.5. Canadian Economic Sectors

For the purposes of analyzing economic trends and policies, and in addition to what is required by inventory reporting requirements, it is useful to allocate emissions 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 proportion of emissions from various IPCC subcategories. This reallocation simply re-categorizes emissions under different headings and does not change the overall magnitude of Canadian emissions estimates.

Overall, GHG emissions trends in Canada's economic sectors are consistent with those described for IPCC sectors. The Oil and Gas, Agriculture and Buildings economic sectors showed emission increases of 21 Mt (11%), 4.6 Mt (7.0%) and 3.9 Mt (4.5%), respectively, since 2005 (Figure ES–6 and Table ES–2). These increases have been more than offset by emission decreases in Electricity (-69 Mt or -59%), Heavy Industry (-10 Mt or -11%), and Waste and others (-4.3 Mt or -7.8%). Since 2005, Transport emissions have generally increased, with an important drop in 2020. Emissions in 2022 from the Transport economic sector are now similar to 2005 levels.

Further information on economic sector trends can be found in Chapter 2. Additional information on the IPCC and economic sector definitions, as well as a detailed crosswalk table between both, can be found in Part 3 of this report.

Figure ES–6 **Breakdown of Canada's GHG Emissions by Economic Sector (2022)**



Note: Totals may not add up due to rounding.

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

	2005	2017	2018	2019	2020	2021	2022
	Mt CO_2 eq						
NATIONAL GHG TOTAL	**761**	**742**	**753**	**752**	**686**	**698**	**708**
Oil and Gas	195	221	228	226	209	216	217
Electricity	117	72	62	61	53	51	47
Transport	156	165	169	170	143	150	156
Heavy Industry	88	77	80	79	74	78	78
Buildings	85	88	92	94	89	85	89
Agriculture	66	67	69	69	70	69	70
Waste and Others	55	51	52	52	48	49	51

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

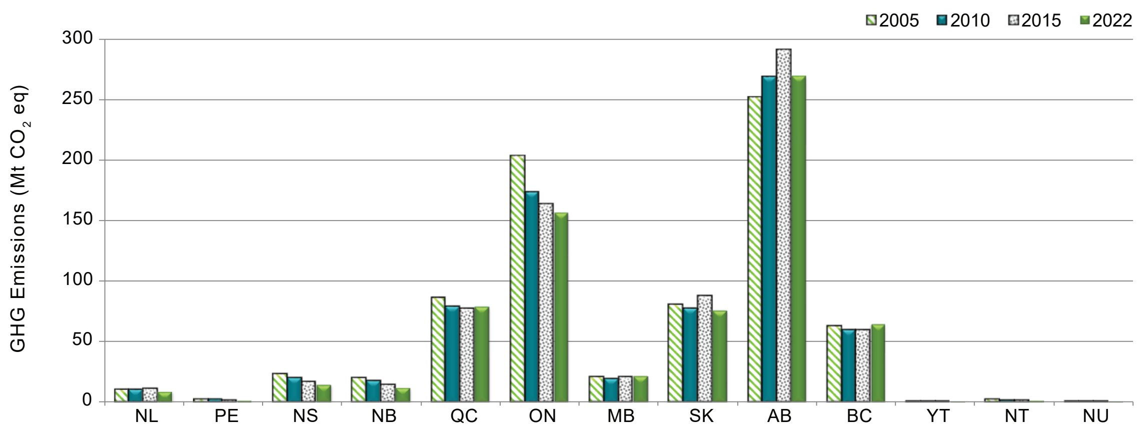
ES.6. Provincial and Territorial GHG Emissions

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.

Historically, Alberta and Ontario have been the highest-emitting provinces. Since 2005, emission patterns in these two provinces have diverged. Those in Alberta have increased by 19 Mt (7.5%) since 2005, primarily because of the expansion of oil and gas operations (Figure ES–7). In contrast, Ontario's emissions have decreased by 46 Mt (23%) since 2005, owing primarily to the closure of the last coal-fired electricity generation plants in 2014.

In most of the other sub-national jurisdictions, emissions have decreased between 2005 and 2022, including in Nova Scotia (-8.0 Mt or -35%), New Brunswick (-7.6 Mt or -38%), Quebec (-6.5 Mt or -7.6%), Saskatchewan (-4.6 Mt or -5.8%), Newfoundland and Labrador (-1.7 Mt or -16%), British Columbia (-1.6 Mt or -2.5%), the Northwest Territories (-0.37 Mt or -22%), and Prince Edward Island (-0.28 Mt or -15%). Emissions have increased in Manitoba (0.99 Mt or 4.8%), Yukon (0.10 Mt or 18%) and Nunavut (0.03 Mt or 5.4%).

Figure ES–7 **GHG Emissions by Province and Territory in 2005, 2010, 2015 and 2022**



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. 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 1990–2022 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. Stationary Fuel Combustion – Manufacturing Industries and Construction, CO_2
2. Fuel Combustion – Road Transportation, CO_2
3. Stationary Fuel Combustion – Energy Industries, CO_2

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

1. LULUCF – Forest Land Remaining Forest Land, CO_2
2. LULUCF – Cropland Remaining Cropland, CO_2
3. Stationary Fuel Combustion – Manufacturing Industries and Construction, 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, correction of errors, updates to activity data, inclusion of categories previously not estimated or compliance with recommendations arising from reviews conducted under the UNFCCC.

ECCC continuously consults and works with scientists and 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 2024 edition of the GHG inventory incorporates significant methodological improvements in the estimation of upstream oil and gas emissions (+17 Mt in 2021), among others. Additionally, important changes were made to the managed forest land estimates, including new and updated data on historical harvest areas that impacted both the level of and the trend in emissions and removals from the land sector (+28 Mt in 2021). Overall, the recalculations resulted in +29 Mt in 2005 and +28 Mt in 2021, including the impact of the implementation of the IPCC's AR5 GWP values. 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 and the implementation of the new GWP values on the overall emission trends.

Improvements to inventory estimates are anticipated in future editions of this report. For example, and amongst several planned improvements, in the Energy sector for Transport, some revisions to the on-road activity data (e.g., vehicle population data) and the migration to the United States Environmental Protection Agency's (U.S. EPA) MOtor Vehicle Emission Simulator 4 (MOVES4) model are planned. Also in the Energy sector, work is underway to incorporate fugitive emission estimates for natural gas transmission, distribution and storage for the years 2016-2022. In the IPPU sector, the methanol production emission factor will be updated. Refer to Chapter 8 for details on these planned improvements and for a complete list covering all sectors.

Furthermore, land use and land use change categories will be updated and additional land use change categories will be included in LULUCF reporting. For additional detail on LULUCF planned improvements, 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 institutional arrangements for the preparation of the inventory include formal agreements on data collection and estimate development; a quality management plan, including an improvement plan; the identification of key categories and generation of quantitative uncertainty analysis; a process for performing recalculations following improvements; procedures for official approval; and a working archive system to facilitate third-party review.

Submission of information regarding the national inventory arrangements, including details on institutional arrangements for inventory preparation, is also an annual requirement under the MPGs (Chapter 1).

Structure of Submission

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

Part 1 of the NIR includes Chapters 1 to 8:

- Chapter 1 (National circumstances, institutional arrangements, and cross-cutting information) provides an overview of Canada's legal, institutional and procedural arrangements for producing the inventory, quality assurance and quality control procedures, and a description of Canada's GHGRP and how the facility-reported data are integrated in the inventory.
- Chapter 2 provides an analysis of Canada's GHG emission trends in accordance with the MPGs structure and a breakdown of emission trends by Canadian economic sectors.
- Chapters 3 to 7 provide descriptions and additional analysis for each sector, according to MPGs requirements.
- Chapter 8 presents a summary of the updated GWPs for the 2024 edition, recalculations and implemented and planned improvements.

Part 2 consists of Annexes 1 to 7, which provide a key category analysis, inventory uncertainty assessment, detailed explanations of estimation methodologies, Canada's energy balance, completeness assessments, emission factors and information on ozone and aerosol precursors. This material is available on the Government of Canada's Open Data website at open.canada.ca in various formats.

Part 3 comprises Annexes 8 to 13, which present rounding procedures, summary tables of GHG emissions at the national level and for each provincial and territorial jurisdiction, sector and gas, as well as additional details on the GHG intensity of electricity generation. Detailed GHG data are also available at open.canada.ca. The complete NIR, in PDF format, can be accessed on the Government of Canada's publications website.

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CHAPTER 1

NATIONAL CIRCUMSTANCES, INSTITUTIONAL ARRANGEMENTS, AND CROSS-CUTTING INFORMATION

1.1. Greenhouse Gas Inventories and Climate Change

Climate change is one of the defining challenges of the 21st century. It is a global problem, and tackling it requires global action. Comprehensive assessment reports prepared by the Intergovernmental Panel on Climate Change (IPCC) have concluded that human activities have unequivocally caused global warming, with global surface temperatures reaching 1.1ºC above 1850–1900 period in 2011–2020 (IPCC, 2023). Governments around the world have committed to work together to limit global warming, recognizing that climate-related risks grow with the magnitude of warming and associated changes in climate.

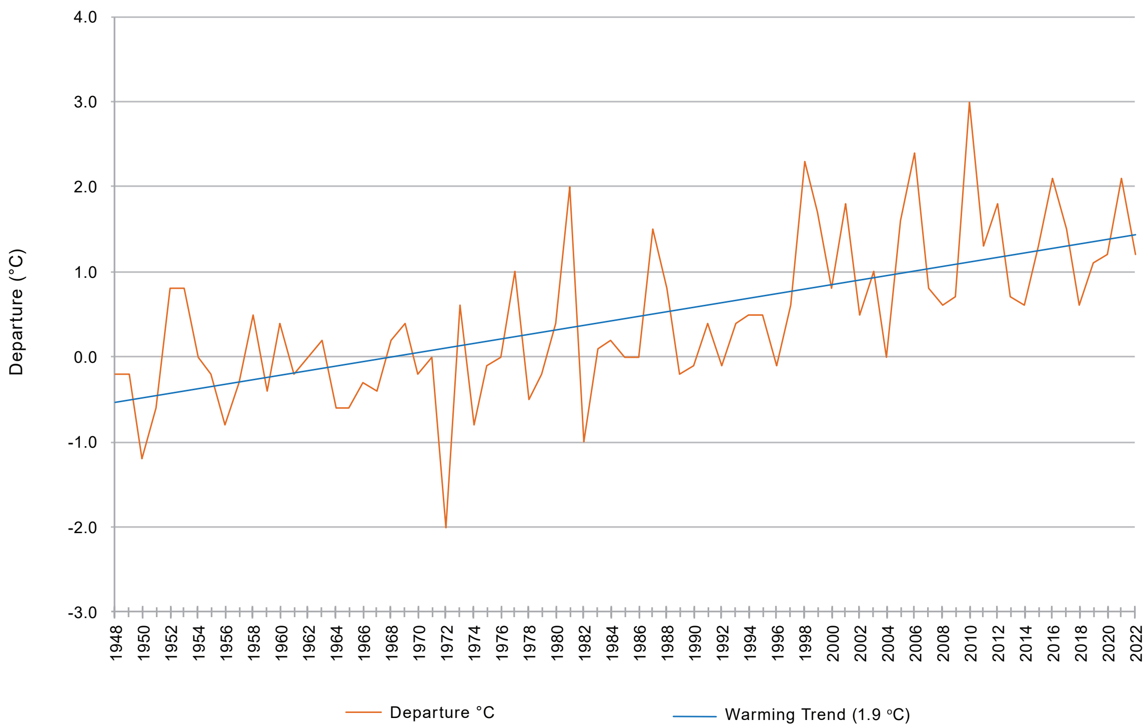
Climate change has caused widespread and rapid changes resulting in impacts on human and natural systems. It has caused substantial damages and increasingly irreversible losses to ecosystems (IPCC, 2023). Atmospheric concentrations of GHGs have increased significantly since pre-industrial times across the globe. Since 1750, the concentration of atmospheric carbon dioxide (CO_2) has increased by 150%; methane (CH_4), by 264%; and nitrous oxide (N_2O), by 124% (WMO, 2023). Observed increases in well-mixed GHG concentrations since around 1750 are unequivocally caused by GHG emissions from human activities over this period (IPCC, 2023).

In Canada, the impacts of climate change may be observed in the increase in extreme weather events, reduction in freshwater resources, increase in the risk and severity of forest fires and pest infestations, reduction in Arctic ice, and acceleration of glacial melting. Canada's national average temperature for 2022 was 1.2°C above the baseline average (defined as the mean over the 1961–1990 reference period) (see Figure 1–1). Average annual temperatures have remained above the baseline average since 2005, with a warming trend of 1.9°C over the past 74 years (ECCC, 2023a). Canada's climate is and will continue to warm rapidly, at a rate that is already two times faster than the global average and three times faster in the North. Emissions must be reduced to limit the extent of climate change and avoid ecological and socio-economic tipping points, understanding that climate change impacts will continue even after global net-zero emission are achieved (ECCC, 2023b).

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.

Figure 1–1 **Annual Canadian Temperature Departures and Long-Term Trend, 1948–2022**



Note:
Source: ECCC (2023a)

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 parties to gather and share information on GHG emissions, national policies, best practices and progress toward their emissions targets among other items. Precisely, it also commits all Parties 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 GHGs. 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 general outline of the National Inventory Report (NIR) was also established in Decision 5/CMA.3 in 2021.

This edition of the NIR documents Canada's annual GHG emissions estimates for the 1990−2022 period. Canada's 2024 submission comprises the NIR and data reporting tables, submitted to the UNFCCC and under the Paris Agreement based on international agreed upon requirements and formats.[2] This edition is the first to be submitted under the Paris Agreement. 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 submitted under the Convention.

Canada's annual submission includes the NIR and data tables in a common reporting format. Exceptionally, for the first year under the Paris Agreement, Common Reporting Tables (CRTs) will be submitted by the end of 2024, or once the UNFCCC submission system is ready.[3] Complimentary to the 2024 NIR submission, Canada also plans to submit the Common Reporting Format (CRF) tables as in previous years, to facilitate data access for users.

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

2 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., reporting structure): https://unfccc.int/sites/default/files/resource/CMA2021_L10a2E.pdf

3 The Common Reporting Tables (CRTs) are still under software development by the UNFCCC Secretariat and are expected to be released in June 2024 with a submission deadline of December 31, 2024. If the CRTs are not ready by June 2024, there may be a corresponding delay that would enable Parties to submit at a later date.

1.1.2. Global Warming Potentials

Each type of GHG has a unique atmospheric lifetime and heat-trapping potential. The radiative forcing[4] 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 time 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 Intergovernmental Panel on Climate Change (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), in the 2024 edition of the NIR, the GWP values used have been updated to the ones provided in the IPCC Fifth Assessment Report (AR5) (IPCC, 2014). Consistent with Decision 5/CMA.3 paragraph 25, the 100-year GWP values provided by the IPCC in its AR5 (IPCC, 2013, Table 8.A.1 and excluding fossil methane) are used in this report (Table 1–1). Previous editions of this report used IPCC Fourth Assessment Report (AR4) GWP values (IPCC, 2007). For more information on recalculations and the impact of the GWP value changes, refer to Chapter 8.

1.2. Canada's National Inventory Arrangements and Focal Point

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. These arrangements, including formal agreements with contributors and descriptions of the latter's roles and responsibilities in the preparation and submission of the national GHG inventory, are fully documented in Canada's inventory archives.

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 inventory preparation process used by PIRD is provided in section 1.2.2.

4 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).

1

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	$c\text{-}C_4F_8$	9 540	3 200
PFC-41-12	$n\text{-}C_5F_{12}$	8 550	4 100
PFC-51-14	$n\text{-}C_6F_{14}$	7 910	3 100
PFC-91-18	$C_{10}F_{18}$	7 190	2 000
PFC-c216	$c\text{-}C_3F_6$	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 stratospheric water vapour.
c. Fossil methane has been excluded as agreed upon per UNFCCC Decision 5/CMA.3.

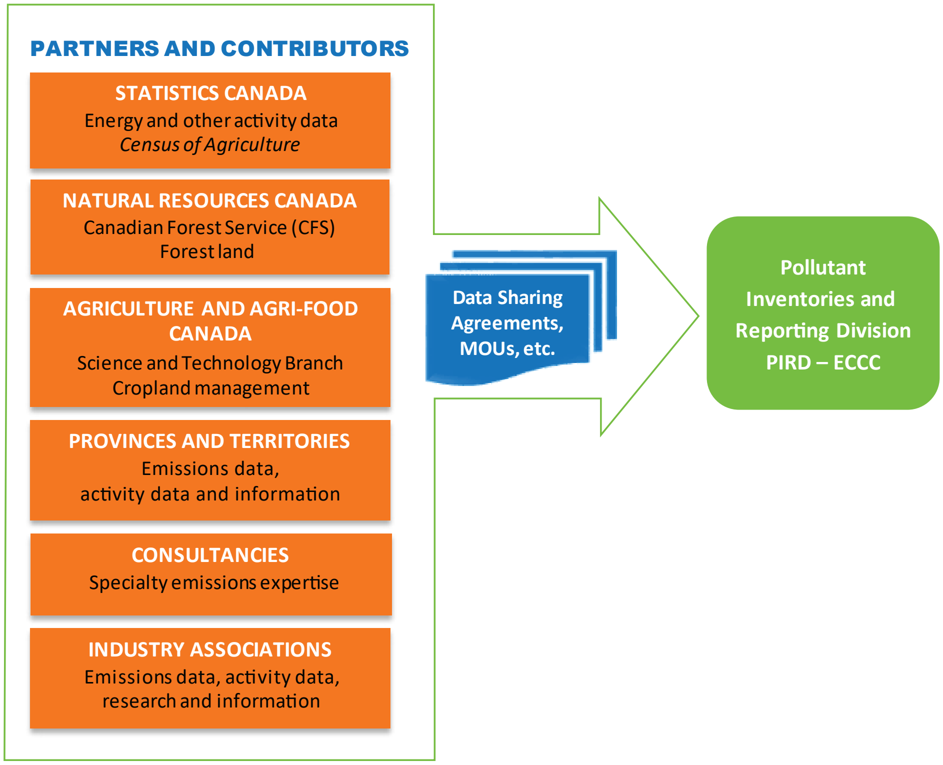
1.2.1. Institutional Arrangements

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 identifies the various partners in and contributors to Canada's national inventory and their contribution to its development.

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.

1.2.1.1. 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, No date). The energy balance utilises a number of Statistics Canada surveys, including, among others, 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 Annexes 3 and 4 of this report for additional information on the use of the energy balance in the development of energy estimates.

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

1.2.1.2. Natural Resources Canada and Agriculture and Agri-Food Canada: Canada's Monitoring System for the Land Use, Land-Use Change and Forestry Sector

ECCC has officially assigned responsibilities to Agriculture and Agri-Food Canada (AAFC) and the Canadian Forest Service of Natural Resources Canada (NRCan/CFS) for the development of key components of the Land Use, Land-Use Change and Forestry (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.

1.2.1.3. Other Agreements and Data Sources

NRCan, in addition to supporting Canada's LULUCF estimates (see section 1.2.1.2), provides energy expertise and analyses, serves as expert reviewer for the Energy sector, and collects and provides activity data on mineral production, ethanol consumption and wood residues. 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 Offshore Petroleum Board.

Under its Greenhouse Gas Reporting Program (GHGRP), 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 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 1.3.4.1.

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.

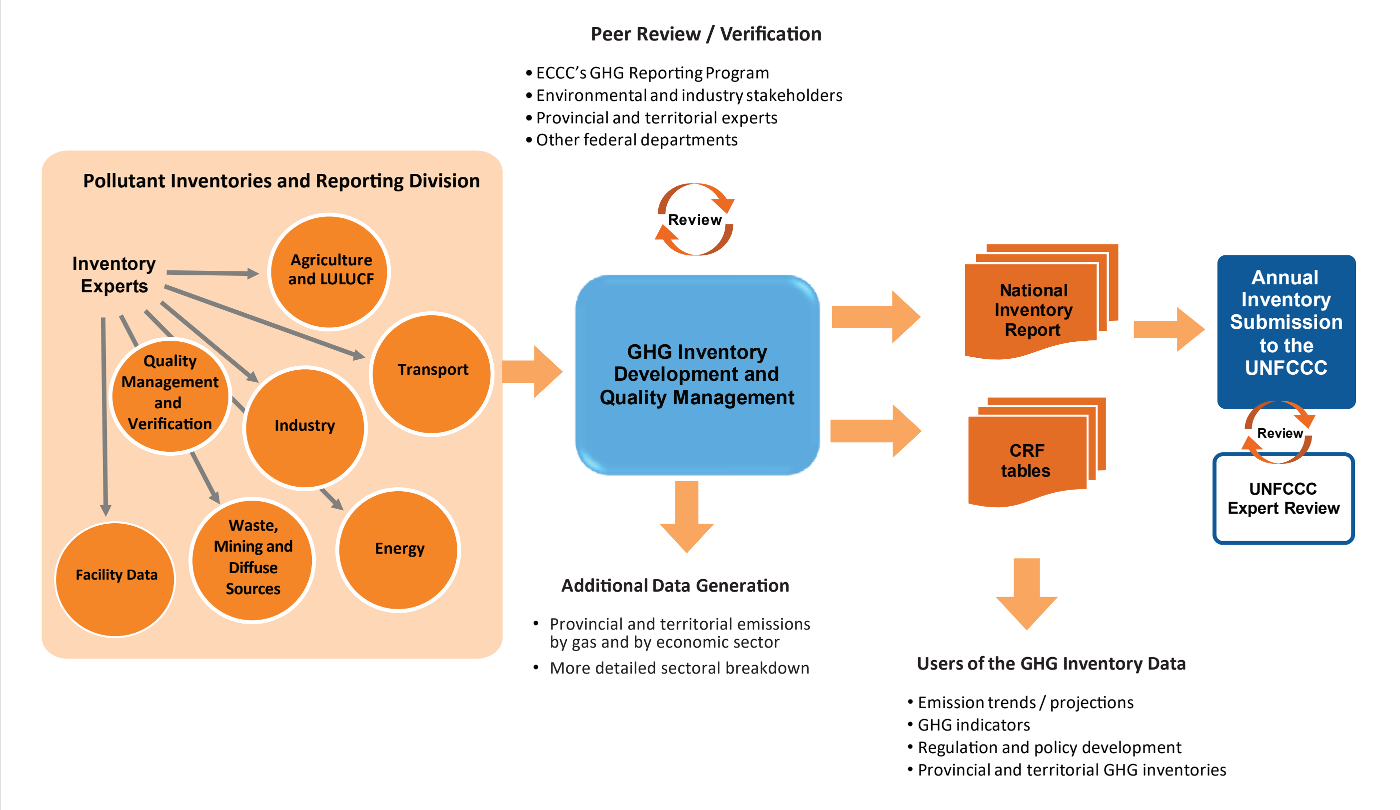
1.2.2. Inventory Preparation Process

Canada's inventory is developed, compiled and published annually by ECCC's Science and Technology Branch, with input from numerous experts and scientists across Canada. Figure 1–3 identifies the various stages of the inventory preparation process.

The inventory is built on a continuous process of methodological improvements, refinements and reviews, in accordance with quality management and improvement planning. Inventory development is based on an annual schedule, which may be adjusted each year based on the results of the lessons-learned review of the previous inventory cycle, QA/QC follow-up, the UNFCCC review report, data collection context, and collaboration with provincial and territorial governments. This process involves ongoing collaboration and consultation with other inventory experts (see Figure 1–3).

Inventory development generally starts in January, when inventory experts plan their work on the data sources, methodologies and EFs that will be reviewed, developed and/or refined during the next cycle, based on the outcomes of the previously mentioned steps. QA reviews of methodologies and EFs typically target the categories scheduled for such a review or in which a change in methodologies or emission factors is proposed. Then, from April to October, the collection of the required data begins and roles and responsibilities are formalized. Methodologies are finalized by the end of September and the data collection process is completed by mid-November. The data used to compile the national inventory are generally taken from published sources, but some require confidentiality. Data are collected from the source agencies, controlled for quality, and entered in emission quantification tools, including spreadsheets, databases and other types of models. In November and December, draft estimates are developed by designated inventory experts and internally reviewed. In the following few months, the NIR text and CRF tables are prepared by inventory experts, according to MPGs. QC checks and estimates are performed before the report and emission estimates are published. The inventory process also includes key category and completeness assessments, recalculations, and uncertainty calculations, all of which are completed before March, along with the accompanying documentation.

Figure 1–3 **Inventory Preparation Process**



Between January and March, the compiled inventory is reviewed internally and then components of it are reviewed externally by experts, government agencies and provincial and territorial governments, after which the NIR is finalized. Comments from reviewers are documented and, where appropriate, incorporated in the NIR and the CRF tables, which are submitted to the UNFCCC electronically annually. Simultaneously, the NIR is also translated in French and made available at the same time. Canada maintains an electronic archive and reference library for these documents.

1.2.3. Procedures for the Official Consideration and Approval of the Inventory

The consideration and approval process involves briefing senior officials from various departments several times before the report is sent to the Minister of Environment and Climate Change. Once the report has been reviewed and/or approved, the National Inventory Focal Point prepares a letter of submission to accompany the NIR and CRF tables, which are then submitted electronically to the UNFCCC.

1.2.4. Treatment of Confidentiality Issues

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.

1.3. 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, to continuously improve data and methods to ensure that a credible and defensible inventory is developed.

1.3.1. 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; information creation, documentation and archiving processes; a standardized process for implementing methodological changes; identification of key roles and responsibilities; and a timeline for completing the various NIR-related tasks and activities. Further details on QA/QC activities are available in chapters 3 to 7.

1.3.2. 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 category and submission year.

1.3.2.1. Quality Control Procedures

Quality control procedures consist of routine technical checks to measure and control the quality of the inventory; ensure data consistency, integrity, correctness and completeness; and 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 CRF online tool by the national inventory compiler and reviewer, and the tables are reviewed by the sector experts, for the entire time series of CRF tables. 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, checklists have been developed to standardize and document the QC procedures. The QC checklists include a record of any corrective action taken and refer to supporting documentation.

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.

1.3.2.2. 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.

1.3.3. 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, expert review teams (ERTs) 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 ERTs, 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 the QA/QC and verification activities (as outlined in the QA/QC Plan), key category and uncertainty analyses, resource availability and assessment of potential impacts. Additional information on inventory improvements can be found in Chapter 8.

1.3.4. Verification

In accordance with the 2006 IPCC Guidelines[5] (IPCC, 2006), inventory verification activities typically consists 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. Details on verification activities are available in chapters 3 to 7.

1.3.4.1. 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 annually in the *Canada Gazette*.[6] 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.

In December 2016, the Government of Canada published a Notice of Intent to inform stakeholders of its aim to expand the GHGRP, and specific requirements were expanded progressively over two phases during 2017 and 2018. It is pursuing this expansion in order to enable the direct use of the reported data in the national GHG inventory, increasing the consistency and comparability of GHG data across jurisdictions, and obtaining a more comprehensive picture of Canadian facility-level emissions. Starting in 2017, the existing reporting threshold was lowered (from 50 kt to 10 kt CO_2eq.), thereby requiring all facilities with annual GHG emissions exceeding 10 kt CO_2eq. to report their emissions to the program. Facilities in 13 industry sectors were also required to use prescribed methods outlined in the Canada's Greenhouse Gas Quantification Requirements manual (ECCC, 2023c) to quantify their emissions and to provide additional information on their calculations. These industry sectors were: cement, lime, aluminium, iron and steel manufacturing; producers of ethanol, ammonia, nitric acid and hydrogen; electricity and heat generation plants; mining operations, petroleum refineries, pulp and paper production, and base metal production facilities. Facilities involved in CO_2 capture, transport, injection and geological storage activities were also required to report on these activities and adhere to the prescribed methods, starting in 2017. 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.

Starting in 2022, key program changes were introduced for the reporting of 2022 and 2023 emissions. 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 introduced. To date, facility-reported GHG

5 2006 IPCC Guidelines, Volume 1, Chapter 6.10: Verification.

6 The notice published in the *Canada Gazette* requiring the reporting of 2022 and 2023 emissions information can be found at: https://canadagazette.gc.ca/rp-pr/p1/2023/2023-01-28/html/sup1-eng.html.

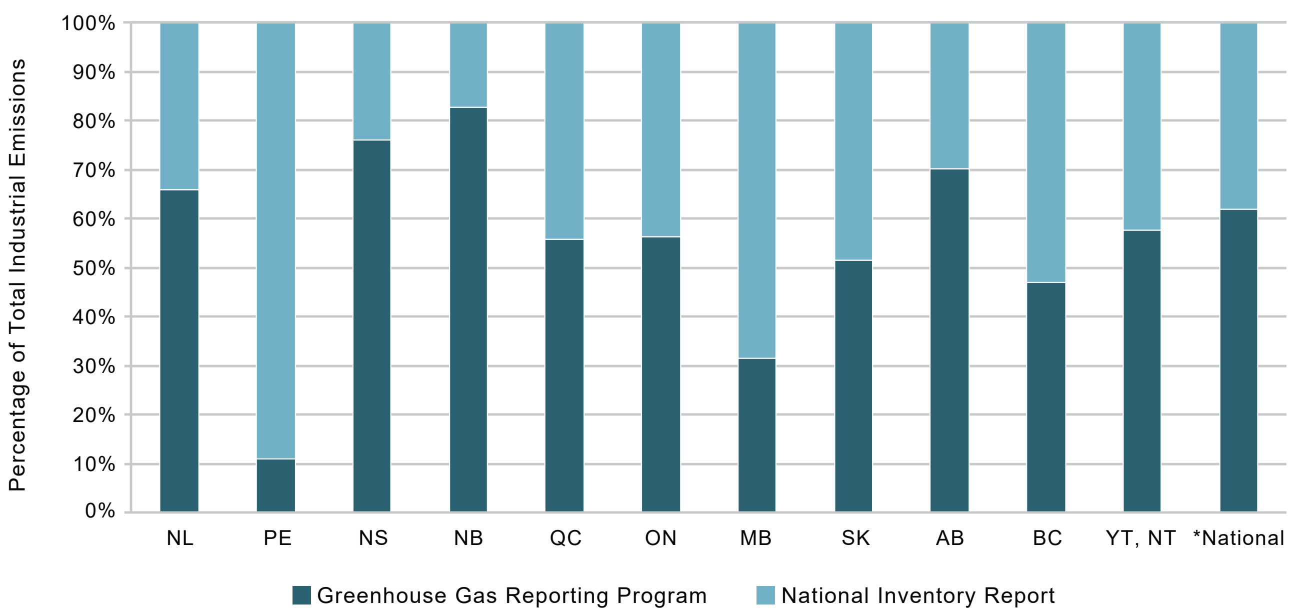
information has been collected and published by the GHGRP for the period 2004 to 2022. In 2022, a total of 1814 facilities (mostly industrial) reported their GHG emissions to the program. The GHGRP website[7] provides public access to this GHG emission information (e.g., emission totals by gas by facility).

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 2022, total facility-reported GHG emissions represented 41% of Canada's total GHG emissions (708 Mt) and 62% 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 industrial facilities in each province that have emissions above the 10 kt reporting threshold (Figure 1–4).

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 IPCC guidelines, FRD—which include all required data and supporting information reported by those facilities subject to the expanded reporting requirements (see Schedule 3)[8]—are used by inventory experts for improvements (e.g., to transparency, accuracy, comparability, consistency, or completeness) when these data are assessed to be of good quality (see Table 1–2). Based on the information provided in Table 1–2, it is estimated that approximately 20% 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 is utilized for various activities such as quality control and analysis.

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. Continuous improvements are underway, including examining approaches for integrating FRD in the inventory and addressing time-series consistency and completeness issues, taking into account 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.

Figure 1–4 **2022 Facility-Reported Emissions as a Percentage of Industrial Greenhouse Gas Emissions by Province and Territory**



Notes:

Canada's industrial GHG emissions include the following GHG categories from the *National Inventory Report, Greenhouse Gas Sources and Sinks in Canada 1990–2022*: Stationary Combustion Sources (except Residential), Other Transportation, Fugitive Sources, Industrial Processes and Product Use, and Waste.

* Nunavut is not included due to the lack of data.

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

8 The notice that required the reporting of 2022 and 2023 emissions information can be found at : https://canadagazette.gc.ca/rp-pr/p1/2023/2023-01-28/html/sup1-eng.html.

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 expert review team's recommendations from the 2021 review 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 (vol. 1, chapter 5) was applied. More details are provided in the corresponding sections in chapters 3 (Energy), 4 (IPPU) and 7 (Waste). Since FRD cover a significant part of industrial emissions in some provinces and territories (Figure 1–4), 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 further NIR integration in the coming years.

Table 1–2 **Use of Facility-Reported Data Collected Under the GHGRP in the National Inventory Report by Corresponding IPCC Sector and CRF Category**

IPCC Sector and CRF 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	• Chapter 3, section 3.4 • CRF 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	• Chapter 3, section 3.2 • Annex 10
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	• Chapter 3, section 3.4 • CRF Table 1.B.2
1.C.1 Transport of CO_2	Amount of captured CO_2 transported by pipelines	Input data for calculated values	• Chapter 3, section 3.4 • CRF Table 1.C
1.C.2 CO_2 injection and storage	Amount of captured CO_2 injected or stored	Input data for calculated values	• Chapter 3, section 3.4 • CRF 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	Chapter 4, section 4.2
2.A.2 Lime production	• CO_2 emissions • Lime production, CaO content of lime • By-product and waste quantities, CaO contents of by-product and waste	• Direct reporting • Input data for emission estimates • Quality control	Chapter 4, section 4.3
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	Chapter 4, section 4.4
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	Chapter 4, section 4.5
2.B.2 Nitric acid production	• Nitric acid production • N_2O emission factors • N_2O emissions	• Input data for emission estimates • Quality control	Chapter 4, section 4.6
2.C.1 Iron and steel production	• Iron and steel 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	Chapter 4, section 4.10
2.C.3 Aluminium production	• Aluminium production • CO_2, CF_4, C_2F_6 and SF_6 emissions	Direct reporting	Chapter 4, section 4.11
Waste			
5.C.1 Waste incineration	GHG emissions	Direct reporting	• Chapter 7, section 7.5 • Annex 3, section 3.6.3
5.D Wastewater treatment	GHG emissions	Direct reporting of industrial wastewater emissions	• Chapter 7, section 7.6 • Annex 3, section 3.6.4

For more information on the facility-level data reported under Canada's GHGRP, including short- and long-term changes observed in facility-reported emissions, see *Facility Greenhouse Gas Reporting Program: Overview of 2022 Reported Emissions* (ECCC, 2024).

1

1.4. Annual Inventory Review

From 2003 to 2016, Canada's national GHG inventory has been examined annually and since 2017, every 2 years by independent expert review teams in accordance with the *Guidelines for the technical review of information reported under the Convention related to greenhouse gas inventories, biennial reports and national communications by Parties included in Annex I to the Convention.* The review process plays a key role in ensuring that inventory quality is improved over time, and that the Parties to the Convention comply with the agreed-upon reporting requirements. The completeness, accuracy, transparency, comparability and consistency of inventory estimates can also be attributed to this well-established process. Once finalized, inventory review reports are posted online by the UNFCCC Secretariat.[9]

1.5. Methodologies and Data Sources

The inventory is structured to match the reporting requirements of the MPGs as defined by the Paris Agreement and is divided into the following five main sectors—Energy, IPPU, Agriculture, LULUCF, and Waste—each of which is further subdivided into subsectors or categories.

The methodologies described in the 2006 IPCC Guidelines (IPCC, 2006) are used to estimate the emissions and removals of each of the following direct GHGs: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3. In some cases, but not mandatory in the reporting requirements, the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019) are also used to further improve methodologies and increase accuracy.

While not mandatory, the MPGs encourage Parties to provide information on the following indirect GHGs: SO_x, NO_x, CO and NMVOCs (see Annex 7: Ozone and Aerosol Precursors). For all sectors except LULUCF, these gases are inventoried and reported separately to the United Nations Economic Commission for Europe.[10]

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. 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.

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.

Manipulated biological systems, such as agricultural lands, forestry, and land converted to other uses, are sources or sinks diffused over large areas. Processes that cause emissions and removals display considerable spatial and interannual variability, and they also span several years or decades. The most practical approach to estimating emissions from and removals by these systems requires a combination of repeated measurements and modelling. The need to separate anthropogenic impacts from large natural fluxes, which is unique to these systems, creates an additional challenge.

The methodologies (Annex 3) and emission factors (Annex 6) described in this document 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 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 refining and increasing 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, planned and implemented improvements, see Chapter 8.

9 Canada's last Annual Inventory Review Report is available online at: https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports-2023.

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

1.6. Inventory Uncertainty

While national GHG inventories should be accurate, complete, comparable, transparent and consistent, estimates will always inherently involve some uncertainty. Uncertainties[11] 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 both the base year and the latest year (2021). While more complex methods (Approach 2) were used in some cases to develop uncertainty estimates at the sectoral 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 chapters 3 to 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 2022. The five emissions source categories that contribute the most to uncertainty at the national level, for 2022, when LULUCF is not included are:

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. Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries, CH_4
5. Agriculture – Indirect Agriculture Soils, N_2O

When the LULUCF emissions and removals are included, the uncertainty in the national total was found to be ±8% for 2022 and ±11% for the base year. For 2022, 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. LULUCF – Harvested Wood Products, CO_2
3. Agriculture – Enteric Fermentation, CH_4
4. Agriculture – Direct Agriculture Soils, N_2O
5. Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries, CH_4

1.7. Completeness Assessment

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

- categories that are not occurring in Canada
- data unavailability at the category level
- methodological issues specific to national circumstances
- emission estimates that are considered insignificant[12]

As part of the inventory improvement process, 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 can be found in Annex 5 and in the individual sector chapters (chapters 3 to 7).

11 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).

12 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 reporting requirements: MPGs, Decision CMA.1 of FCCC/Cp/2018/L.13).

CHAPTER 2

GREENHOUSE GAS EMISSIONS TRENDS

2.1. Summary of GHG Emissions Trends

In 2022, the most recent year for which data are available for this report, Canada's greenhouse gas (GHG) emissions were 708 megatonnes of carbon dioxide equivalent (Mt CO_2 eq).[1] This represents a decrease of 54 Mt or 7.1% from 2005 emissions and an increase of 21 Mt (3.1%) from 2020; in addition, emissions remained 44 Mt (5.9%) below pre-pandemic 2019 emission levels (Figure 2–1).[2] In terms of the overall trend since 1990, annual emissions steadily increased for 10 years, fluctuated between 2000 and 2008, dropped in 2009, gradually increased until 2019, dropped significantly between 2019 and 2020, and increased slightly between 2020 and 2022. Emission trends and drivers since 1990 and 2005 are discussed in this chapter, while sub-sector specific information is presented in each sectoral chapter (3 to 7).

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 66 Mt (8.7%) in total GHG emissions between 2019 and 2020. These changes occurred in numerous subsectors between 2019 and 2020, most notably in Transport (-31 Mt or -15%), Stationary Combustion Sources (-23 Mt or -7.2%) and Fugitive Sources (-9.4 Mt or -11%). The year after, between 2020 and 2021, emissions increased slightly by 12 Mt (1.8%). Finally, in the latest year, between 2021 and 2022, they continued to increase by 9.3 Mt (1.3%), while remaining below their 2019 pre-pandemic levels.

Some emission sources contributed significantly to these recent emission changes. Specifically, Transport emissions are down by 14 Mt (6.7%) between 2019 and 2022 as travel demand decreased because of the pandemic and has yet to return to pre-pandemic levels. Within the Transport subsector, between 2019 and 2020, the first year of the pandemic, these emissions included a decrease in Light-Duty Gasoline Vehicles and Trucks (-15 Mt or -17%) and Domestic Aviation (-3.8 Mt or -45%). Between 2020 and 2022, Road Transportation (9.3 Mt or 8.4%) was responsible for most of the emissions increase in Transport (17 Mt or 9.7%) as vehicle travel continued to return to pre-pandemic levels.

For Fuel Combustion Sources (excluding Transport), emissions are down by 23 Mt (6.1%) between 2019 and 2022. Between 2019 and 2020, decreases in Public Electricity and Heat Production (-7.6 Mt or -11%) were due to reduced coal consumption partially offset by an increase in natural gas consumption. Plant closures during the pandemic can partially explain decreases in Manufacturing Industries (-3.8 Mt or -8.7%). Between 2020 and 2021, the second year of the pandemic, combustion emissions from Oil and Gas Extraction increased by 3.7 Mt (3.6%), consistent with a rise in crude bitumen (13%), synthetic crude oil (6%) from oil sands and natural gas (4%) production. Contributing to the 2021-2022 overall increase, Commercial and Institutional, and Residential combustion emissions increased by 3.8 Mt (5.3%), consistent with a 6% increase in heating degree days, indicating a colder winter and therefore longer heating season in 2022. In contrast, Public Electricity and Heat Production decreased by 4.3 Mt (7.0%) during the same period, due to further reductions in coal consumption.

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

2 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.

For Fugitive Sources, emissions decreased by 11 Mt (13%) between 2019 and 2022. In the first year, emission decreases between 2019 and 2020 included venting (-9.0 Mt or -15%), and leaks from oil (-0.4 Mt or -4.5%) and natural gas production and processing facilities (-0.4 Mt or -3.6%). In the latest year, Fugitive Sources from oil and natural gas systems continued to decrease by 2.1 Mt (2.8%) between 2021 and 2022, mainly due to decreased venting in Alberta and Saskatchewan.

Between 2019 and 2022, IPPU sector emissions are down by 1.0 Mt (1.9%). Temporary plant shutdowns during the first pandemic year can partially explain the decrease between 2019 and 2020 in this sector (-2.6 Mt or -5.0%). Between 2020 and 2022, the IPPU sector emissions increased by 1.6 Mt (3.3%) overall, most notably, from the use of fuels for non-energy purposes (1.8 Mt or 18%), which is consistent with the increase in fuel quantities reported to Statistics Canada for this use.

Finally, Agriculture emissions increased by 1.6 Mt between 2019 and 2022 (3.0%), mainly due to emissions of nitrous oxide associated with the loss of soil organic carbon following a drought on the prairies in 2021, as well as increased inorganic nitrogen fertilizer use.

Notwithstanding the 2019–2020 abrupt decrease 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, by 42% since 1990 and by 30% since 2005 (Figure 2–2 and Table 2–1). While the COVID-19 pandemic undoubtedly impacted recent year emissions, the sustained decline in emissions intensity over time can be attributed to factors such as fuel switching, increases in efficiency and the modernization of industrial processes.

Canada accounts for approximately 1.5% of global GHG emissions (Climate Watch, 2024 for the year 2020), 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 18 t CO_2 eq/capita in 2021 (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 2022 can be found on open.canada.ca (ECCC, 2024).

Figure 2–1 **Canadian GHG Emission Trend (excluding Land Use, Land-Use Change and Forestry) (1990–2022)**

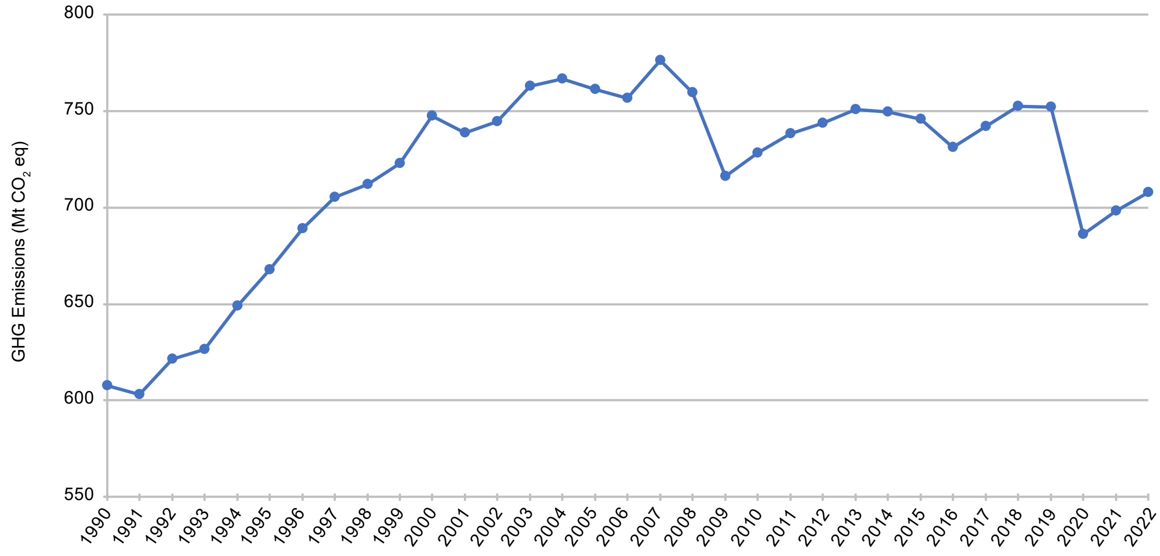
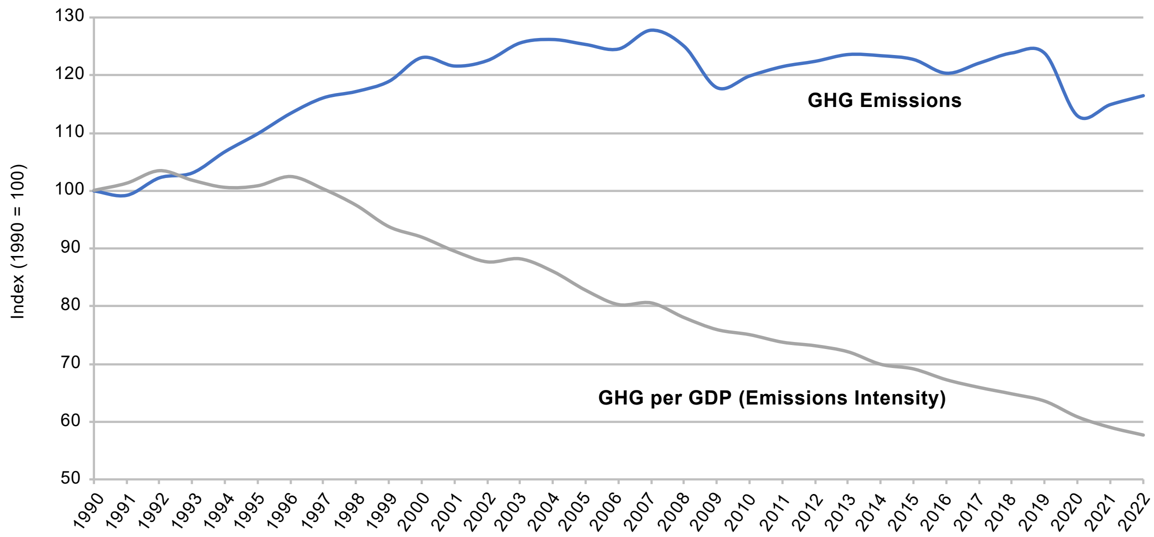


Figure 2–2 **Indexed Trend in GHG Emissions and GHG Emissions Intensity (excluding Land Use, Land-Use Change and Forestry) (1990–2022)**



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

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

Year	1990	2005	2017	2018	2019	2020	2021	2022
Total GHG (Mt)	**608**	**761**	**742**	**753**	**752**	**686**	**698**	**708**
Change since 2005 (%)	NA	NA	-2.6%	-1.2%	-1.2%	-10%	-8.3%	-7.1%
Change since 1990 (%)	NA	25%	22%	24%	24%	13%	15%	16%
GDP[a] (Billion 2012$)	**1 092**	**1 654**	**2 022**	**2 086**	**2 126**	**2 027**	**2 126**	**2 204**
Change since 2005 (%)	NA	NA	22%	26%	29%	23%	29%	33%
Change since 1990 (%)	NA	51%	85%	91%	95%	86%	95%	102%
GHG Intensity (Mt/$B GDP)	**0.56**	**0.46**	**0.37**	**0.36**	**0.35**	**0.34**	**0.33**	**0.32**
Change since 2005 (%)	NA	NA	-20%	-22%	-23%	-26%	-29%	-30%
Change since 1990 (%)	NA	-17%	-34%	-35%	-36%	-39%	-41%	-42%

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.

Throughout the whole time series, Alberta and Ontario have been the highest-emitting provinces, accounting for 60% of Canada's total emissions in 2022. Since 2005, emission patterns in these two provinces have diverged. Emissions in Alberta have increased by 19 Mt (7.5%) since 2005, primarily because of the expansion of oil and gas operations (Table 2–2). Specifically, Oil and Gas emissions in Alberta have increased by 39 Mt, but have been offset by decreases in Electricity (-28 Mt). In contrast, Ontario's emissions have decreased by 46 Mt (23%) since 2005, including a decrease of 29 Mt in the Electricity sector, owing primarily to the closure of the last coal-fired electricity generation plants in 2014.

In most of the other sub-national jurisdictions, emissions have decreased between 2005 and 2022, including in Nova Scotia (-8.0 Mt or -35%), New Brunswick (-7.6 Mt or -38%), Quebec (-6.5 Mt or -7.6%), Saskatchewan (-4.6 Mt or -5.8%), Newfoundland and Labrador (-1.7 Mt or -16%), British Columbia (-1.6 Mt or -2.5%), the Northwest Territories (-0.37 Mt or -22%), and Prince Edward Island (-0.28 Mt or -15%). Emissions have increased in Manitoba (0.99 Mt or 4.8%), the Yukon (0.10 Mt or 18%) and Nunavut (0.03 Mt or 5.4%).

Figure 2–3 **GHG Emissions by Province and Territory in 2005, 2010, 2015, and 2022**

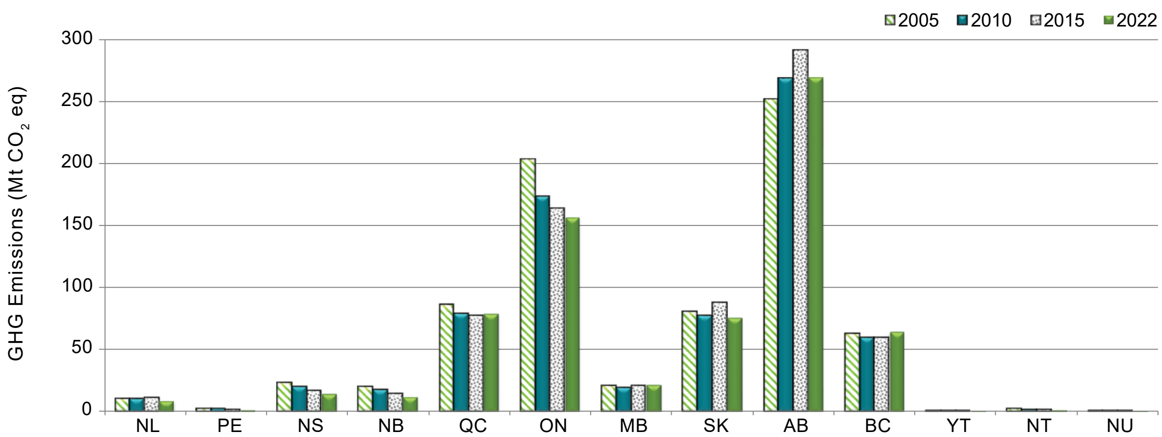


Table 2–2 **GHG Emissions by Province and Territory, Selected Years**

Year	GHG Emissions (Mt CO_2 eq)								Change (%)
	1990	2005	2017	2018	2019	2020	2021	2022	2005–2022
GHG TOTAL (CANADA)	**608**	**761**	**742**	**753**	**752**	**686**	**698**	**708**	**-7.1%**
NL	9.5	10	11	11	11	8.9	8.4	8.6	-16%
PE	1.8	1.9	1.6	1.6	1.6	1.6	1.6	1.6	-15%
NS	20	23	16	16	16	15	15	15	-35%
NB	16	20	14	13	13	11	12	12	-38%
QC	84	86	79	81	82	74	77	79	-7.6%
ON	178	203	158	164	165	149	151	157	-23%
MB	18	21	22	22	22	21	21	22	4.8%
SK	49	80	88	89	87	75	77	76	-5.8%
AB	177	251	287	286	287	269	271	270	7.4%
BC	51	63	63	65	64	60	62	64	2.5%
YT	0.55	0.56	0.56	0.64	0.69	0.60	0.65	0.66	18%
NT	NA	1.7	1.4	1.4	1.4	1.2	1.3	1.4	-22%
NU	NA	0.58	0.74	0.74	0.75	0.59	0.63	0.62	5.4%

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 551 Mt or 78% of total emissions in 2022 (Figure 2–4). As a result, trends in CO_2 emissions follow the same pattern as total GHG emissions (Figure 2–1). Most of the CO_2 emissions in Canada result from the combustion of fossil fuels (Figure 2–4).

Methane (CH_4)

Methane (CH_4) emissions in 2022 amounted to 117 Mt of CO_2 eq or 17% of Canada's total. These emissions consist largely of fugitive emissions from oil and natural gas systems (56 Mt or 48% of total CH_4 emissions), agriculture (31 Mt or 27% of total CH_4 emissions), and landfills (municipal solid waste disposal and industrial wood waste) (20 Mt or 17% of total CH_4 emissions). CH_4 emissions have increased steadily since 1990, peaking in 2006 at 152 Mt (41% increase), then fluctuated until 2018 and decreased in recent years to reach the same emission level as 1992 in 2022 (117 Mt) (Figure 2–5).

From 1990 to 2006, emissions from fugitive oil and gas increased by 32 Mt, agriculture by 10 Mt and landfills by 2.5 Mt. The increase in fugitive oil and gas emissions is consistent with a 60% increase in natural gas production and an 11% increase in conventional oil production over the same 1990–2006 period.[3]

2

From 2006 to 2019, CH_4 emissions decreased from 152 to 131 Mt. Of this 22 Mt decrease in emissions, 14 Mt occurred in the oil and gas industry due to reductions in venting emissions (-11 Mt), and the combination of improved leak detection and repair (LDAR) programs with a 9% decrease in natural gas production, both of which contributed to a further 3.4 Mt decrease in fugitive emissions from oil and gas systems. Agricultural CH_4 emissions decreased by 6.3 Mt (17%) between 2006 and 2011, mainly due to a 17% decline in beef cattle populations that led to a reduction in enteric fermentation emissions, but populations and emissions have since stabilized. The decrease in landfill emissions of 1.2 Mt (5.7%) over this period is from a mixture of decreases in methane generation from wood waste landfills (252 kt), and from increased capture and recovery of landfill gas from municipal landfills (2.5 Mt), offset by an increase in methane generated (2.8 Mt).

The significant decrease (11 Mt) in CH_4 emissions between 2019 and 2020 coincides with federal regulations to reduce methane emissions from the upstream oil and gas industry and equivalent provincial regulations in Saskatchewan, Alberta and British Columbia as fugitive CH_4 emissions from oil and gas operations decreased by 9.7 Mt over this period. Please see section 2.3.1.3 for more detailed discussion of the trends in emissions from fugitive sources. National CH_4 emissions continued to decrease between 2020 and 2022 (-2.5 Mt or -2.1%).

Nitrous Oxide (N_2O)

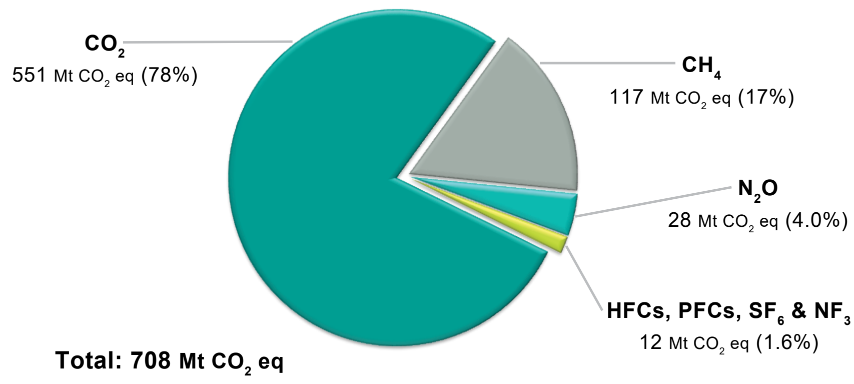
Nitrous oxide (N_2O) emissions accounted for 28 Mt of CO_2 eq (4.0%) of Canada's emissions in 2022, down 2.3 Mt (7.4%) from 1990 levels and 0.24 Mt (0.85%) from 2005 levels. The primary source of N_2O emissions is the application of nitrogen fertilizers to agricultural soils. In 2022, the Agriculture sector accounted for 76% of national N_2O emissions, up from 62% in 1990 and 36% in 2005. Since 2005, nitrogen fertilizer use has increased by 79% and N_2O emissions from nitrogen fertilizer use have increased by 83%. Since 1990, a 10 Mt decrease in N_2O emissions has occurred due to the cessation of adipic acid production in Canada.

Synthetic Gases

Emissions of synthetic gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), SF_6 and NF_3) accounted for 12 Mt of CO_2 eq, or 1.6%, of Canada's emissions in 2022. From 1990 to 2022, emissions of HFCs rose by 9.8 Mt (1201%), while emissions of PFCs and SF_6 decreased by 6.0 Mt (89%) and 3.0 Mt (90%), respectively. Similar trends are observed since 2005, with a 5.8 Mt (120%) increase in HFC emissions, and 2.7 Mt (78%) and 1.1 Mt (77%), decreases in emissions of PFCs and SF_6, respectively. Increases in HFC emissions can be explained by the replacement of ozone-depleting substances (ODSs)—specifically chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)—with HFCs in refrigeration, air conditioning and foam blowing applications before the gradual phase-out of HFCs mandated under the Kigali Amendment to the Montreal Protocol, which came into force in 2019. The decreases in emissions of PFCs are largely due to the modernization in the aluminium industry. The decreases in SF_6 are mainly due to a decline in the number of magnesium smelters and casters.

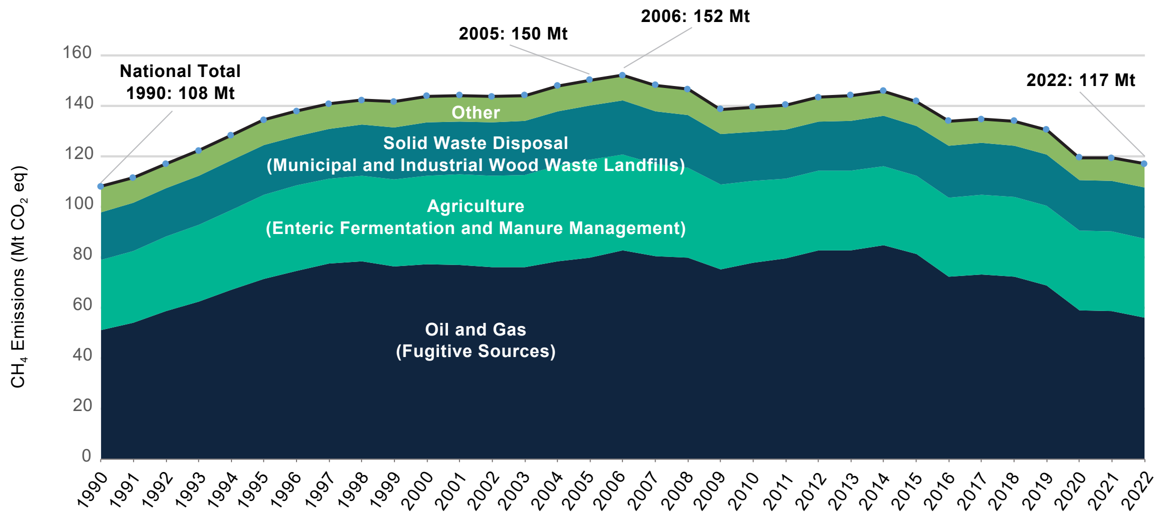
3 From 1990 to 2022, production of crude bitumen and synthetic crude oil from Canada's Oil Sands increased by over 815% with CO_2-eq emissions increasing by over 460%. However, CH_4 emissions from the Oil Sands increased by only 111% and the contribution to total Oil and Gas CH_4 emissions increased from 3.6% in 1990 to 6.9% in 2022, showing that the Oil Sands is not a significant source of CH_4 as compared to conventional oil and gas production.

Figure 2–4 **Breakdown of Canada's Emissions by GHG (2022)**



Note: Totals may not add up due to rounding.

Figure 2–5 **Methane Emissions Trends in Canada (1990–2022)**



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

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 IPPU sector, the Waste sector, and the Land Use, Land-Use Change and Forestry (LULUCF) sector.

In 2022, the Energy sector accounted for 577 Mt, or 82%, of Canada's total GHG emissions with the remainder being shared between Agriculture (56 Mt or 7.9%), IPPU (51 Mt or 7.3%) and Waste (23 Mt or 3.3%). The general emission breakdown by IPCC sector has not substantially changed over time (Figure 2–6).

The Energy sector dominated the long-term trend over the 1990–2022 period, with increases of 51 Mt (35%) in Transport, 28 Mt (10%) in Stationary Combustion, and 9.0 Mt (14%) in Fugitive Sources. Over the same period, emissions in the Agriculture sector increased by 13 Mt (32%), while the IPPU sector saw a decrease of 3.6 Mt (6.5%). Emissions in the Waste sector have increased by 2.0 Mt (10%) since 1990. In 1990, net emissions from the LULUCF sector were 49 Mt, and decreased to 14 Mt in 2021 before rising sharply to 51 Mt in 2022 as a result of an increase in emissions from Cropland (Figure 2–6 and Table 2–3).

Over the 2005–2022 period, total emissions have decreased by 54 Mt or 7.1%. Two sources of the Energy sector dominated this trend, with emission decreases of 32 Mt (9.6%) in Stationary Combustion and 22 Mt (22%) in Fugitive Sources. Over the same period, emissions have decreased by 4.1 Mt (7.4%) in the IPPU sector and 0.9 Mt (3.7%) in the Waste sector. In contrast, from 2005 to 2019, emissions from Transport have generally increased. Transport emissions decreased by 31 Mt (15%) between 2019 to 2020 and increased by 17 Mt (9.7%) between 2020 to 2022, bringing them above 2005 levels by 5.6 Mt. The Agriculture sector emissions have remained relatively stable with a 0.29 Mt or 0.52% decrease since 2005 (Figure 2–7). The net fluxes in the LULUCF sector have fluctuated between net emissions of 66 Mt in 2005 and net emissions of 5.6 Mt in 2014, representing a net decrease in emissions of 52 Mt between 2005 and 2021. Net emissions increased to 51 Mt in 2022 due to the impact of drought on Cropland emissions (Figure 2–6).

2

Several emission sources, while not major contributors to Canada's overall GHG emissions, have changed significantly since 1990; these include a 10 Mt (or 1200%) increase in emissions from the Production and Consumption of Halocarbons, SF_6 and NF_3, a 6.4 Mt (109%) increase from the Non-Energy Products from Fuels and Solvent Use, a 1.7 Mt (140%) increase in CO_2 emissions from the application of lime, urea and carbon-containing fertilizers, a 0.39 Mt (484%) increase in emissions from Biological Treatment of Solid Waste. Also included are decreases of 9.2 Mt (100%) from Adipic Acid Production, 2.9 Mt (95%) from SF_6 Used in Magnesium Smelters and Casters, 0.74 Mt (85%) from Nitric Acid Production and 0.19 Mt (79%) from Field Burning of Agricultural Residues.

Between 2005 and 2022, some of the noteworthy changes in emission sources that are minor contributors to the national total include a 5.8 Mt (or 120%) increase in emissions from the Production and Consumption of Halocarbons, SF_6 and NF_3, a 1.4 Mt (101%) increase in CO_2 emissions from the application of lime, urea and carbon-containing fertilizers, a 0.23 Mt (95%) increase in emissions from Biological Treatment of Solid Waste, a 2.3 Mt (100%) decrease in emissions from Adipic Acid Production, a 1.1 Mt (87%) decrease in emissions of SF_6 Used in Magnesium Smelters and Casters and a 0.9 Mt (88%) decrease in Nitric Acid Production emissions.

Figure 2–6 **Trends in Canadian GHG Emissions by IPCC Sector (1990–2022)**

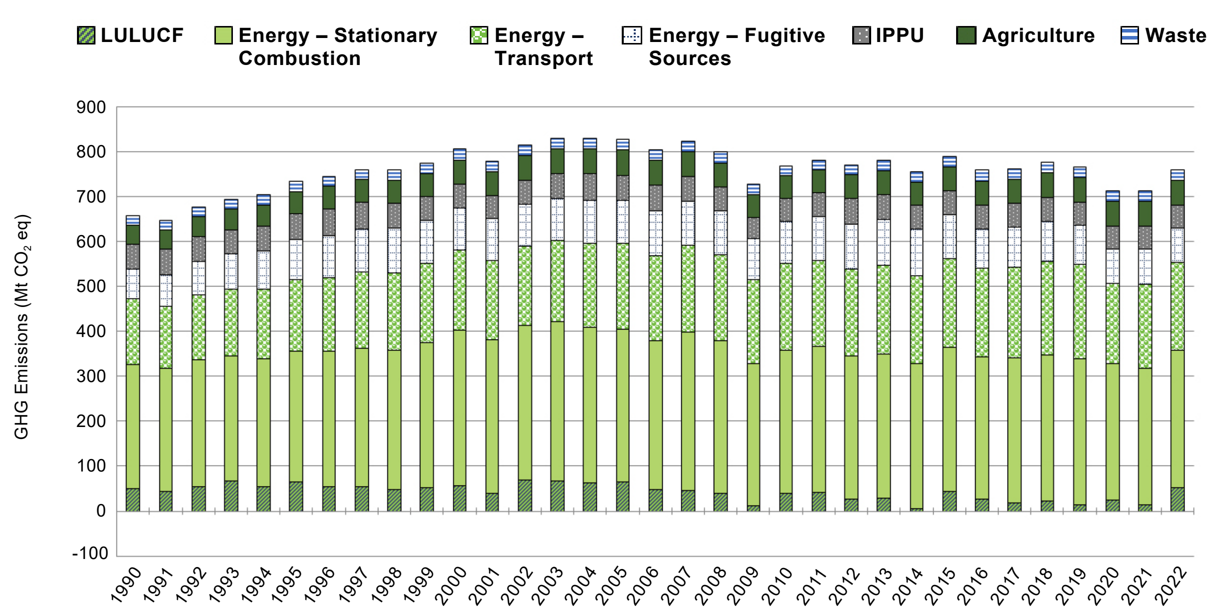
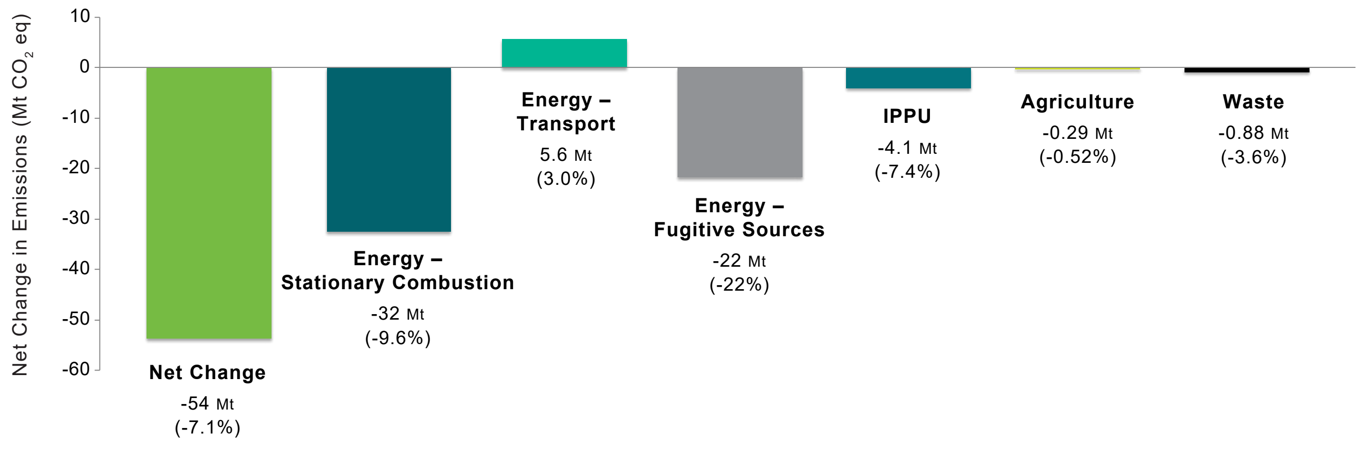


Figure 2–7 **Changes in GHG Emissions by IPCC Sector (2005–2022)**



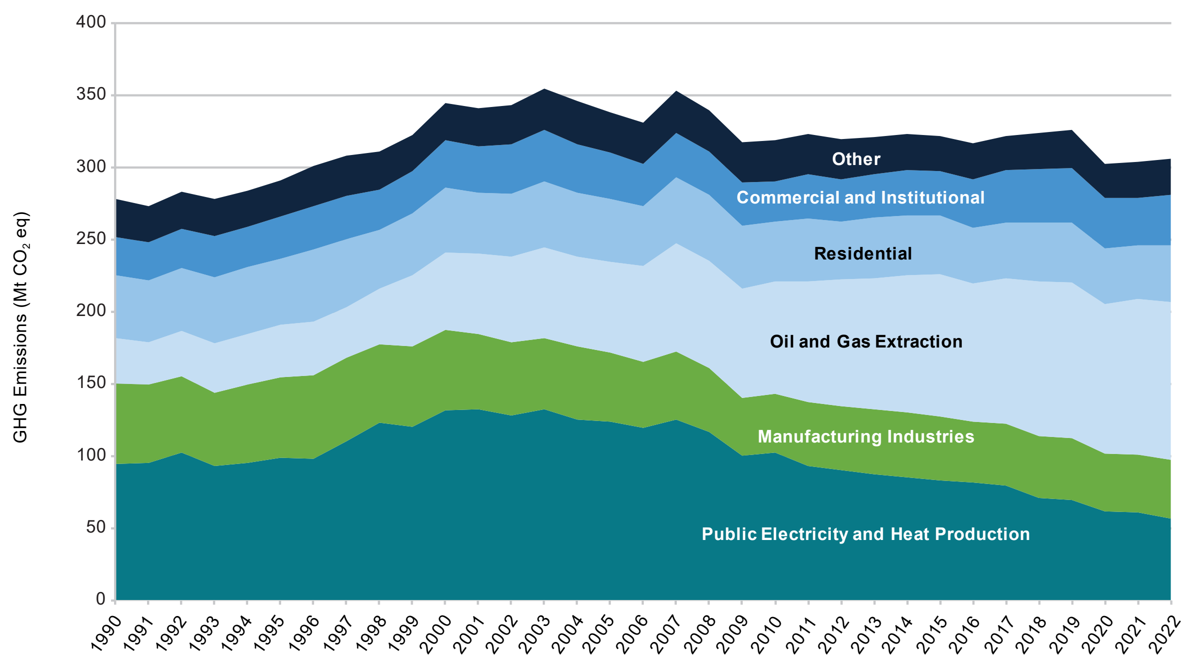
2.3.1. Energy Sector (2022 GHG emissions, 577 Mt)

In 2022, the Energy sector contributed 82% of Canada's total GHG emissions. In line with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), 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 (2022 GHG Emissions, 306 Mt)

Stationary Combustion Sources accounts for 53% of emissions from the Energy sector. In 2022, emissions totalled 306 Mt, an increase of 10% from the 1990 emissions level of 278 Mt and a decrease of 10% from the 2005 emissions level of 338 Mt (Figure 2–8, Table 2–4). Dominant categories in Stationary Combustion Sources are Oil and Gas Extraction and Public Electricity and Heat Production, which in 2022 contributed 36% and 18%, respectively, of the total Stationary Combustion emissions. Manufacturing Industries, Residential Buildings, and Commercial and Institutional Buildings contributed 13%, 13% and 11%, respectively, of total Stationary Combustion emissions in 2022.

Figure 2–8 **Trends in Canadian GHG Emissions from Stationary Combustion Sources (1990–2022)**



Note: "Other" includes Petroleum Refining, Construction, Mining, Agriculture and Forestry

Table 2–3 **Canada's GHG Emissions by IPCC Sector (1990–2022)**

Greenhouse Gas Categories		1990	2005	2017	2018	2019	2020	2021	2022
		Mt CO_2 eq							
TOTAL[a, b]		**608**	**761**	**742**	**753**	**752**	**686**	**698**	**708**
ENERGY		**489**	**626**	**613**	**622**	**622**	**558**	**569**	**577**
a.	**Stationary Combustion Sources**	**278**	**338**	**321**	**324**	**326**	**302**	**304**	**306**
	Public Electricity and Heat Production	94	124	79	71	69	62	61	56
	Petroleum Refining Industries	17	20	15	15	16	14	14	14
	Oil and Gas Extraction	31	63	101	107	108	104	108	109
	Mining	4.7	4.3	4.5	6.0	6.0	5.3	6.1	6.2
	Manufacturing Industries	56	48	43	43	43	39	40	41
	Construction	1.9	1.4	1.3	1.4	1.4	1.4	1.5	1.6
	Commercial and Institutional	26	32	36	37	38	35	33	35
	Residential	44	43	39	40	41	39	37	39
	Agriculture and Forestry	2.4	2.2	3.1	3.2	3.3	3.0	3.1	3.3
b.	**Transport**	**145**	**190**	**202**	**209**	**210**	**179**	**188**	**196**
	Aviation	7.5	7.7	7.9	8.7	8.6	4.7	5.6	7.7
	Domestic Aviation (Civil)	7.3	7.5	7.7	8.4	8.3	4.6	5.4	7.5
	Military	0.23	0.26	0.23	0.25	0.24	0.18	0.20	0.20
	Road Transportation	92	122	129	132	132	111	116	120
	Light-Duty Gasoline Vehicles	44	41	34	33	32	25	24	23
	Light-Duty Gasoline Trucks	25	41	52	53	55	47	50	53
	Heavy-Duty Gasoline Vehicles	4.8	4.6	4.4	4.5	4.5	4.2	4.3	4.1
	Motorcycles	0.20	0.46	0.90	0.92	0.95	0.77	0.77	0.72
	Light-Duty Diesel Vehicles	0.37	0.66	0.61	0.59	0.50	0.31	0.33	0.34
	Light-Duty Diesel Trucks	0.89	0.75	0.64	0.72	0.74	0.60	0.72	0.92
	Heavy-Duty Diesel Vehicles	16	34	37	38	37	33	35	37
	Propane and Natural Gas Vehicles	0.76	0.02	0.11	0.13	0.17	0.18	0.19	0.21
	Railways	6.8	6.5	7.2	7.3	7.4	6.8	6.8	6.8
	Marine	3.1	4.0	3.5	3.5	4.3	3.8	4.4	5.0
	Domestic Navigation	2.2	3.1	3.2	3.2	4.0	3.6	4.2	4.7
	Fishing	0.87	0.87	0.15	0.16	0.16	0.15	0.18	0.17
	Military Water-Borne Navigation	0.03	0.03	0.10	0.09	0.10	0.08	0.08	0.11
	Other Transportation	36	50	55	58	58	52	55	56
	Off-Road Agriculture and Forestry	8.7	9.9	13	14	14	13	13	13
	Off-Road Commercial and Institutional	4.2	4.5	5.7	5.9	6.0	5.5	5.9	6.0
	Off-Road Manufacturing, Mining and Construction	12	16	19	20	20	17	18	19
	Off-Road Residential	0.37	1.2	1.0	1.0	1.0	1.0	0.98	0.87
	Off-Road Other Transportation	3.5	7.8	8.1	8.1	8.0	7.5	7.7	7.5
	Pipeline Transport	6.9	10	7.6	8.4	8.5	7.8	8.7	10
c.	**Fugitive Sources**	**66**	**97**	**89**	**89**	**86**	**77**	**77**	**75**
	Coal Mining	3.2	1.6	1.4	1.5	1.6	1.3	1.4	1.5
	Oil and Natural Gas	63	95	88	88	85	75	76	74
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		**55**	**55**	**52**	**54**	**52**	**50**	**51**	**51**
a.	Mineral Products	8.5	10	8.6	8.7	8.9	8.2	9.0	8.4
	Cement Production	5.8	7.6	6.9	7.0	7.2	6.7	7.4	6.8
	Lime Production	1.8	1.8	1.4	1.4	1.3	1.2	1.3	1.3
	Mineral Product Use	0.86	0.91	0.33	0.33	0.32	0.31	0.31	0.31
b.	Chemical Industry	16	10	6.3	6.4	6.2	5.9	5.7	5.8
c.	Metal Production	23	20	15	15	14	13	14	14
d.	Production and Consumption of Halocarbons, SF_6 and NF_3	0.82	4.8	11	12	11	11	11	11
e.	Non-Energy Products from Fuels and Solvent Use	5.8	10	11	11	11	10	11	12
f.	Other Product Manufacture and Use	0.36	0.51	0.58	0.65	0.62	0.66	0.66	0.65
AGRICULTURE		**42**	**56**	**53**	**54**	**54**	**56**	**55**	**56**
a.	Enteric Fermentation	25	35	27	27	27	27	27	27
b.	Manure Management	6.0	8.7	7.9	7.9	7.9	7.8	7.9	7.8
c.	Agricultural Soils	10	12	15	16	16	18	17	18
d.	Field Burning of Agricultural Residues	0.24	0.05	0.05	0.05	0.05	0.06	0.04	0.05
e.	Liming, Urea Application and Other Carbon-Containing Fertilizers	1.2	1.4	2.4	2.6	2.7	3.0	3.1	2.9
WASTE		**21**	**24**	**24**	**23**	**24**	**23**	**23**	**23**
a.	Solid Waste Disposal (Landfills)	18	20	20	19	20	19	19	19
b.	Biological Treatment of Solid Waste	0.08	0.24	0.34	0.38	0.38	0.39	0.48	0.47
c.	Wastewater Treatment and Discharge	1.9	2.2	2.5	2.6	2.5	2.5	2.5	2.5
d.	Incineration and Open Burning of Waste	0.26	0.34	0.18	0.17	0.17	0.15	0.14	0.16
e.	Industrial Wood Waste Landfills	1.0	1.1	0.86	0.84	0.82	0.80	0.78	0.76
LAND USE, LAND-USE CHANGE AND FORESTRY		**49**	**66**	**19**	**23**	**14**	**26**	**14**	**51**
a.	Forest Land	-89	-64	-99	-99	-103	-101	-104	-108
b.	Cropland	0.31	-23	-24	-23	-19	-16	-19	22
c.	Grassland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
d.	Wetlands	5.4	3.1	3.1	2.8	3.1	3.5	3.2	3.3
e.	Settlements	1.8	1.8	2.4	2.3	2.2	2.3	2.2	2.2
g.	Harvested Wood Products	131	148	137	139	130	136	131	132

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

Table 2–4 **GHG Emissions from Stationary Combustion Sources, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2017	2018	2019	2020	2021	2022	1990–2022	2005–2022
STATIONARY COMBUSTION SOURCES	**278**	**338**	**321**	**324**	**326**	**302**	**304**	**306**	**10%**	**-10%**
Public Electricity and Heat Production	**94**	**124**	**79**	**71**	**69**	**62**	**61**	**56**	**-40%**	**-54%**
Petroleum Refining	**17**	**20**	**15**	**15**	**16**	**14**	**14**	**14**	**-18%**	**-29%**
Oil and Gas Extraction	**31**	**63**	**101**	**107**	**108**	**104**	**108**	**109**	**253%**	**73%**
Mining	**4.7**	**4.3**	**4.5**	**6.0**	**6.0**	**5.3**	**6.1**	**6.2**	**32%**	**42%**
Manufacturing Industries	**56**	**48**	**43**	**43**	**43**	**39**	**40**	**41**	**-27%**	**-14%**
Iron and Steel	4.9	5.5	6.0	6.4	6.1	4.6	5.1	4.9	-1%	-11%
Non-Ferrous Metals	3.5	3.8	3.4	3.0	3.4	3.2	3.0	3.2	-9%	-16%
Chemicals	8.3	8.3	9.8	9.4	9.6	9.6	9.4	9.2	11%	12%
Pulp, Paper and Print	14	8.6	6.4	7.1	7.1	6.5	6.8	6.9	-53%	-20%
Cement	3.9	5.4	4.2	4.3	4.2	3.7	3.7	3.8	-4%	-30%
Other Manufacturing	21	16	13	13	13	12	12	13	-38%	-19%
Construction	**1.9**	**1.4**	**1.3**	**1.4**	**1.4**	**1.4**	**1.5**	**1.6**	**-15%**	**10%**
Commercial and Institutional	**26**	**32**	**36**	**37**	**38**	**35**	**33**	**35**	**34%**	**8%**
Residential	**44**	**43**	**39**	**40**	**41**	**39**	**37**	**39**	**-11%**	**-10%**
Agriculture/Forestry/Fishing	**2.4**	**2.2**	**3.1**	**3.2**	**3.3**	**3.0**	**3.1**	**3.3**	**38%**	**52%**

Note: Totals may not add up due to rounding.

Public Electricity and Heat Production (2022 GHG emissions, 56 Mt)

Emissions from the Public Electricity and Heat Production category decreased by 40% between 1990 and 2022.

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 2022, Statistics Canada (StatCan) data shows electricity generation (driven by demand) increased by 33% (StatCan, n.d. [c]), from 433 TWh[4] to 583 TWh. Despite the increase in demand over this period, GHG emissions dropped by 40% (38 Mt) between 1990 and 2022. Likewise, between 2005 and 2022, electricity generation rose by 5%, while corresponding emissions fell by 54% (67 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 2–9).

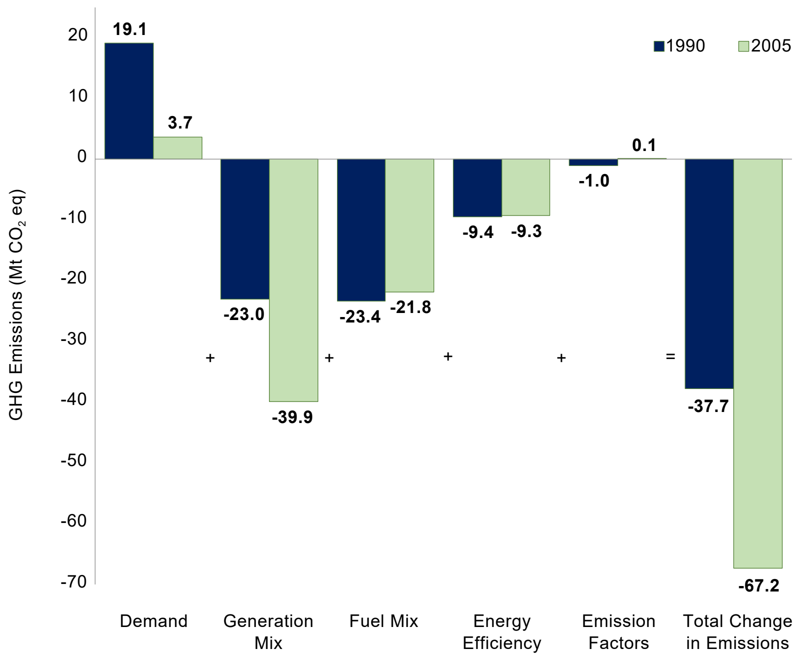
Low-emitting non-combustion sources—hydroelectric generation, nuclear power and non-hydro renewables (wind turbines, solar photovoltaic cells and tidal power)—accounted for 108% of the increased generation between 1990 and 2022 and for 85% of the total electricity generated in Canada in 2022. Hydroelectric generation alone accounted for 64% of the total electricity generated in 2022, followed by nuclear power generation at 14% and non-hydro-based renewables at 7%. The increased level of non-combustion sources in the generation mix in 2022 was the largest contributor to emission reductions since 1990 (23 Mt) and 2005 (40 Mt) (Figure 2–9).

In addition, the fuel mix used for combustion generation has been steadily moving to less GHG-intensive fossil fuels. Between 2005 and 2022, the quantity of electricity generated by natural gas-fired units increased by 93% (28 TWh), while the amount generated by coal and refined petroleum products decreased by 74% (70 TWh) and 75% (8.1 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 23 Mt between 1990 and 2022 and about 22 Mt between 2005 and 2022.

The efficiency of combustion equipment has also played a role in the GHG emission reductions. Energy efficiency improvements resulted in an approximately 9.4 Mt reduction in GHG emissions between 1990 and 2022 and a 9.3 Mt reduction between 2005 and 2022.

4 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 2–9 **Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 1990–2022 and 2005–2022**



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.

Oil and Gas Extraction (2022 GHG emissions, 109 Mt)

Stationary combustion emissions from Oil and Gas Extraction increased by 78 Mt (253%) between 1990 and 2022 and by 46 Mt (73%) between 2005 and 2022. This category includes emissions associated with fuel combustion for Natural Gas Production and Processing, Conventional Oil Production, and Oil Sands Mining, Extraction and Upgrading. Increases in emissions are consistent with a 215% increase in the production of non-upgraded crude bitumen and synthetic crude oil from the oil sands industry since 2005 (AER, 2023) and the increased use of more energy-intensive extraction techniques, such as horizontal drilling, hydraulic fracturing and enhanced oil recovery.

In the oil sands industry, crude bitumen 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. Since 2005, total natural gas consumption in the Oil and Gas Extraction category has increased by approximately 96%, and in-situ thermal production has increased by over 425% (AER, 2023). In general, while emission increases from Oil and Gas Extraction may originate from multiple activities, they tend to be consistent with the 528% increase in the production of non-upgraded bitumen through mining or thermal extraction in Canada's oil sands area, particularly in SAGD production. In contrast, since 2005, natural gas production has increased by less than 1% (StatCan, n.d.[c]) while conventional oil production, including primary production of crude bitumen in oil sands areas, has increased by only 13% (AER, 2023, StatCan, n.d.[d], n.d.[e]).

Additional information about the Oil and Gas Extraction category is provided in Table 2–12, where emissions are broken down by economic sectors (Natural Gas Production and Processing, Conventional Oil Production and Oil Sands). Section 2.4.1 presents short discussion of trends in the oil and gas industry by economic sector.

Manufacturing Industries (2022 GHG emissions, 41 Mt)

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

In 2022, GHG emissions from the Manufacturing Industries category were 41 Mt, which represents a 27% (15 Mt) decrease from 1990 and a 14% (6.6 Mt) decrease from 2005. The decrease between 2005 and 2022 is driven by Other Manufacturing (-3.1 Mt), Pulp, Paper and Print (-1.7 Mt), Cement (-1.6 Mt), Non-Ferrous Metals (-0.6 Mt), and Iron and Steel (-0.6 Mt), offset by an increase in Chemicals (1.0 Mt).

As with Electricity Generation, emission decreases in Manufacturing Industries 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 2022 it only made up 68%; replacing the natural gas with wood combustion, which together made up 95% of the fuel mix in 2022. In 1990, heavy fuel oil made up 17% of the fuel mix in the Pulp, Paper and Print subcategory while in 2022, 98% 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 1.0 Mt (12%). This is generally consistent with a 33% (CEEDC, n.d.) growth in the production of chemicals between 1990 and 2022.

Residential, Commercial and Institutional (2022 GHG emissions, 74 Mt)

GHG emissions in the Residential and the Commercial and Institutional categories 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 74 Mt of GHG emissions in 2022, a 5.7% increase since 1990.

Overall, Residential emissions decreased by 4.8 Mt (11%) between 1990 and 2022 and by 4.3 Mt (10%) between 2005 and 2022. In contrast, Commercial and Institutional emissions increased by 8.8 Mt (34%) from 1990 to 2022 and by 2.6 Mt (8.2%) from 2005 to 2022. Energy efficiency improvements, new home construction 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 categories (Figure 2–10 and Figure 2–11).

In the Residential category, 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 27.3 Mt decrease in emissions between 1990 and 2022. Decreasing consumption of light fuel oil in all provinces and territories but especially Quebec and Ontario, between 1990 and 2022 is the largest driver of the 1.7 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 category, having increased by 50% since 1990.[5] The resulting 12 Mt increase in emissions was partially offset by improvements in the fuel mix and energy efficiency, equivalent to a 1.0 Mt and 1.5 Mt decrease in GHG emissions, respectively (Figure 2–11).

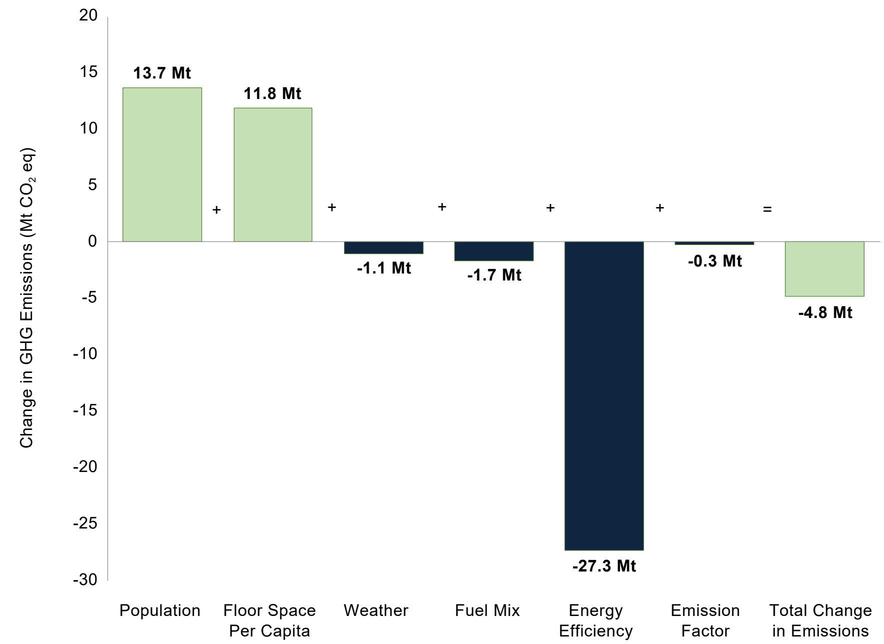
Weather patterns can influence emissions when comparing different years, as suggested by the close relationship between heating degree-days (HDDs) and GHG emissions (Figure 2–12). The impact that weather can have on space heating requirements and fuel demand results in emission patterns that mirror interannual weather variability.

Other Stationary Combustion Sources (2022 GHG emissions, 25 Mt)

Other Stationary Combustion Sources comprise fuel combustion emissions from the Petroleum Refining Industries, Mining, Construction, and Agriculture and Forestry categories. From 1990 to 2022, the Petroleum Refining Industries category showed a decrease in GHG emissions of 3.2 Mt (18%), the Mining category showed an increase of 1.5 Mt (32%), the Agriculture and Forestry category showed an increase of 0.91 Mt (38%), and the Construction category showed a decrease of 0.29 Mt (15%).

5 Kaymak, D. 2023. Personal communication (email from Kaymak D. to Kay J., Physical Scientist, PIRD, dated November 23, 2023). Economic Analysis Directorate, Environment and Climate Change Canada.

Figure 2–10 **Factors Contributing to the Change in Stationary GHG Emissions from the Residential Category between 1990 and 2022**



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.

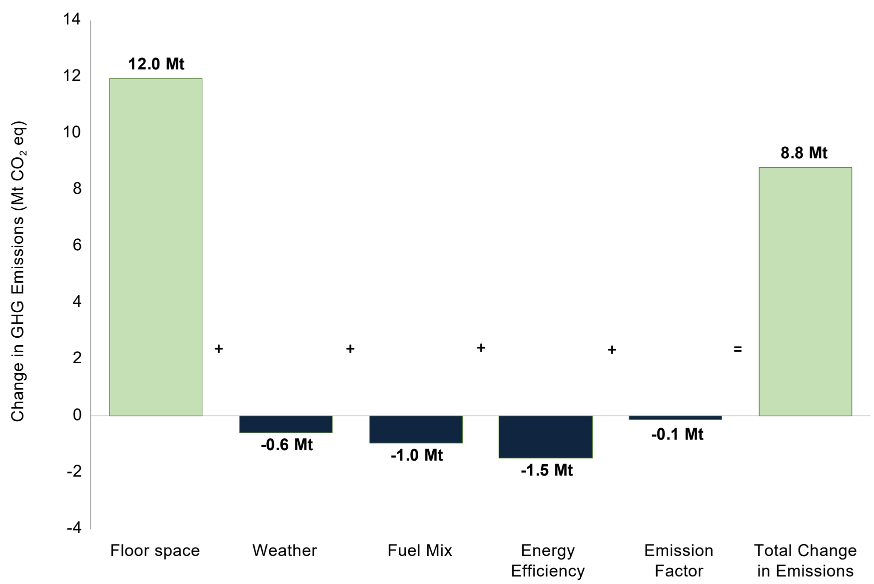
Weather – Weather refers to the fluctuations in weather conditions, particularly outdoor winter temperature.

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 2–11 **Factors Contributing to the Change in Stationary GHG Emissions from the Commercial and Institutional Category between 1990 and 2022**



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.

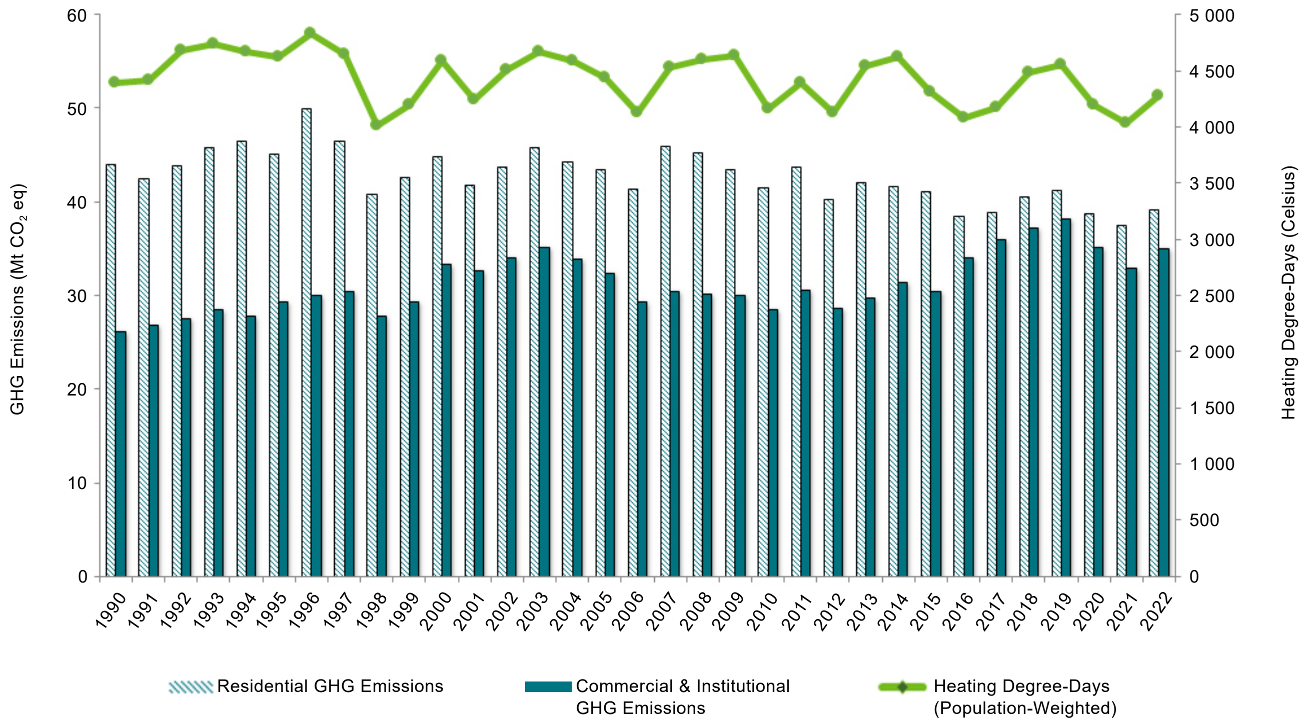
Weather – Weather refers to the fluctuations in weather conditions, particularly outdoor winter temperature.

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 2–12 **Heating Degree-Days (HDDs) and GHG Emissions from the Residential and the Commercial and Institutional Categories (1990–2022)**



2.3.1.2. Transport (2022 GHG emissions, 196 Mt)

Transport is a large and diverse sector, accounting for 196 Mt of GHG emissions or 31% of Canada's Energy sector emissions in 2022. Transport includes emissions from fuel combustion in five categories: Road Transportation, Aviation, Marine, Railways, and Other Transportation (Off-Road and Pipelines) (Table 2–5). From 1990 to 2022, Transport emissions rose by 35% (51 Mt), accounting for a significant portion of Canada's emissions growth. Between 2019 and 2020, Transport emissions decreased by 15% (31 Mt), the first notable year-to-year decrease to occur since 2008–2009, which had a year-to-year decrease of 2.7% (5.1 Mt). Between 2020 and 2022, Transport emissions increased by 10% (17 Mt).

Emissions from Transport result primarily from Road Transportation, which includes personal transportation (light-duty gasoline vehicles and trucks) and heavy-duty diesel vehicles (Figure 2–13), accounting for 61% of Transport emissions in 2022. Other Transportation (Off-Road and Pipelines) is the second-largest category, accounting for 29% of Transport emissions in 2022, 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 2022, the Aviation category increased by 52% (2.9 Mt). The Marine and Railways categories combined contributed to approximately 6.0% of the Transport emissions in 2022 and, overall, were stable over the 1990–2022 time series.

Road Transportation (2022 GHG emissions, 120 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 vehicle kilometres travelled (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 both KAR and vehicle fleet size. In 2022, total VKT is 12% higher than 2020 levels but is 7.3% below 2019 levels.

Figure 2–13 **Trends in Canadian GHG Emissions from Transport (1990–2022)**

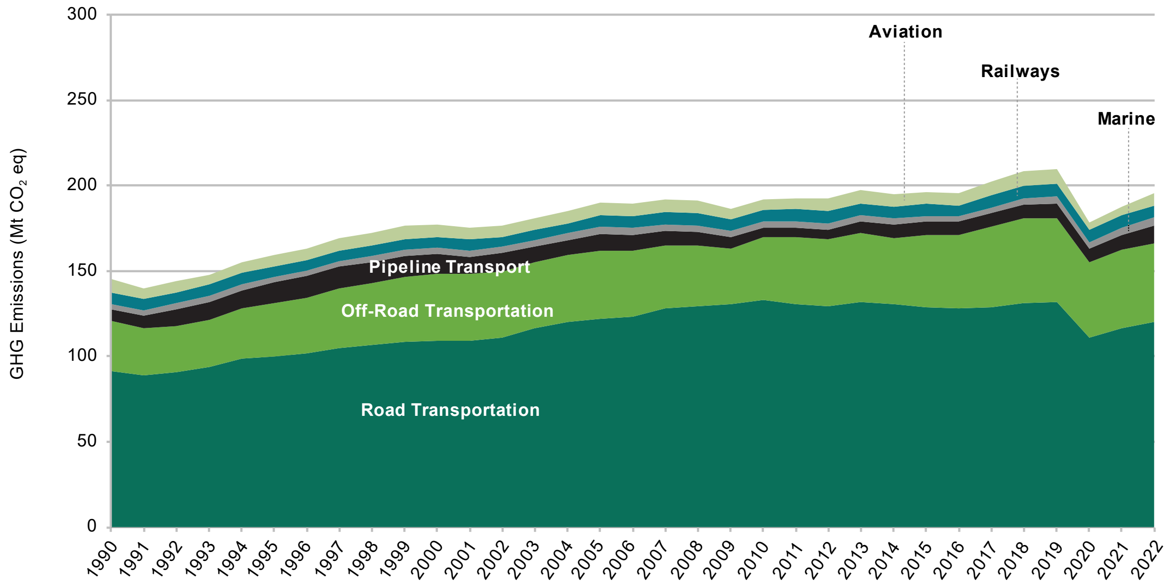


Table 2–5 **GHG Emissions from Transport, Selected Years**

CRF Code		GHG Emissions (Mt CO_2 eq)								Change (%)	
		1990	2005	2017	2018	2019	2020	2021	2022	1990–2022	2005–2022
1.A.3	**TRANSPORT**	**145**	**190**	**202**	**209**	**210**	**179**	**188**	**196**	**35%**	**3%**
	Aviation	**7.5**	**7.7**	**7.9**	**8.7**	**8.6**	**4.7**	**5.6**	**7.7**	**2%**	**0%**
1.A.3.a	Domestic Aviation (Civil)	7.3	7.5	7.7	8.4	8.3	4.6	5.4	7.5	3%	0%
1.A.5.b	Military	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	-16%	-24%
	Road Transportation	**92**	**122**	**129**	**132**	**132**	**111**	**116**	**120**	**31%**	**-2%**
1.A.3.b.i	Light-Duty Gasoline Vehicles	44	41	34	33	32	25	24	23	-47%	-42%
1.A.3.b.ii	Light-Duty Gasoline Trucks	25	41	52	53	55	47	50	53	116%	30%
1.A.3.b.iii	Heavy-Duty Gasoline Vehicles	4.8	4.6	4.4	4.5	4.5	4.2	4.3	4.1	-15%	-12%
1.A.3.b.iv	Motorcycles	0.2	0.5	0.9	0.9	1.0	0.8	0.8	0.7	253%	57%
1.A.3.b.i	Light-Duty Diesel Vehicles	0.4	0.7	0.6	0.6	0.5	0.3	0.3	0.3	-8%	-49%
1.A.3.b.ii	Light-Duty Diesel Trucks	0.9	0.7	0.6	0.7	0.7	0.6	0.7	0.9	4%	23%
1.A.3.b.iii	Heavy-Duty Diesel Vehicles	16	34	37	38	37	33	35	37	136%	8%
1.A.3.b.v	Propane and Natural Gas Vehicles	0.8	0.0	0.1	0.1	0.2	0.2	0.2	0.2	-73%	786%
1.A.3.c	**Railways**	**6.8**	**6.5**	**7.2**	**7.3**	**7.4**	**6.8**	**6.8**	**6.8**	**-1%**	**4%**
	Marine	**3.1**	**4.0**	**3.5**	**3.5**	**4.3**	**3.8**	**4.4**	**5.0**	**60%**	**23%**
1.A.3.d	Domestic Navigation	2.2	3.1	3.2	3.2	4.0	3.6	4.2	4.7	113%	50%
1.A.4.c.iii	Fishing	0.9	0.9	0.2	0.2	0.2	0.2	0.2	0.2	-81%	-81%
1.A.5.b	Military Water-Borne Navigation	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	302%	323%
	Other Transportation	**36**	**50**	**55**	**58**	**58**	**52**	**55**	**56**	**56%**	**14%**
1.A.4.c.ii	**Off-Road Agriculture and Forestry**	**8.7**	**10**	**13**	**14**	**14**	**13**	**13**	**13**	**52%**	**34%**
1.A.4.a.ii	Off-Road Commercial and Institutional	4.2	4.5	5.7	5.9	6.0	5.5	5.9	6.0	42%	34%
1.A.2.g.vii	Off-Road Manufacturing, Mining and Construction	12	16	19	20	20	17	18	19	51%	15%
1.A.4.b.ii	Off-Road Residential	0.4	1.2	1.0	1.0	1.0	1.0	1.0	0.9	137%	-29%
1.A.3.e.ii	Off-Road Other Transportation	3.5	7.8	8.1	8.1	8.0	7.5	7.7	7.5	117%	-3%
1.A.3.e.i	Pipeline Transport	6.9	10	7.6	8.4	8.5	7.8	8.7	10	47%	0%

The total vehicle fleet has increased by 50% since 1990 (26% since 2005), most notably for light-duty trucks, which have steadily increased throughout the 1990–2022 time series (Table 2–6). 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, driving the decrease observed for the total vehicle fleet for 2019 and later.

Despite decreases to total VKT and vehicle populations from 2019 levels, the steady expansion of the overall fleet prior to 2019 resulted in the total VKT for 2022 being 72% and 22% 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 2022, approximately 225 000 fully electric vehicles were in the vehicle fleet, a 47% growth from 2021 (StatCan, n.d.[f]).

Table 2–6 **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
2017	10 578	11 302	1 945	24 546
2018	10 494	11 847	1 952	25 023
2019	10 328	12 347	1 940	25 351
2020	9 667	12 503	1 898	24 804
2021	8 939	13 014	1 948	24 637
2022	8 331	13 487	1 936	24 500
Change since 1990	-23%	232%	78%	50%
Change since 2005	-21%	95%	18%	26%

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.

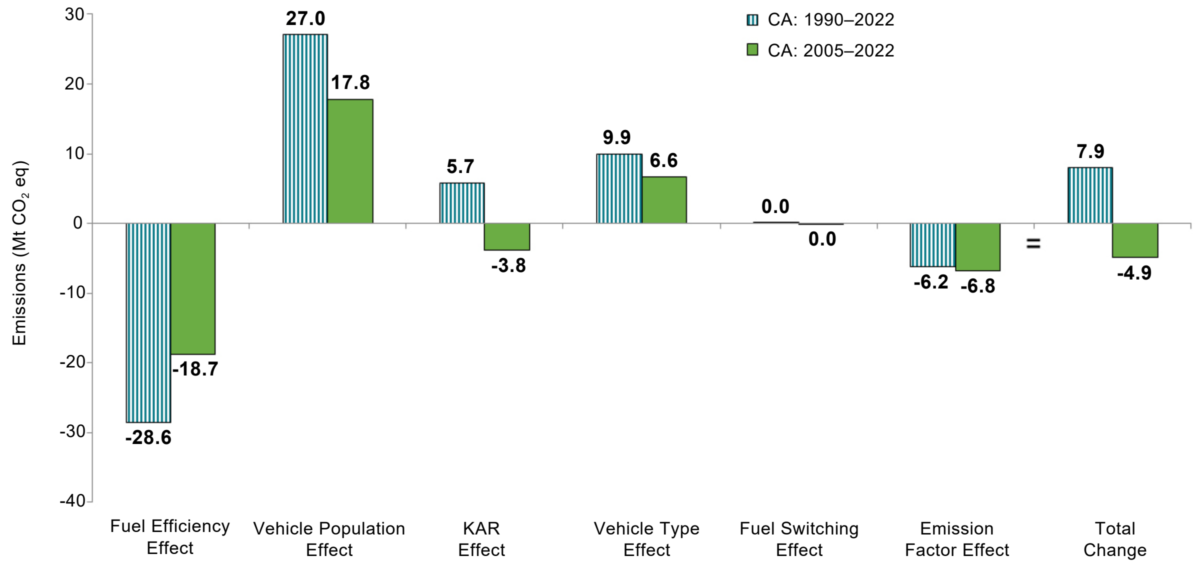
Light-Duty Gasoline Vehicles (2022 GHG emissions, 23 Mt)

Since 1990, emissions from Light-Duty Gasoline Vehicles (i.e., passenger cars) have steadily decreased and in 2022 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 and have also contributed to decreased emissions (Figure 2–14).

Light-Duty Gasoline Trucks (2022 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 2022 being 116% (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 2–14). Since 2005, emissions from the light-duty gasoline trucks category have been the top contributor to transportation emissions totals, making up 22% and 27% of that total for 2005 and 2022, respectively.

Figure 2–14 **Factors Contributing to Changes in Light-Duty Vehicle Emissions, 1990–2022 and 2005–2022**



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, 1990–2022 and 2005–2022.

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 light cars and trucks 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 (2022 GHG emissions, 37 Mt)

From 1990 to 2011, emissions from Heavy-Duty Diesel Vehicles steadily increased, peaking at 45 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 2022, emissions from these vehicles were estimated to be about 37 Mt, which is 136% (21 Mt) and 8.1% (2.8 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 (2022 GHG emissions, 46 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 2022, the Off-Road Manufacturing, Mining and Construction subcategory and the Off-Road Agriculture and Forestry subcategory accounted for 40% and 29% of off-road emissions, respectively. The net emissions for all off-road subcategories have increased by 59% (17 Mt) since 1990 and increased by 17% (6.7 Mt) since 2005. These increases are largely due to increased fleet-average engine power as well as increased total equipment use.

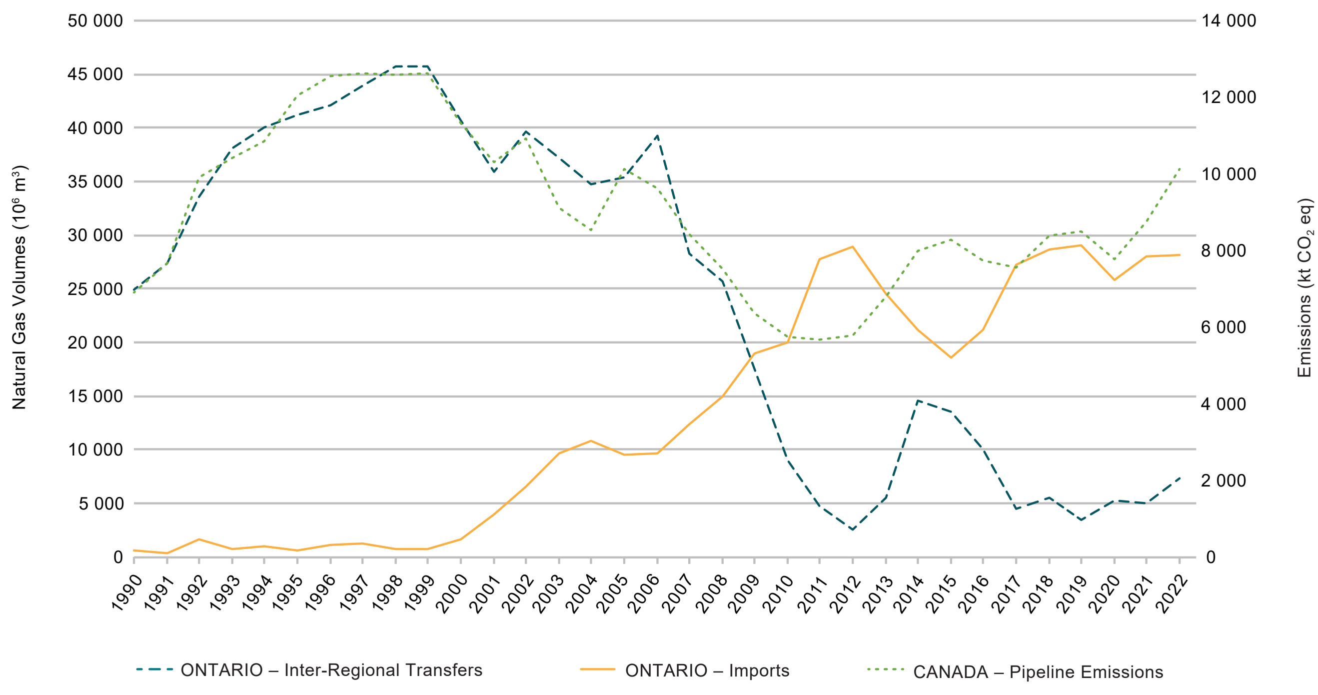
Other Transportation: Pipeline Transport (2022 GHG emissions, 10 Mt)

Pipeline emissions result from the combustion of natural gas at compressor stations used for natural gas transport. In 2022, over 99% of marketable natural gas production occurred in western Canada: Alberta (66%), British Columbia (31%) and Saskatchewan (2.0%). While these provinces account for approximately 65% of marketable natural gas consumption in Canada, Ontario, the most populous province, accounts for approximately 25% of natural gas consumption but produces less than 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 2–15).

The increase in emissions from 2021 to 2022 reflects a 16% increase in natural gas consumption resulting from a 13% increase in volumes of natural gas transported from British Columbia and Alberta to other provinces and an 8% increase in exports to the United States.

Figure 2–15 **Relationship between Canadian Pipeline Emissions, US Imports into Ontario and Inter-Regional Transfers of Western Canadian Natural Gas**

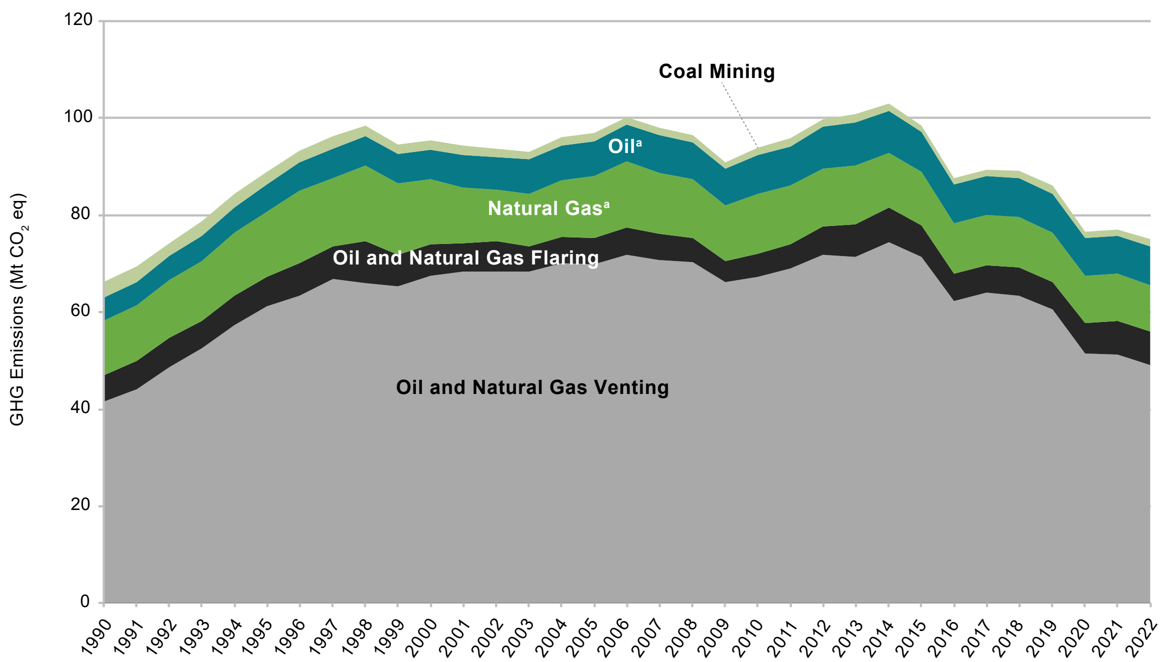


2.3.1.3. **Fugitive Sources (2022 GHG Emissions, 75 Mt)**

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 9 Mt (14%) between 1990 (66 Mt) and 2022 (75 Mt) (Table 2–7) with considerably more variation over the time series. Fugitive emissions peaked in 2014 at 103 Mt (Figure 2–16), 56% higher than 1990. Fugitive emissions from Oil and Natural Gas alone increased by 39 Mt (61%) over this period, while releases from Coal Mining decreased by 1.7 Mt (54%), mainly due to mine closures in eastern Canada.

Figure 2–16 **Trends in Canadian GHG Emissions from Fugitive Sources (1990–2022)**



Notes:

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

Table 2–7 **GHG Emissions from Fugitive Sources, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2017	2018	2019	2020	2021	2022	1990–2022	2005–2022
FUGITIVE SOURCES[a]	**66**	**97**	**89**	**89**	**86**	**77**	**77**	**75**	**14%**	**-22%**
Coal Mining	**3.2**	**1.6**	**1.4**	**1.5**	**1.6**	**1.3**	**1.4**	**1.5**	**-52%**	**-2%**
Oil and Natural Gas	**63**	**95**	**88**	**88**	**85**	**75**	**76**	**74**	**17%**	**-23%**
Oil[b]	4.7	7	8	8	8	8	8	8	70%	12%
Natural Gas[b]	11	13	10	10	10	10	10	10	-15%	-25%
Venting	42	70	64	63	61	52	51	49	18%	-30%
Flaring	5.4	5.3	5.8	6.0	5.8	6.3	6.9	6.9	28%	30%

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.

Although oil sands production represented approximately 72% of total oil production in 2022, it accounted for only 16% 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).

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. 2014–2022: declining emissions

Fugitive oil and gas emissions increased steadily from 63 Mt in 1990 to 93 Mt in 2000 (48%). Additionally, over 120,000 oil and gas wells were drilled between 1990 and 2000 (CAPP, 2023). 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 8.1 Mt (9%) between 2000 and 2014, peaking in 2014 at 102 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, 2023; StatCan, n.d.[d], n.d.[e]) and the average production per natural gas well decreased by 62% in western Canada (CAPP, 2023; StatCan, n.d.[g], n.d.[h]).

From 2014 to 2019, emissions dropped by 17 Mt (17%), mainly due to reductions in venting and flaring as more gas was conserved. There was also contraction within the sector as the number of operating wells decreased by 10% and the number of wells drilled was almost 50% lower than the previous 6-year period.

From 2019 to 2020, emissions dropped by 9.2 Mt (11%). This drop coincides with several contributing factors, including:

1. Federal (ECCC, 2018) and equivalent[6] provincial regulations (AB, 2018; BC, 2021; SK, 2020) to reduce CH_4 emissions from oil and gas operations that came into effect January 1, 2020.
2. Overall contraction of the industry, which experienced a 9% reduction in conventional oil production, a 1% reduction in natural gas production, and an 11% reduction in the number of operating oil and gas wells.
3. Updated vent gas volume reporting requirements in Alberta, British Columbia and Saskatchewan that resulted in a methodological inconsistency between 2019 and 2020. As the reported data is used to estimate emissions, changes to the reporting requirements complicated the estimation process and may have artificially contributed to the drop in estimated emissions between 2019 and 2020. See Annex 3.2, section 3.2.2.1.5 for more details.
4. A drastic decrease in the price of oil at the onset of the COVID-19 pandemic.

Fugitive oil and gas emissions in 2021 were roughly equivalent to 2020, then dropped by 2.1 Mt (3%) from 2021 to 2022. Activity in the sector rebounded after the initial impacts of the COVID-19 pandemic in 2020. Between 2020 and 2022, natural gas production increased by 6%, and while the number of operating oil and gas wells remained constant, the number of wells drilled increased by over 60%. Increased compliance with the federal and provincial regulations likely offset the expected increases due to the production growth.

6 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 come 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).

TOP-DOWN VERSUS BOTTOM-UP METHANE ESTIMATES FOR THE OIL AND GAS SECTOR

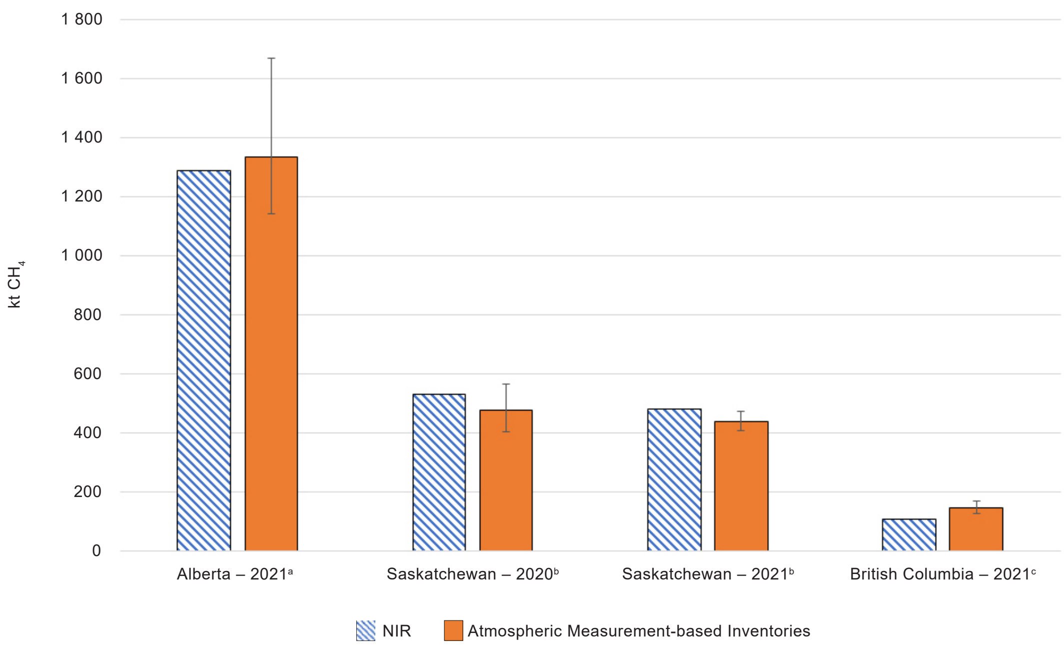
Accurately estimating fugitive emissions from oil and gas operations is a challenge. The industry in Canada includes tens of thousands of facilities, hundreds of thousands of wells and millions of components with the potential to emit. Traditional "bottom-up" approaches use engineering methods to estimate 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.

Recent studies in Canada that have used atmospheric measurements to derive "top-down" estimates suggest that "bottom-up" inventories underestimate methane (CH_4) emissions from the oil and gas industry (e.g., Atherton et al., 2017; Johnson et al., 2017; Zavala-Araiza et al., 2018; Chan et al., 2020; Mackay et al., 2021; Tyner and Johnson, 2021; Festa-Bianchet et al., 2023; Johnson et al., 2023; Conrad et al., 2023a,b). Many of these studies highlight the significance of "super-emitters," where a small number of facilities contribute a disproportionately high quantity of total emissions.

Historically, atmospheric measurements have only produced large-scale, regional or facility-level estimates and have not been able to resolve emission sources within a facility. However, recent advances in measurement technology have allowed the development of a protocol to create robust source-resolved atmospheric 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).

These atmospheric measurement-based inventories have been leveraged to include emission estimates for unlit flares and improve estimates for storage tanks, compressors, wellheads, and engine sheds. See Annex 3.2, section A3.2.2.1.5 for more details. Figure 2–A shows the convergence of oil and gas methane emission estimates from this inventory report with the atmospheric 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 atmospheric measurements with the goal of further improving the accuracy of inventory estimates in future editions of this report.

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



Notes:
a. Conrad et al., 2023a
b. Conrad et al., 2023b
c. Johnson et al., 2023

2.3.1.4. Trends in CO_2 Transport and Storage

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, Saskatchewan. As well as imported CO_2, in 2014, the Weyburn operations began receiving most of the CO_2 captured at the Boundary Dam coal-fired power plant in Saskatchewan. In addition, the Aquistore Project and its Basal Cambrian storage complex annually inject a modest amount of CO_2 from Boundary Dam 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.

Table A10-3 (Annex 10) presents 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.

Annex 9 of this report presents emissions from CO_2 transport systems in the annual GHG summary tables for Canada while Annex 11 presents emissions by provincial/territorial regions.

2

2.3.2. Industrial Processes and Product Use (2022 GHG emissions, 51 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 51 Mt (7.3%) to Canada's 2022 emissions, compared with 55 Mt (7.3%) in 2005, a decrease of approximately 4.1 Mt, or 7%. 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.

Emission reductions have occurred since 2005 in Iron and Steel Production (CO_2), Aluminium Production (PFCs), Adipic Acid Production (N_2O), Use of SF_6 in Magnesium Production (SF_6), Nitric Acid Production (N_2O), and Cement Production (CO_2). These reductions were mainly offset by increases observed in the Production and Consumption of Halocarbons, SF_6 and NF_3 (mostly HFCs) (Figure 2–17 and Table 2–8).

Figure 2–17 **Trends in Canadian GHG Emissions from Industrial Processes and Product Use Sources (1990–2022)**

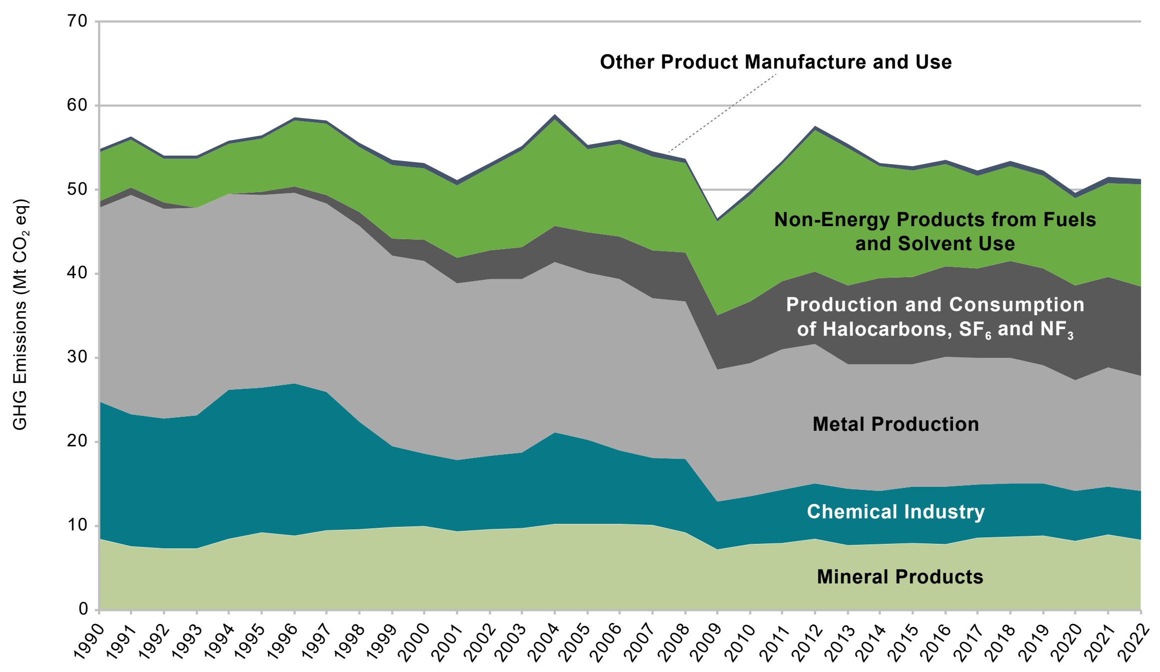


Table 2–8 **GHG Emissions from Industrial Processes and Product Use Categories, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2017	2018	2019	2020	2021	2022	1990–2022	2005–2022
TOTAL – INDUSTRIAL PROCESSES	**55**	**55**	**52**	**54**	**52**	**50**	**51**	**51**	**-7%**	**-7%**
Mineral Products	**8.5**	**10**	**8.6**	**8.7**	**8.9**	**8.2**	**9.0**	**8.4**	**-1%**	**-18%**
Cement Production	5.8	7.6	6.9	7.0	7.2	6.7	7.4	6.8	16%	-11%
Lime Production	1.8	1.8	1.4	1.4	1.3	1.2	1.3	1.3	-26%	-23%
Mineral Product Use	0.86	0.91	0.33	0.33	0.32	0.31	0.31	0.31	-64%	-66%
Chemical Industry	**16**	**10**	**6.3**	**6.4**	**6.2**	**5.9**	**5.7**	**5.8**	**-65%**	**-42%**
Ammonia Production	2.7	2.7	2.6	2.4	2.5	2.3	2.5	2.6	-5%	-4%
Nitric Acid Production	0.87	1.1	0.22	0.24	0.23	0.17	0.19	0.13	-85%	-88%
Adipic Acid Production	9.2	2.3	-	-	-	-	-	-	-100%	-100%
Petrochemical Production & Carbon Black Production	3.5	3.9	3.5	3.7	3.5	3.5	3.0	3.1	-13%	-22%
Metal Production	**23**	**20**	**15**	**15**	**14**	**13**	**14**	**14**	**-41%**	**-31%**
Iron and Steel Production	10	10	9.1	9.3	8.6	7.3	8.2	7.8	-25%	-24%
Aluminium Production	10	8.3	5.9	5.4	5.2	5.8	5.8	5.7	-41%	-32%
SF_6 Used in Magnesium Smelters and Casters	3.1	1.3	0.14	0.15	0.30	0.10	0.14	0.17	-95%	-87%
Production and Consumption of Halocarbons, SF_6 and NF_3	**0.82**	**4.8**	**11**	**12**	**11**	**11**	**11**	**11**	**1200%**	**120%**
Non-Energy Products from Fuels and Solvent Use	**5.8**	**10**	**11**	**11**	**11**	**10**	**11**	**12**	**109%**	**23%**
Other Product Manufacture and Use	**0.36**	**0.51**	**0.58**	**0.65**	**0.62**	**0.66**	**0.66**	**0.65**	**79%**	**27%**

Note: Totals may not add up due to rounding.

2

Decreases in process emissions from 2021 to 2022 of 0.2 Mt (-0.4%) were observed. Some subsectors and categories decreased, notably, the Iron and Steel Industry and Cement Production; however, these decreases were offset by an increase in the Non-Energy Products from Fuels and Solvent Use source category due to greater quantities of fuels being reported for non-energy purposes to the RESD. In 2022, the largest contributions to emissions in the sector originated from Metal Production (14 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) (11 Mt) (Table 2–8).

2.3.2.1. Mineral Products (2022 GHG Emissions, 8.4 Mt)

Cement Production dominates this subsector, accounting for 80% of emissions from Mineral Products in 2022. 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 Québec in 2017. Emission reductions in this subsector contributed to an overall reduction of 1.9 Mt (18%) from 2005 to 2022.

2.3.2.2. Chemical Industry (2022 GHG Emissions, 5.8 Mt)

From 2005 to 2022, an emissions decrease of 4.2 Mt (42%) is observed in the Chemical Industry as a whole. The main driver of emission reductions in this industry was the discontinuation of adipic acid production in 2009; this alone represents a decrease of 2.3 Mt from 2005.[7] N_2O emissions abatement installations at a nitric acid production facility are mainly responsible for a decrease of 0.94 Mt (88%) in the subsector since 2005. Other changes included a decrease in Petrochemical and Carbon Black Production (0.87 Mt) due to facility closures and feedstock changes in ethylene production, as well as a small decrease (0.11 Mt) 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 (2022 GHG Emissions, 14 Mt)

Emission reductions in the production of magnesium, aluminium, and iron and steel contributed to Metal Production overall reductions of 6.2 Mt (31%) between 2005 and 2022.

The aluminium industry decreased its PFC emissions by 2.7 Mt (79%), largely due to technological improvements. The Magnesium Production and Magnesium Casting industries also showed a decrease in emissions as a result of the replacement of SF_6 with alternatives and the closure of plants over the years. Primary magnesium production in Canada ceased in 2009.

From 2005 to 2022, emissions in the iron and steel industry decreased by 2.5 Mt (24%). The main driver behind the decrease in emissions was the 2013 closure of the iron and steel production processes at an integrated mill.

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

2.3.2.4. Production and Consumption of Halocarbons, SF_6 and NF_3 (2022 GHG Emissions, 11 Mt)

There is currently no 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. Hence, all emissions in this subsector are associated with the consumption of HFCs, PFCs, SF_6 and NF_3 only. Emissions from the consumption of HFCs increased by 5.8 Mt (120%) from 2005 to 2022. This can be explained by the replacement of ODSs by HFCs within the refrigeration, air conditioning, and foam blowing agent markets since the Montreal Protocol came into effect in 1996. HFC emissions decreased by 0.92 Mt (8%) between 2018 and 2022 due in part to reduced bulk imports. This reduction coincides with the implementation of the *Ozone-depleting Substance and Halocarbon Alternatives Regulations*, which for calendar years 2019 to 2023 limited total net HFC imports (expressed in CO_2 equivalent mass) to 90% of their average annual net imports in 2014 and 2015.[8] 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 (2022 GHG Emissions, 12 Mt)

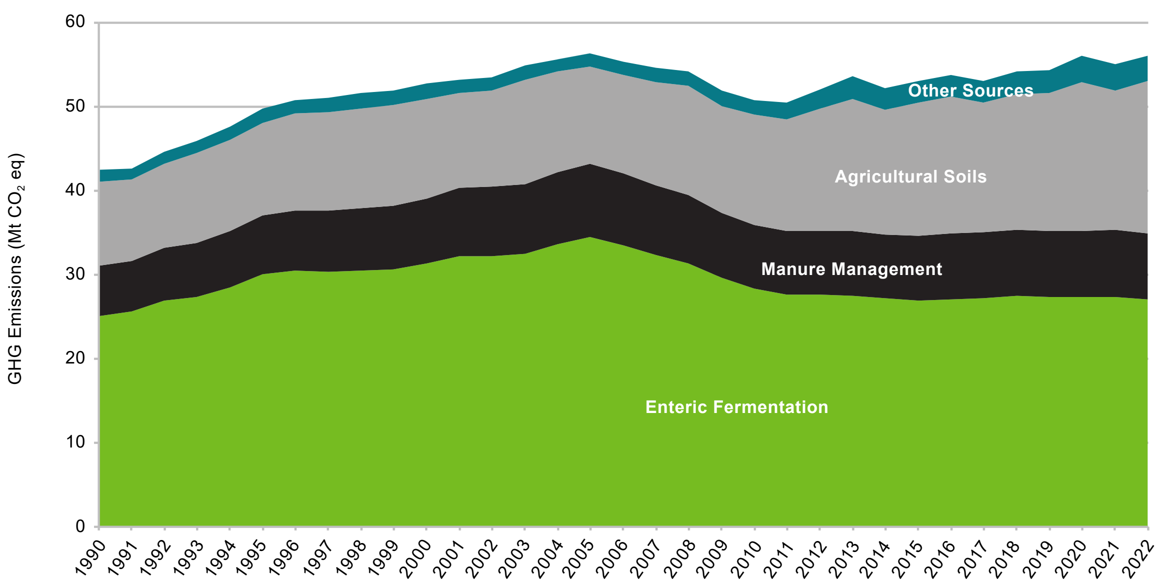
The Non-Energy Products from Fuels and Solvent Use category is one of the largest emission sources in the IPPU sector with its emissions increasing by 2.3 Mt (23%) from 2005 to 2022. The observed change is mostly attributable to the emissions from the feedstock use of butane and waxes, paraffin and unfinished products, which increased by 1.2 Mt (155%) and 0.8 Mt (22%), respectively over the period.

2.3.3. Agriculture Sector (2022 GHG Emissions, 56 Mt)

In 2022, emissions from the Agriculture sector accounted for 56 Mt, or 7.9%, of total GHG emissions in Canada, equivalent to 2005 levels, but corresponding to an increase of 14 Mt or 32% since 1990 (Figure 2–18 and Table 2–9). In 2022, the Agriculture sector accounted for 27% of national CH_4 emissions and 76% of national N_2O emissions, up from 26% and 43% 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.

Figure 2–18 **Trends in Canadian GHG Emissions from Agriculture Sources (1990–2022)**



8 The *Ozone-depleting Substances and Halocarbon Alternative Regulations* can be accessed here: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2016-137/ (Government of Canada, 2020).

Table 2–9 **GHG Emissions from Agriculture, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2017	2018	2019	2020	2021	2022	1990–2022	2005–2022
AGRICULTURE[a]	**42**	**56**	**53**	**54**	**54**	**56**	**55**	**56**	**32%**	**-1%**
By IPCC Category										
Enteric Fermentation	25	35	27	27	27	27	27	27	8%	-22%
Manure Management	6.0	8.7	7.9	7.9	7.9	7.8	7.9	7.8	31%	-10%
Agricultural Soils	10	12	15	16	16	18	17	18	81%	56%
Field Burning of Agricultural Residues	0.24	0.05	0.05	0.05	0.05	0.06	0.04	0.05	-79%	11%
Liming, Urea Application and Other Carbon-Containing Fertilizers	1.2	1.4	2.4	2.6	2.7	3.0	3.1	2.9	140%	101%
By Production System										
Livestock	33	45	37	37	37	37	37	37	13%	-18%
Dairy Cows	6.0	5.2	5.5	5.7	5.7	5.8	5.9	5.9	-2%	12%
Beef Cattle	23	35	26	27	26	26	26	26	12%	-25%
Swine	2.0	3.3	3.1	3.1	3.1	3.1	3.2	3.1	54%	-4%
Other Livestock[b]	1.4	2.1	1.9	1.9	1.9	1.9	1.8	1.8	35%	-14%
Crop	9.4	10	16	16	17	18	17	19	98%	78%
Inorganic Nitrogen Fertilizers[c]	5.7	6.7	10.4	11.5	11.7	13.2	13.1	12.4	119%	85%
Crop Residue Decomposition	2.8	3.2	4.5	4.4	4.3	4.5	3.5	4.4	57%	37%
Other Practices[d]	0.9	0.5	0.6	0.6	0.6	0.8	0.8	1.8	99%	254%

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.

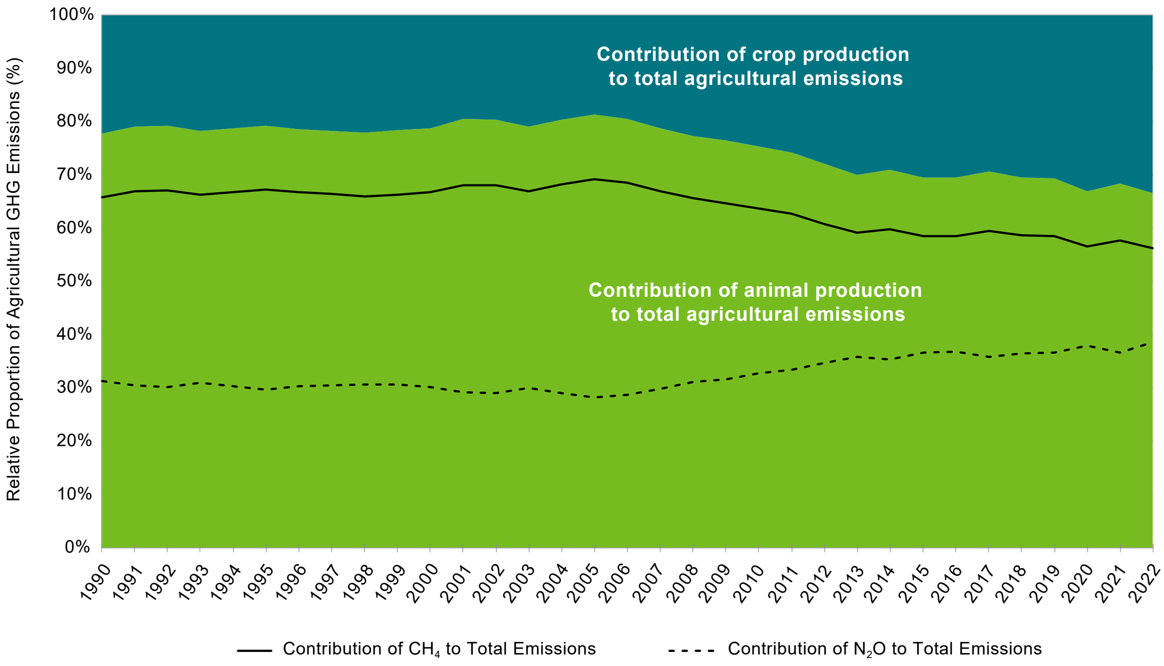
c. Inorganic fertilizers includes emissions of N_2O from the soil and the CO_2 emissions from the hydrolysis of carbon stored in urea.

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.

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 2022 are 6%, 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 67% of total agricultural emissions in 2022, considerably lower than the proportion in 2005 (81%) (Figure 2–19). 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 2022 are roughly equivalent to 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 the 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 2–19 **Proportions of Canadian Agricultural GHG Emissions Emitted as CH_4 and N_2O, or Attributed to Livestock and Crop Production (1990–2022)**



2.3.3.1. Enteric Fermentation (2022 GHG Emissions, 27 Mt)

Emissions from enteric fermentation originate almost entirely (96%) from Cattle Production in Canada. From 1990 to 2022, emissions increased from 25 Mt to 27 Mt, or 8%. 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 by 27% 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 13% since 1990, mainly due to a 30% reduction in the dairy cow population from 1990 to 2022 (StatCan, n.d.[i]). However, the average dairy cow today also consumes more feed and produces 58% 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 (2022 GHG emissions, 7.8 Mt)

Emissions from animal manure management systems increased from 6.0 Mt in 1990 to 7.8 Mt in 2022 (or 31%), driven by increases in livestock populations of beef, swine and poultry. The storage of manure results in both CH_4 (14% total agricultural CH_4) and N_2O (16% total agricultural N_2O). The management of beef and poultry manure produces predominantly N_2O, whereas pork 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 2.8 Mt in 1990 to 4.3 Mt (57%) in 2022. N_2O emissions closely follow the trend in beef populations, increasing from 3.2 Mt in 1990 to 4.3 Mt (33%) in 2005 and subsequently declining to 3.5 Mt (-19%) in 2022. 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 (2022 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 2022, 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 11 Mt in 2022, an increase of 130%, as inorganic nitrogen fertilizer consumption increased steadily from 1.2 Mt N to 2.8 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 2022. 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 1.9 Mt (233%) increase in emissions of CO_2 from urea and urea ammonium nitrate.

Emissions from crop residue decomposition ranged from a minimum of 2.3 Mt in 2002 (a drought year) to a maximum of 4.8 Mt in 2020, 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 as a result of severe drought conditions in the prairies that led to a sharp decline in crop production. Emissions rebounded to 4.7 Mt in 2022 as crop production, and therefore crop residue, returned to previous levels resulting in emissions from the loss of native soil carbon due to the lack of carbon input from crop residues to prairie soils in 2021. 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 2022, the adoption of conservation tillage (approximately 17 million hectares of cropland since 1990) reduced emissions by 2.2 Mt, while increases in irrigation increased emissions by 1.2 Mt, for a net reduction in emissions of 1.1 Mt.

2.3.4. Land Use, Land-Use Change and Forestry Sector (2022 Net GHG Emissions, 51 Mt, Not Included in National Totals)

The LULUCF sector reports anthropogenic GHG fluxes between the atmosphere and 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 as the sum of CO_2 and non-CO_2 emissions to the atmosphere and CO_2 removals from the atmosphere.

In 2022, LULUCF was estimated to emit 51 Mt to the atmosphere, compared with net emissions of 49 Mt in 1990 and 66 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 8% in 1990, 9% in 2005 and 7% in 2021 (Figure 2–6).

The net fluxes reported in the LULUCF sector were positive (emissions) for all years of the time series. Emissions increased over the early part of the time series until 2005 but have demonstrated a generally decreasing trend between 2005 and 2022. (Table 2–10). 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

Table 2–10 **GHG Emissions and Removals from LULUCF, Selected Years**

Sectoral Category		Net GHG Flux (Mt CO_2 eq)[a]									
		1990	2005	2017	2018	2019	2020	2021	2022	Change 1990–2022	Change 2005–2022
LAND USE, LAND-USE CHANGE AND FORESTRY TOTAL		**49**	**43**	**54**	**67**	**55**	**65**	**55**	**54**	**5**	**11**
a.	Forest Land	-89	-90	-91	-90	-90	-84	-90	-89	0	1.3
b.	Cropland	0.3	-6	-4	4	-9	-10	-9	-12	-13	-5.9
c.	Grassland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d.	Wetlands	5.4	5.3	5.2	5.5	3.3	3.2	3.1	3.2	-2.2	-2.1
e.	Settlements	1.8	1.9	1.7	1.6	1.4	1.3	1.3	1.3	-0.6	-0.6
g.	Harvested Wood Products	130	130	140	150	150	150	150	150	20	18

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

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. In recent years, since 2005, the decline and subsequent stabilization of harvest rates has resulted in a reduction in net CO_2 emissions from Forest Land from 2005 to 2022. 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 in some regions. Net fluxes from the LULUCF sector have fluctuated over recent years between lows in emissions of 5 Mt in 2015 to peaks of 43 Mt and 51 Mt in 2015 and 2022 respectively; The peak emissions in 2022 resulting 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 2–21).

2.3.4.1. Forest Land and Harvested Wood Products (2022 GHG Emissions, 24 Mt)

The Forest Land and Harvested Wood Products categories combined include GHG fluxes between the atmosphere and Canada's managed forests and emission and transfers out of the global harvested wood products (HWP) pool originating from domestic harvest. The total net flux from managed forests and resulting HWP amounted to an estimated net emissions of 24 Mt in 2022 (Figure 2–20), which combines net removals of 108 Mt from Forest Land and net emissions of 132 Mt from HWP from forest harvest.

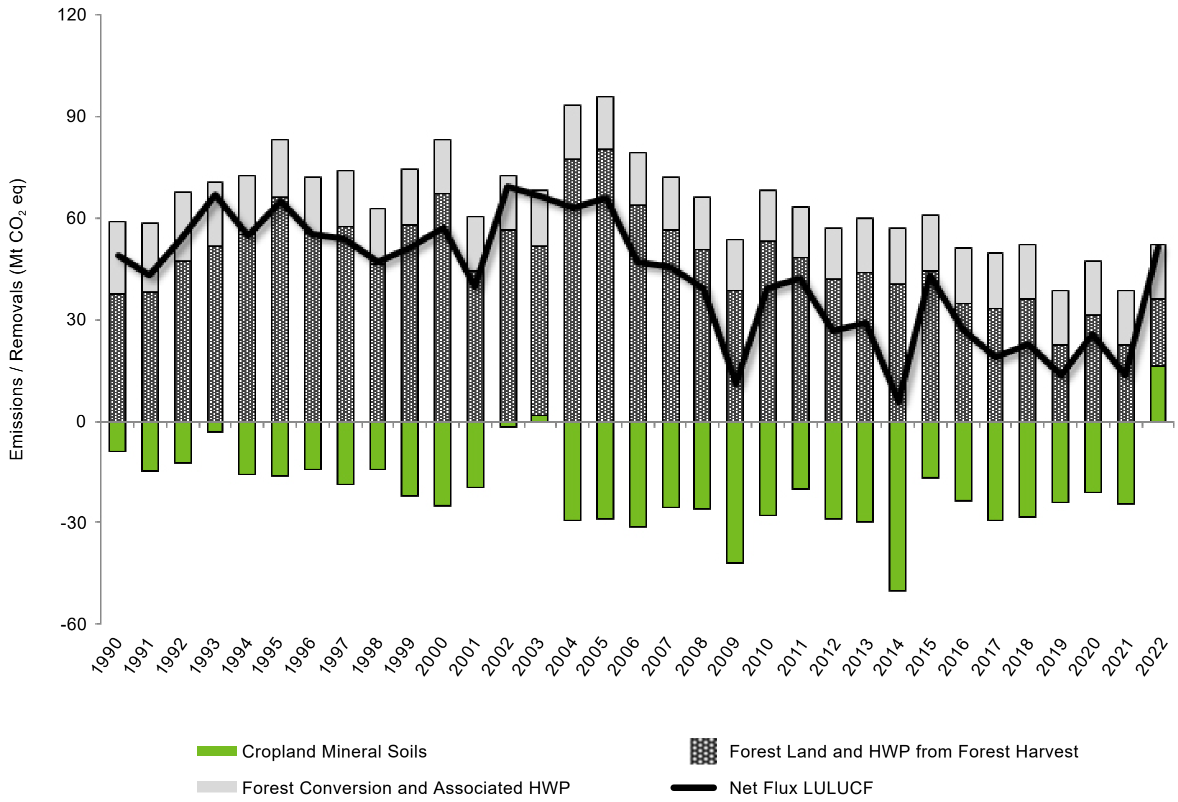
Net removals reported from Forest Land—after separating GHG fluxes associated with severe natural disturbances from anthropogenic fluxes—decreased from 89 Mt in 1990 to 64 Mt in 2005. The predominant anthropogenic trend directly associated with human activities in managed forests is a 34% increase in the carbon removed from forests through harvest and transferred to HWP between 1990 and the peak harvest year, 2004. This trend represented an increase in annual area harvested from 1.0 Mha in 1990 to 1.4 Mha in 2004. Of that annual harvest area 8.9%, 7.8% and 4.3% was harvested as clearcut with slash burning and further, there were 60 kha, 72 kha and 66 kha of commercial thinning in 1990, 2005 and 2022 respectively. The rest of annual harvest was clear cut leaving residue to decompose in place.

Since 2005, net removals from forest land increased to 110 Mt in 2022 as the area of mature forest has increased, and a greater proportion of past harvest disturbance is switching from a net source to a net sink in combination with increases in harvest that occurs on lands that had already been historically harvested. Harvest levels have remained relatively constant in recent years, with 2022 levels still 27% 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), and the indirect effect of exceptionally high wildfires in several years of the last decade, mainly in western Canada, that have impacted the commercially mature forest area in some regions and result in Forest Management agencies re-evaluating rates of harvest.

The decrease in forest removals nationally 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 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, 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 decrease in removals 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 an increasing sink in the Boreal East partially offsets the decline in the forest sink 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, as a result of increased insect disturbance. Since 2005, all ecozones have tended towards increasing sinks driven 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. In recent years, since 2017, wildfire has emitted on average 170 Mt CO_2 eq resulting in important changes in the age-class structure of the forest and carbon storage.

Emissions from HWP reflect the long-term storage of carbon in wood harvested in Canada's forests. Approximately one third of HWP (33% in 2022) 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 emissions for short-lived products, namely pulp and paper and bioenergy products, accounted for 26% and 37% of HWP emissions, respectively, in 2022. These same products accounted for 30% and 40% in 1990 and 35% and 40% in 2005. Wood processing waste in 1990 accounted for 15% of HWP emissions prior to the common practice in recent years of using wood waste for bioenergy production. In general, fluctuations in emissions from short-lived wood products more closely track recent trends in forest harvest rates and mainly as a result of these fluctuations, emissions from HWP from forests fluctuated between 120 Mt in 2009 (lowest harvest year), and a peak of 150 Mt in 1995.

Figure 2–20 **LULUCF Sector Net GHG Flux and Major Emission and Removal Components, 1990–2022**



EMISSIONS FROM FORESTRY

Forest lands used to produce commercial forest products are managed according to sustainable forest management principles (The State of Canada's Forests Report 2022). Forest management activities include harvesting, thinning, burning, volume inventory and assessment, site preparation, regeneration, stand tending, fertilization, weeding, fire suppression and pest management.

A subset of managed forests is used to produce commercial forest products. Timber harvesting for wood products results in the transfer of the C from the forest (i.e., within stem wood) to the harvested wood products (HWP) pool. Conversely, in natural ecosystems, this carbon is cycled within the forest between the atmosphere, the living biomass pool, the dead organic matter pool and the forest soil organic C pool. In both cases, the release of C from the stem wood occurs over multiple years.

When forested landscapes formed by natural disturbance dynamics transition to landscapes where human-caused disturbance such as timber harvest plays a significant role, there are changes in carbon (C) stocks and fluxes. Cases in which natural forests characterized by long natural disturbance intervals are replaced by managed forests with shorter harvest rotations results in a reduction in the total C stock (Harmon et al. 1990). During the transition from natural to managed forests, changes in C stocks are predominantly affected by the change in disturbance intervals and the age of the forest (Kurz et al. 1998).

While timber harvesting transfers the majority of carbon from stem wood to HWPs, this anthropogenic disturbance also results in emissions at the harvest site during the years immediately following the disturbance, largely attributed to decomposition. On harvested forest land, net emissions follow a similar pattern over the time series; for example, increasing initially, followed by a decrease as forests age and become productive, and eventually becoming a net sink. Over the period 40 to 60 years prior to 2005, the rate of harvested area in Canada increased and, consequently, the proportion of land emitting carbon also increased. With the reduction and subsequent levelling-off of the rate of area harvested since 2005, the proportion of land acting as a carbon sink is now increasing.[9]

As a result of increased harvest rates, C transfers to the HWP pool increased from 1990 to 2004 but have declined in recent years. Global C stocks of solid wood products from Canadian forests have continually increased from 1990 to present, whereas C stocks of paper products increased until 2005 and have since declined. At the end of their useful life, HWPs are transferred out of the HWP pool to the waste stream. Since the early 2000's, almost all wood waste produced during both the primary and secondary production of wood products in Canada is used in the production of bioenergy. The energy produced through wood waste is largely used in the production of HWP.[10]

Other forestry related emissions include the installation of permanent road infrastructure which results in deforestation emissions.[11] Further, fossil-fuel related GHG emissions occur from the use of fuel-based equipment in road building, harvesting, transportation and in wood products manufacturing and are quantified under various emission categories such as Energy, Transport and Industrial Processes. Finally, methane emissions from industrial wood waste are reported under the Waste category.[12]

2.3.4.2. Forest Conversion (2022 GHG Emissions, 16 Mt)

Forest conversion[13] 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 the emissions from HWP resulting from forest conversion activities since 1990. Emissions due to forest conversion fell from 21 Mt in 1990 to 16 Mt in 2022.

The conversion of forests to other land use 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. Since 1990, 1.7 million hectares of forest have been converted to other land uses in Canada. Geographically, the highest average annual rates of forest conversion occur in the Boreal Plains (24 kha per year) and the Boreal Shield East (8 kha per year), which account for 45% and 15%, respectively, of the total loss of forest area in Canada.

9 The trend in net emissions and removals from historically harvested land is reported in Table 6–5 and Figure 6–3 in Chapter 6, Part 1 and the full time series is available on open.canada.ca.

10 Details of HWP stocks and transfers can be found in CRF Tables 4s1 and 4s2 as well as Table 6–7 and Figure 6–8 of Chapter 6 with full time series available on open.canada.ca.

11 Areas of deforestation for forest roads is presented in Figure 6–11 with the underlying data available on open.canada.ca.

12 Details on emissions from other sectors are available in Table 2–12 and Economic Sector Tables, Table A10-3 with the full time series available on open.canada.ca.

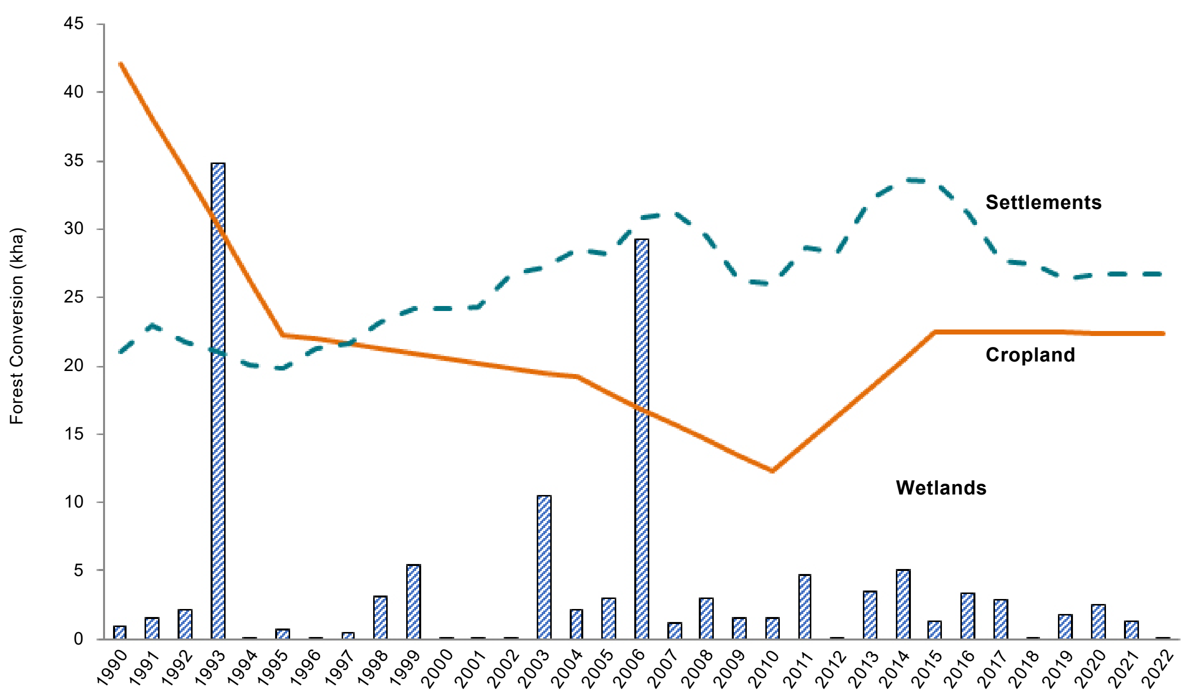
13 Forest conversion emissions are incorporated within sums of emissions of other land-use categories; therefore, the 16 Mt reported in this section is included in the sums associated with the other land-use category totals.

With a current annual conversion rate of 27 kha, Forest Land Converted to Settlements now accounts for the largest share of forest loss, comprising 54% in 2022, up from 33% in 1990 and slightly down from 57% in 2005 (Figure 2–21). This increase is mostly driven by an increasing trend in forest conversion for oil and gas infrastructure during the 1990–2006 period and for mining operations and industry around the years 2004–2015. 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 has occurred in the Boreal Plains (12 kha per year) followed by the Boreal Shield East (4.0 kha per year).

Forest clearing for agricultural expansion (Cropland) is the second-largest driver of forest conversion, accounting for 46% of all forest area lost in 2022. Annual rates dropped 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 previous decades. After 2010, annual rates increased to levels around 22 kha—similar to those observed in mid-1990s—due to more recent agricultural expansion primarily in the Boreal Plains, Subhumid Prairies and Mixedwood Plains (Figure 2–21).

Forest conversion to Wetlands is mainly driven by hydroelectric development (flooded land), which is episodic, corresponding to the occasional impoundment of large reservoirs (e.g., LaForge-1 in 1993 and Eastmain-1 in 2006, Figure 2–21). Cumulative areas of forest converted for the creation of hydro reservoirs since 1990 and the associated infrastructure equal 210 kha, accounting for 12% of total forest conversion areas over the reporting period. Hydroelectric development occurs mainly in the Taiga Shield East and the Boreal Shield East.

Figure 2–21 **Trends in Annual Rates of Forest Conversion to Cropland, Wetlands and Settlements**



2.3.4.3. Cropland (2022 GHG Emissions, 22 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 0.3 Mt in 1990, net removals of 23 Mt in 2005 and net emissions of 22 Mt in 2022, to the land sector estimates. This land category has net removals ranging from 4.2 to 45 Mt in all years except 1990, 1993, 2002, 2003, and 2022 where drought conditions in previous years decreased the crop production resulting in net emissions of 0.3, 4.3, 4.6, 8.3 and 22 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.

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 summerfallow 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 during the 1990–2006 period. 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 (-36 Mt) and 2014 (-45 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).

2.3.4.4. Other LULUCF Sources/Sinks (2022 GHG emissions, 5.6 Mt)

Other LULUCF sources/sinks include Wetlands, Settlements and Grassland, which contributed 3.3 Mt, 2.2 Mt and 0.001 Mt, respectively, to their combined net emissions of 5.6 Mt reported in 2022, down from 7.3 Mt in 1990. The Settlements category includes the growth of urban trees (annual removals of 4.4 Mt on average throughout the reporting period) and Land Converted to Settlements (annual emissions range between 5.5 Mt in 1996 and 7.0 Mt in 2016). The Wetlands category includes emissions from peatlands managed for peat extraction and from flooded lands (hydroelectric reservoirs). Trends in this category are mainly driven by the creation of large reservoirs before 1990, resulting in higher emissions over the 1990–1993 period. 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.

2.3.5. Waste Sector (2022 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 2022, comparable to emission levels of 21 Mt in 1990 (3.5% of total emissions) and of 24 Mt (3.2%) in 2005 (Figure 2–22 and Table 2–11). In 2022, landfilling (including municipal solid waste and industrial wood waste disposal) accounted for 19 Mt (or 84% of total Waste sector emissions), while Biological Treatment of Solid Waste (composting and anaerobic digestion), Wastewater Treatment and Discharge, and Incineration and Open Burning of Waste (excluding CO_2 emissions from incineration of biomass material) contributed 0.47 Mt, 2.5 Mt and 0.16 Mt, respectively.

Figure 2–22 **Trends in Canadian GHG Emissions from Waste (1990–2022)**

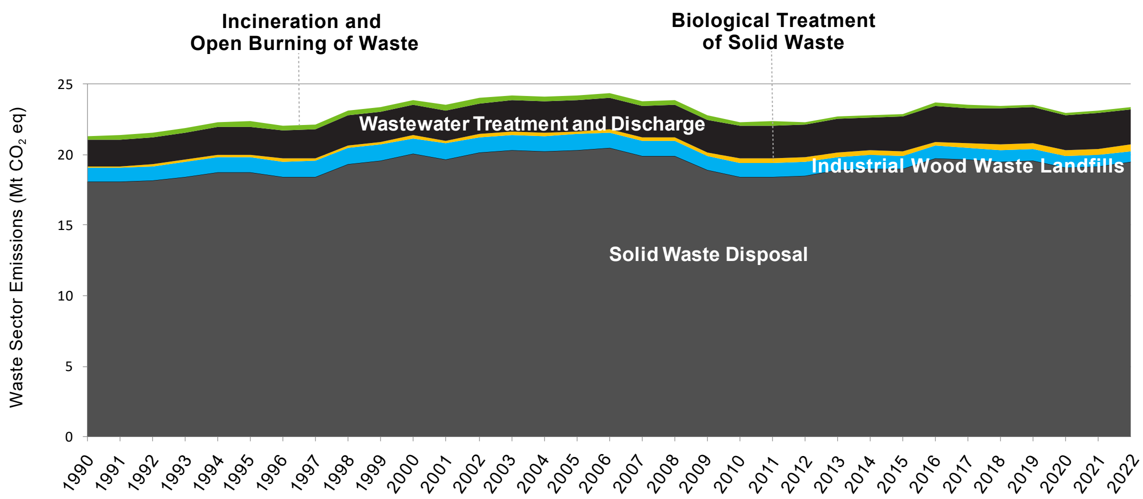


Table 2–11 **GHG Emissions from Waste, Selected Years**										
GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2017	2018	2019	2020	2021	2022	1990–2022	2005–2022
WASTE SECTOR	**21**	**24**	**24**	**23**	**24**	**23**	**23**	**23**	**10%**	**-4%**
Solid Waste Disposal (Landfills)	18	20	20	19	20	19	19	19	8%	-4%
Biological Treatment of Solid Waste	0.08	0.24	0.34	0.38	0.38	0.39	0.48	0.47	484%	95%
Wastewater Treatment and Discharge	1.9	2.2	2.5	2.6	2.5	2.5	2.5	2.5	31%	12%
Incineration and Open Burning of Waste	0.26	0.34	0.18	0.17	0.17	0.15	0.14	0.16	-39%	-53%
Industrial Wood Waste Landfills	1.00	1.08	0.86	0.84	0.82	0.80	0.78	0.76	-24%	-30%

Note: Totals may not add up due to rounding.

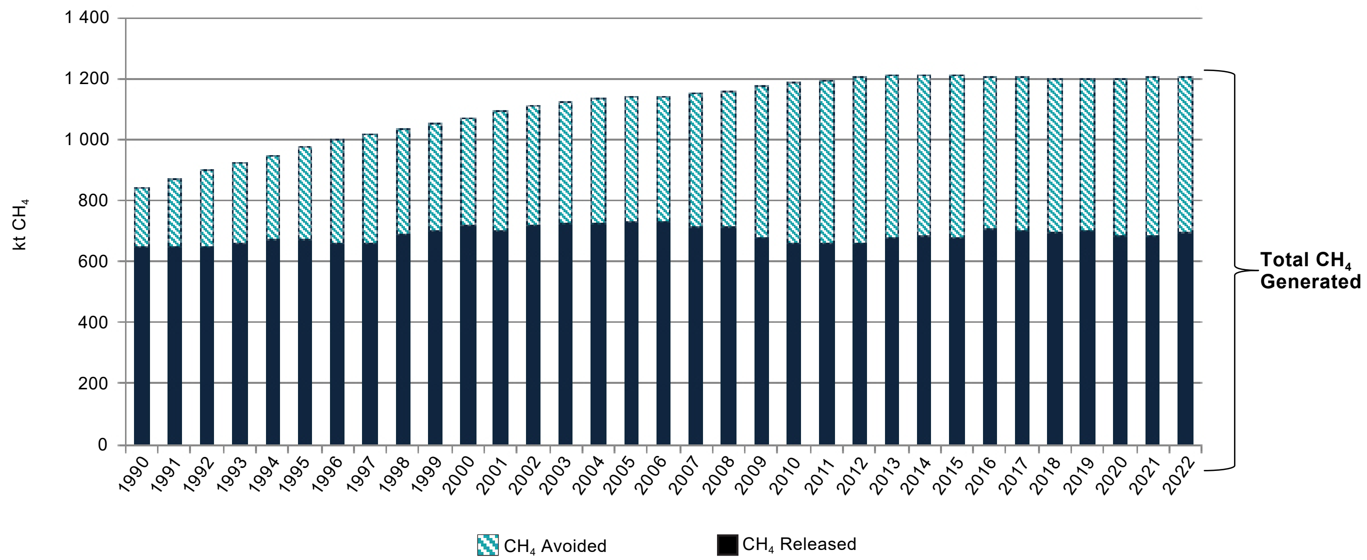
2

2.3.5.1. Solid Waste Disposal and Industrial Wood Waste Landfills (2022 GHG Emissions, 20 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. 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 increasing use of LFG capture technologies.

In 2022, emissions from MSW landfills were 19 Mt, while emissions from wood waste landfills were 1 Mt. Emissions from MSW landfills increased by 10% from 1990 to 2022 and have decreased by 4% from 2005 to 2022. Emissions from wood waste landfills decreased by 24% from 1990 to 2022 and by 30% from 2005 to 2022. The amount of CH_4 generated by MSW landfills has steadily increased since 1990, primarily as a result of a growing population producing more waste. This increase has been offset by an increase in the capture of LFG at landfills. In 2022, 42% of the LFG generated in landfills was recovered through LFG capture technologies or oxidized through cover material, compared with 23% in 1990 (Figure 2–23).

Figure 2–23 **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 (2022 GHG Emissions, 3.1 Mt)

Over the 1990–2022 time 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 39% (Figure 2–21 and Table 2–11).

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, emissions estimates are primarily grouped into the activity sectors defined by the IPCC (section 2.3). While this categorization is consistent with the UNFCCC reporting guidelines, 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 other (Table 2–12).

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. This is the approach that has been taken for reporting emission projections and progress towards Canada's GHG reduction targets in Canada's 2022 Greenhouse Gas and Air Pollutant Emissions Projections report, past Canada's Emissions Trends reports, in Canada's national communications and in biennial reports to the UNFCCC. Examining the historical path of 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. This approach is also more closely aligned with the sectoral categories of the Pan-Canadian Framework on Clean Growth and Climate Change, allowing Canada to track progress of its key policies and measures to reduce emissions.

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. For example, 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).

Annex 10 (available at open.canada.ca) contains a series of tables which show the distribution of national emissions allocated on the basis of the Canadian economic sector from which they originate for all years in the time series (1990–2022) and the relationship between economic and IPCC categories or sectors. Each Canadian economic sector includes all applicable emissions from energy-related and non-energy-related processes. Specifically, the Oil and Gas sector represents all emissions that are created in 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, and the production and processing of industrial goods such as paper or cement; the Buildings sector represents emissions arising directly from residential homes and commercial buildings; the Waste and other sector represents emissions that arise from solid and liquid waste, waste incineration, and coal production, light manufacturing, construction and forestry activities; and finally, 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. Similar tables for provinces and territories can be found in Annex 12 (available at open.canada.ca).

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, Agriculture and Building economic sectors (21 Mt or 11%, 4.6 Mt or 7.0%, and 3.9 Mt or 4.5%, respectively) being offset by decreases in other sectors, notably Electricity (-69 Mt or -59%), Heavy Industry (-10 Mt or -11%); and Waste and others (-4.3 Mt or -7.8%). Since 2005, Transport emissions have generally increased, with an important drop in 2020, bringing 2022 levels now similar to 2005 ones (0.13 Mt or 0.08%).

Oil and Gas

In 2022, the Oil and Gas sector produced the largest share of GHG emissions in Canada (31%) (Figure 2–24). Between 1990 and 2022, emissions from this sector increased by 99 Mt. 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 2022, emissions from this sector have generally increased steadily from 118 Mt in 1990 to 230 Mt in 2014. 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 was followed by a significant decrease of 17 Mt (7%) between 2019 and 2020. Most of the increase between 1990 and 2022 is due to considerable expansion in Canada's oil sands. Since 1990, oil sands production has increased by over 800% and emissions have increased by over 71 Mt (~470%) (refer to 'Trends in the Oil and Gas Sector' text box). The decrease between 2019 and 2020 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, as well as a sharp decrease in the price of crude oil in the early days of the COVID-19 pandemic. In 2021, emissions increased by 7 Mt (3%) as the industry rebounded from the early impacts of the pandemic. Emissions in 2022 were relatively stable with a 0.4% increase from 2021.

Transport

Canada's Transport sector is the second-largest contributor to Canada's GHG emissions, accounting for 22% of total emissions in 2022 (Figure 2–24). Between 1990 and 2022, emissions rose by 38 Mt (33%). Since then, emissions from this sector have continued to increase gradually, apart from a decrease between 2019 and 2020 largely due to fewer kilometers driven. Transport emissions in 2022 are slightly above 2005 levels (0.13 Mt or 0.08% since 2005). Section 2.3 discusses the main drivers of historical emissions trends associated with passenger and freight transport.

Electricity

In 2022, the Electricity sector (excluding industrial and commercial cogeneration) contributed 6.7% to total Canadian emissions (Figure 2–24). Between 1990 and 2022, emissions decreased by 47 Mt (50%). 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 69 Mt or 59% since 2005, despite the 10% increase in demand. Section 2.3 discusses the main historical drivers of emissions trends associated with electricity generation.

Heavy Industry

The Heavy Industry sector experienced some fluctuation in emissions over the reporting period. In 2022, the Heavy Industry sector contributed 11% to Canada's total emissions (Figure 2–24). Emissions from this sector were responsible for 16% of total Canadian emissions in 1990, falling to 12% in 2005. 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, representing a decrease of 10 Mt (11%) between 2005 and 2022.

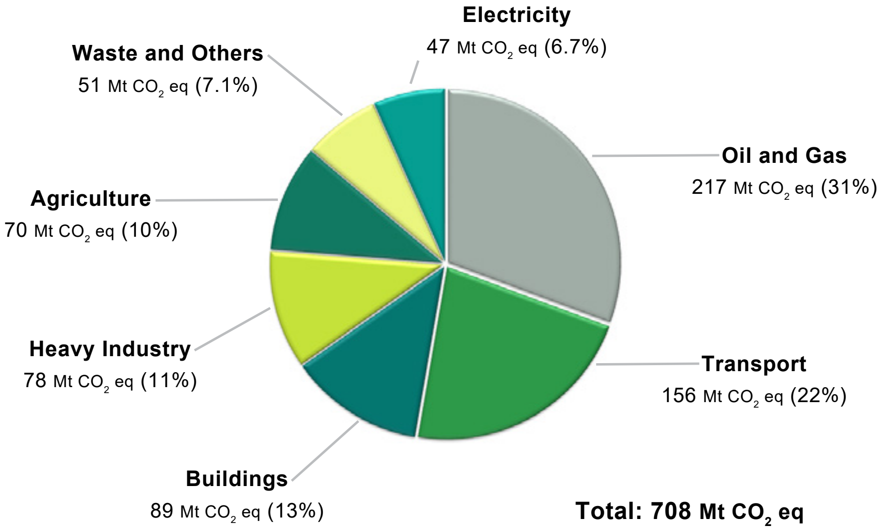
Buildings

In 2022, the Buildings sector contributed 13% to total Canadian emissions (Figure 2–24). While residential fuel use has remained relatively steady since 1990, increases in the service industry have resulted in an increase in emissions of 16 Mt (23%) between 1990 and 2022. Since 2005, emissions increased by 3.9 Mt or 4.5%. GHG emissions from the Buildings sector have increased with population growth and commercial development but, like all sectors of the economy, decreased in the 2008–2009 recessionary period and have remained relatively steady since then.

Agriculture and Waste and Others

Emissions from the Agriculture sector continued a slow upward trend throughout the reporting period, rising from 51 Mt in 1990 to 66 Mt in 2005, and70 Mt in 2022 (Figure 2–24). Emissions from the Waste and others sector decreased by 6.9 Mt (12%) since 1990 and 4.3 Mt (7.8%) since 2005. Overall, Waste emissions fluctuated and generally increased over the time series, from 21 Mt in 1990 to 23 Mt in 2022. Section 2.3 discusses the main historical drivers of emissions trends associated with Agriculture and Waste.

Figure 2–24 **Breakdown of Canada's GHG Emissions by Economic Sector (2022)**



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 2022, the largest contributor to O&G emissions was the Oil Sands category (87 Mt, or 40%), followed by Natural Gas Production and Processing (60 Mt, or 28%), Conventional Oil Production (39 Mt, or 18%) and Petroleum Refining (17 Mt, or 8%). 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 2022, the production of total crude oil increased by 193%. The increase was driven almost entirely by Canada's oil sands operations (mining, thermal in-situ extraction and crude bitumen/heavy oil upgrading) with total oil sands output (non-upgraded bitumen and synthetic crude oil production) increasing by over 800% since 1990, accounting for 80% of total crude oil production growth. In contrast, conventional crude oil production (including primary extraction in designated oil sands areas) increased by 40% over the same period. Consistent with the production increases, emissions from Conventional Oil Production increased by 8 Mt (about 24%), while emissions from oil sands increased by 71 Mt (about 470%).

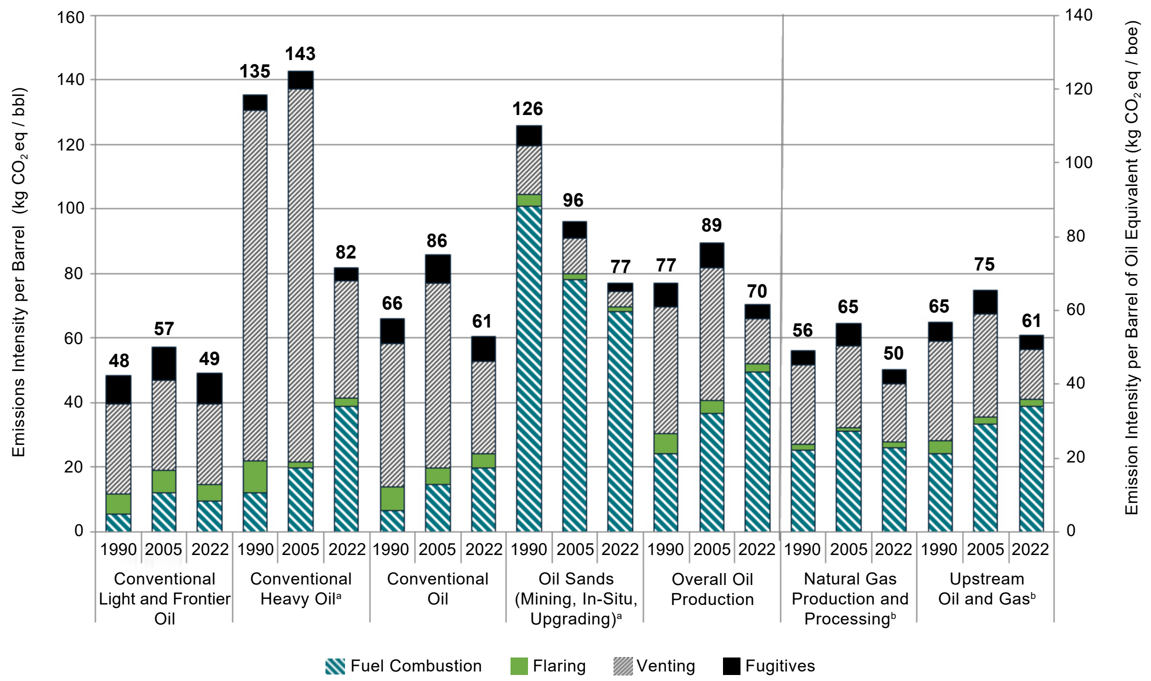
Emissions from Natural Gas Production and Processing have increased by 22 Mt (56%) since 1990, consistent with a 57% increase in gross production volumes. Most of this growth has occurred in northeastern British Columbia, which has accounted for 75% of the national production growth.

Emission Intensity

The emission intensity of overall oil production in Canada decreased by 8% between 1990 and 2022, from 77 to 70 kg CO_2 eq per barrel (Figure 2–B) with the most notable decrease of 21% occurring since 2015 where intensity was 89 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 over 100% per barrel of oil extracted (24 kg CO_2-eq per bbl in 1990 to 49 kg CO_2-eq per bbl in 2022), 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 operations themselves has declined steadily from 126 kg CO_2 eq per barrel in 1990 to 77 kg CO_2 eq per barrel in 2022. 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 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 180% while SCO production increased by only 43%. 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 8 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.

Figure 2–B **Emissions Intensity by Source Type for Oil and Gas (1990, 2005 and 2022)**



Notes:

Intensities are based on total subsector emissions and relevant production amounts. They represent overall averages, not facility intensities.

a. For intensity calculations, emissions and production associated with primary extraction of crude bitumen in designated oil sands areas (i.e. Athabasca, Cold Lake, Peace River) are removed from Oil Sands (Mining, In-situ, Upgrading) and included in Conventional Heavy Oil.

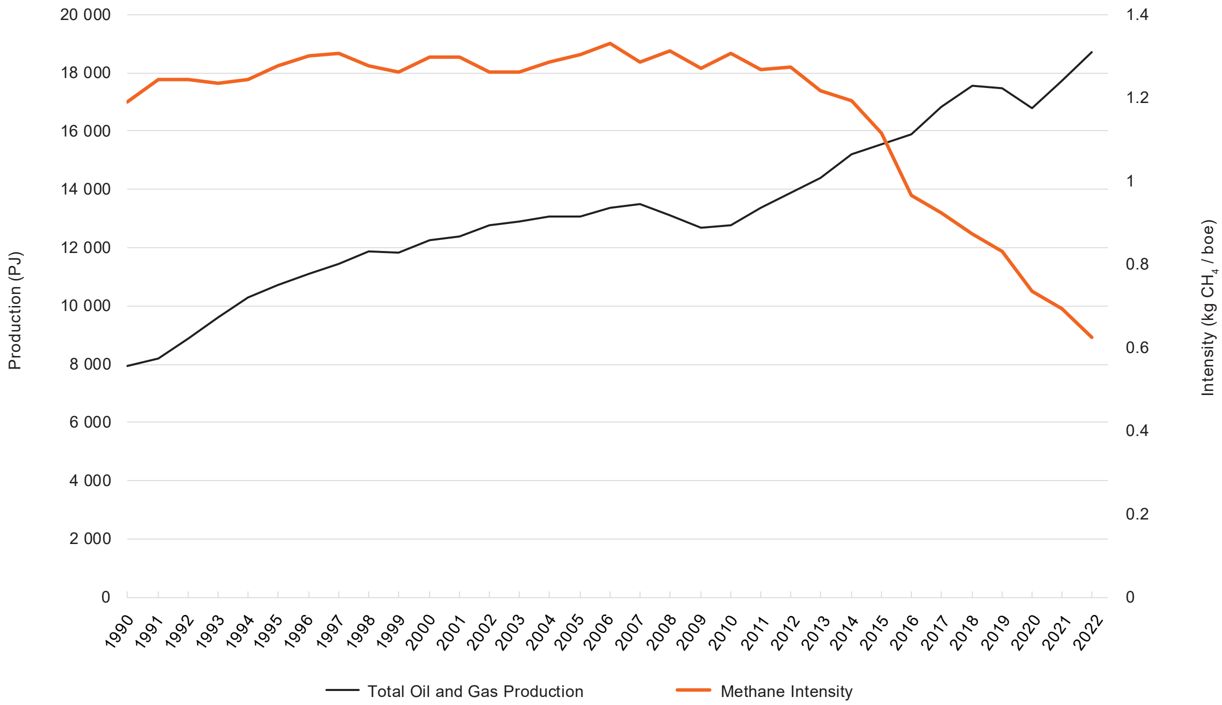
b. Calculated on a barrel of oil equivalent (boe) basis by converting production volumes to energy basis and then dividing by energy content of light crude oil (6.1215 GJ/bbl). [1 barrel (bbl) = 0.159 m^3]

Production data sources = Natural Gas: StatCan (1990–); Crude Oil: NB NRED (2023), SK MER (1990–2008, 2009–2011, 2012–), StatCan (n.d.[d], n.d.[h]); Oil Sands: AER (2023), Cenovus (2023).

In contrast to combustion emissions, venting, flaring and fugitive emissions per barrel of oil extracted have decreased by 64%, 60% and 41%, respectively, since 1990. These reductions are due to increased oil sands production, which produces much fewer fugitive emissions per barrel than conventional oil production, and 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 also contributed to a 50% 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 35%. 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 53% while production increased by 31%. Similarly, in British Columbia, the intensity decreased by 54%[14] at the same time as an 80% increase in production. In Saskatchewan, both methane intensity (-39%) and production (-10%) 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]

14 Emission estimates for this source are currently under review and upward revisions to CH_4 emissions in the years prior to 2020 are anticipated in the 2025 edition of this report, pending further data collection and analysis.

Table 2–12 **Trends in GHG Emissions by Canadian Economic Sector**

	1990	2005	2017	2018	2019	2020	2021	2022
	Mt CO_2 eq							
NATIONAL GHG TOTAL	**608**	**761**	**742**	**753**	**752**	**686**	**698**	**708**
Oil and Gas	**118**	**195**	**221**	**228**	**226**	**209**	**216**	**217**
Upstream Oil and Gas	98	172	201	209	206	192	198	198
Natural Gas Production and Processing	38	75	63	64	62	60	61	60
Conventional Oil Production	32	48	51	51	49	40	39	39
Conventional Light Oil Production	19	22	30	31	30	24	22	21
Conventional Heavy Oil Production	13	25	19	19	17	14	16	17
Frontier Oil Production	0.26	1.7	1.6	1.8	1.8	1.6	1.4	1.3
Oil Sands (Mining, In-situ, Upgrading)	15	36	77	82	84	81	86	87
Mining and Extraction	2.3	5.8	13	15	16	15	16	16
In-situ	4.6	13	42	44	44	42	45	45
Upgrading	8.4	17	22	24	25	25	25	25
Oil, Natural Gas and CO_2 Transmission	13	12	9.9	11	11	10	11	13
Downstream Oil and Gas	20	23	19	19	20	18	18	19
Petroleum Refining	18	22	18	18	19	16	17	17
Natural Gas Distribution	1.8	1.4	1.2	1.3	1.3	1.3	1.3	1.3
Electricity	**94**	**117**	**72**	**62**	**61**	**53**	**51**	**47**
Transport	**118**	**156**	**165**	**169**	**170**	**143**	**150**	**156**
Passenger Transport	80	95	100	102	103	83	86	90
Cars, Trucks and Motorcycles	71	85	89	90	91	75	78	80
Bus, Rail and Aviation	8.8	10	12	12	12	7.6	8.0	10
Freight Transport	30	48	50	52	52	46	50	52
Heavy-Duty Trucks, Rail	25	42	45	47	46	41	43	44
Aviation and Marine	4.7	5.4	4.7	4.8	5.5	5.4	6.7	7.3
Other: Recreational, Commercial and Residential	8.1	14	15	15	15	14	15	14
Heavy Industry	**97**	**88**	**77**	**80**	**79**	**74**	**78**	**78**
Mining	7.2	8.1	9.0	11	11	10	11	11
Smelting and Refining (Non-Ferrous Metals)	17	14	11	9.9	10	10	9.8	10
Pulp and Paper	15	9.0	6.9	7.9	8.2	7.3	7.6	7.6
Iron and Steel	17	16	15	16	15	12	14	13
Cement	10	13	11	11	11	10	11	11
Lime and Gypsum	2.8	3.5	2.6	2.4	2.3	2.2	2.2	2.6
Chemicals and Fertilizers	28	24	21	21	22	22	22	23
Buildings	**72**	**85**	**88**	**92**	**94**	**89**	**85**	**89**
Service Industry	28	40	47	49	50	47	45	46
Residential	45	45	42	44	44	42	41	42
Agriculture	**51**	**66**	**67**	**69**	**69**	**70**	**69**	**70**
On-Farm Fuel Use	8.2	9.4	14	15	15	14	14	14
Crop Production	9.4	10	16	16	17	18	17	19
Animal Production	33	46	37	38	38	38	38	37
Waste and Others	**57**	**55**	**51**	**52**	**52**	**48**	**49**	**51**
Waste	21	24	24	23	24	23	23	23
Coal Production	4.6	3.0	3.0	3.1	3.3	2.7	2.8	3.3
Light Manufacturing, Construction and Forest Resources	32	28	25	25	25	22	23	24

Notes:
Totals may not add up due to rounding.
Please refer to Annex 10 for a description of the relationship between these Canadian economic sectors and the IPCC sectors and categories. This Annex provides detailed tables showing the correspondence between emissions allocated to both breakdowns.
Provincial and territorial GHG emissions allocated to economic sectors are provided in Annex 12 of this report.
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.

ENERGY (CRF SECTOR 1)

3.1. Overview

In 2022, the Energy sector contributed 577 Mt (82%) 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 502 Mt (87%) of the Energy sector's GHG emissions while the remaining 75 Mt (13%) 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 3.2.4 to 3.2.8.

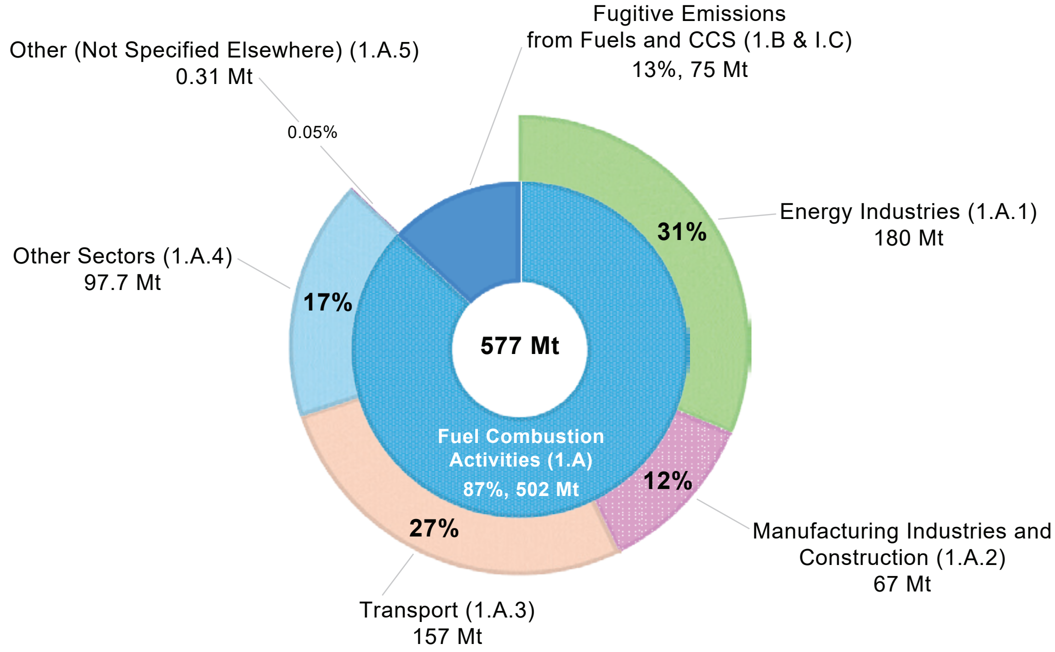
Table 3–1 **GHG Emissions from Energy**

GHG Source Category	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
ENERGY SECTOR	**489 000**	**626 000**	**613 000**	**622 000**	**622 000**	**558 000**	**569 000**	**577 000**
Fuel Combustion Activities (1.A)	**423 000**	**529 000**	**524 000**	**532 000**	**536 000**	**481 000**	**492 000**	**502 000**
Energy Industries (1.A.1)	143 000	207 000	195 000	193 000	193 000	180 000	183 000	180 000
Manufacturing Industries and Construction (1.A.2)	74 700	69 400	67 200	69 600	70 300	63 100	65 800	67 000
Transport (1.A.3)	118 000	157 000	163 000	167 000	168 000	141 000	149 000	157 000
Other Sectors (1.A.4)	86 800	94 500	98 300	102 100	104 000	96 700	93 900	97 700
Other (Not Specified Elsewhere) (1.A.5)	262	286	335	333	342	267	282	310
Fugitive Emissions from Fuels (1.B)	**66 000**	**97 000**	**89 000**	**89 000**	**86 000**	**77 000**	**77 000**	**75 000**
CO_2 Transport and Storage (1.C)	**NO**	**0.09**	**0.27**	**0.28**	**0.28**	**0.49**	**0.65**	**0.64**

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

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

Figure 3–1 **2022 Emission Contribution**



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.

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 **GHG Emission Change Due to Recalculations**

IPCC Categories	GHG Emissions (Mt CO_2 eq)							
	1990	2005	2016	2017	2018	2019	2020	2021
1 ENERGY SECTOR								
2022 submission	472	600	577	586	596	596	532	543
2023 submission	489	626	600	613	622	622	558	569
Total change due to recalculations	**17.5**	**25.7**	**23.6**	**26.8**	**25.6**	**25.8**	**25.8**	**25.6**
1.A – Fuel Combustion								
Method/Data/EFs	-0.3	-0.9	1.9	3.2	2.5	4.0	4.5	3.5
GWPs	-0.2	-0.2	0.1	0.1	0.1	0.1	0.1	0.1
1.B – Fugitive and 1.C – CO_2 Transport & Storage								
Method/Data/EFs	12.2	18.1	13.7	15.4	15.1	14.2	14.8	15.5
GWPs	5.8	8.7	7.9	8.0	7.9	7.5	6.5	6.4

Note: Totals may not add up due to rounding.

Overall, recalculations resulted in an increase of 25.6 Mt compared to the 2023 UNFCCC submitted value for 2021 with 6.5 Mt of the upward revision due to the adoption of AR5 global warming potentials (GWPs). Recalculations occurred for the following reasons:

Activity data: Revisions to activity data are a result of quality assurance/quality control (QA/QC) checks, data correction, reallocation or new information, and are as follows:

- Revisions of fuel consumption data in the *Report on Energy Supply and Demand in Canada (RESD) (Statistics Canada, No date)* generally result in a recalculation of most combustion sources. Revisions to the 2021 RESD data have been incorporated (as per standard practice) as an update to the 2021 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:
    - 2015 to 2021 coal data
    - 2018 to 2021 coke (coal) data
    - 2016 to 2021 diesel fuel oil data
    - 2016 to 2021 heavy fuel oil data
    - 2005 to 2021 light fuel oil data
    - 2005 to 2021 natural gas data
    - 2019 to 2021 still gas data
- Revisions of non-RESD data consist of:
    - 2002 to 2015 quantity of coal produced
    - 1990 to 2021 quantity of landfill gas combusted
    - 2015 to 2021 quantity of mixed waste fuel combusted
    - 1996 to 2015 quantity of municipal solid waste combusted
    - 1990 to 2015 quantity of medical waste 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 include:

- a method of estimating emissions for sludge gas from wastewater treatment used for energy purposes (refer to Annex 3, section A3.6.4 for a detailed description of the method);
- methodological updates to incorporate atmospheric measurements of methane emissions from key sources (storage tanks, unlit flares, compressor buildings, wellheads, and engine sheds) in the upstream oil and gas (UOG) sector in Alberta, British Columbia, and Saskatchewan into emission estimates (refer to Annex 3, section A3.2.2 for more details); and
- improvements to methods used to estimate emissions from pneumatic equipment in the UOG sector.

Emission Factors: Recalculation occurred due to revisions (presented in Annex 6, section 6.1) of:

- CO_2 oxidation factors for all coal used in stationary fuel combustion;
- CO_2 emission factors for petroleum coke stationary fuel combustion; and
- CH_4 emission factors for producer-consumed natural gas stationary fuel combustion in British Columbia, Alberta and Saskatchewan.

Finally, corrections to modelled surface casing vent flow (SCVF) emissions also resulted in recalculations to fugitive emissions.

2 Statistics Canada (StatCan) annually publishes a revised, final version of the previous year's (preliminary) energy data. Currently, energy data for 2022 are preliminary and are subject to revision in late 2024.

MEMO ITEMS AND EMISSION ALLOCATION

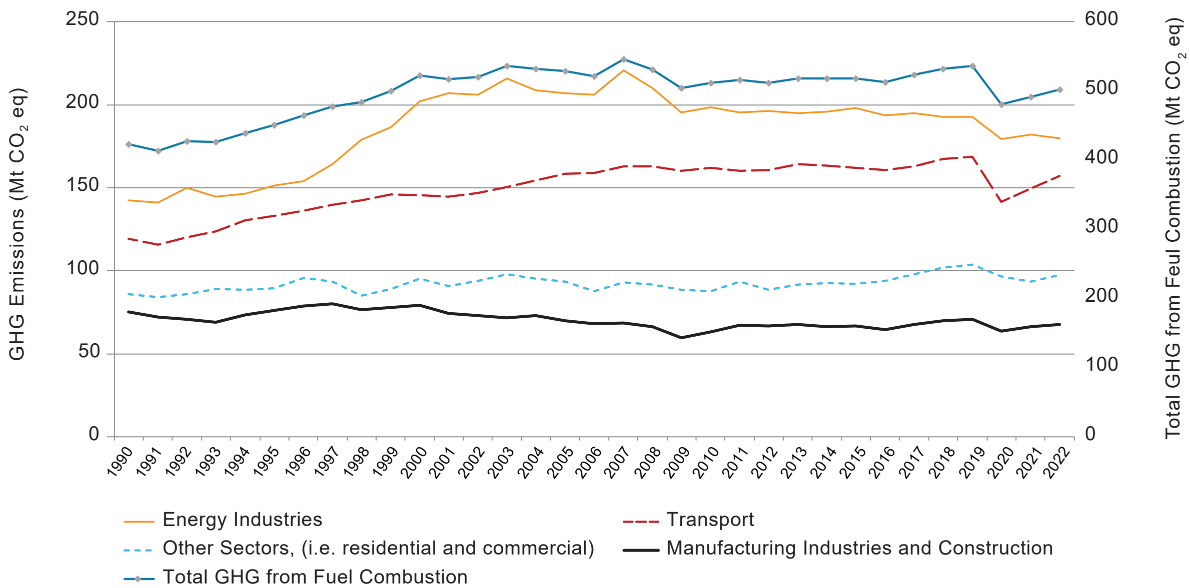
- Only the CH_4 and N_2O emissions from the combustion of biomass and biofuels are included while their CO_2 emissions appear as a memo item in UNFCCC inventory reporting tables.
- GHGs from international aviation and international navigation activities are also reported as a memo item.
- Off-road emissions from vehicles and machinery including fishing vessels appear in the separate and distinct mobile subcategor ies where they occur such as 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 reporting table categorization, and differs from the emissions allocation presented in Chapter 2, Annex 9 and Annex 11, 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 (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).

3.2. Fuel Combustion Activities (CRF 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 the use of residential fuel wood and biodiesel. Instead, CO_2 from biomass combustion appears in the memo item section of the CRF table. Major categories include Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors. Annex 3.1, Methodology and Data for Estimating Emissions from Fossil Fuel Combustion, presents the methods used to calculate emissions from fuel combustion. The estimation methods are consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) Tier 2 and Tier 3 approach, with country-specific emission factors and parameters.

In 2022, about 502 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 18.7% since 1990. Between 1990 and 2022, emissions from the Energy Industries (1.A.1) category increased by 26.1% (37.3 Mt), the Manufacturing Industries and Construction (1.A.2) category decreased by 10.3% (-7.7 Mt), the Transport (1.A.3) category increased by 32.5% (38.4 Mt), and the Other Sectors (1.A.4) category increased by 12.7% (11.0 Mt) (see Figure 3–2).

Figure 3–2 **GHG Emissions from Fuel Combustion**



3.2.1. Comparison of the Sectoral Approach with the Reference Approach

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

3.2.2. International Bunker Fuels

Emissions from fuels used for international navigation and international aviation are reported separately under the memo item International Bunkers, following 2006 IPCC Guidelines and UNFCCC reporting guidance.

3.2.2.1. International Aviation (CRF Category 1.D.1.a)

Emissions (Table 3–3) were calculated using the same methods listed in the Domestic Aviation section (see section 3.2.6.2). Fuel-use data are reported in the RESD as being sold to domestic and foreign airlines. However, with the Aviation Greenhouse Gas Emission Model (AGEM), flight-by-flight aircraft movements are used to determine whether a flight stage is domestic or international. This method greatly improves the allocation between domestic and international flights.

Exercise care when comparing emission estimates in this category against those reported by the International Energy Agency (IEA). The method employed in the national inventory uses detailed domestic and international movements based on the flight's origin and destination. The fuel consumption values (broken down into domestic and international sectors) reported to the IEA by Canada assume that all fuel sold to Canadian carriers is domestic and that all fuel sold to foreign carriers is international. Given that many movements by Canadian carriers are international in nature and that the reporting requirements for these two separate reports (UNFCCC, IEA) do not align, the reported values also will not align.

3

Table 3–3 **GHG Emissions from Domestic and International Aviation**

GHG Source Category	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
International Aviation	5 800	10 100	13 100	15 000	15 200	6 580	6 610	11 400
Domestic & Military Aviation	7 510	7 710	7 930	8 660	8 580	4 750	5 600	7 680
Total	**13 300**	**17 800**	**21 100**	**23 700**	**23 700**	**11 300**	**12 200**	**19 100**

Note: Totals may not add up due to rounding.

3.2.2.2. International Navigation (CRF Category 1.D.1.b)

Emissions (Table 3–4) were calculated using the same methods listed in the Domestic Navigation section (see section 3.2.6.2). Fuel-use data are reported in the RESD as being sold to domestic or foreign flag vessels. However, with the Marine Emission Inventory Tool (MEIT), vessel movements determine whether a voyage is domestic or international, as defined by the 2006 IPCC Guidelines. This method greatly improves the allocation between domestic and international movements.

Similar to the Aviation subcategory, take careful consideration when comparing fuel consumption (in energy terms) in this subcategory against those of the RESD and IEA due to different approaches. The method employed in the national inventory uses detailed domestic and international movements based on a vessels 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.

Table 3–4 **GHG Emissions from Domestic and International Navigation**

GHG Source Category	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
International Navigation	7 210	9 390	7 260	7 720	7 220	5 990	6 270	6 060
Domestic, Fishing & Military Navigation	3 100	4 020	3 460	3 470	4 310	3 840	4 420	4 960
Total	**10 300**	**13 400**	**10 700**	**11 200**	**11 500**	**9 830**	**10 700**	**11 000**

Note: Totals may not add up due to rounding.

3.2.3. Feedstocks and Non-Energy Use of Fuels

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).

3.2.4. Energy Industries (CRF Category 1.A.1)

3.2.4.1. Source 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.

In 2022, the Energy Industries category accounted for 180 Mt (26%) of Canada's total GHG emissions, with a 26% (37.3 Mt) increase in total GHG emissions since 1990. The Public Electricity and Heat Generation subcategory accounted for 31% (56.4 Mt) of the GHG emissions from Energy Industries, while the Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries subcategories contributed 7.9% (14.2 Mt) and 61% (110 Mt), respectively (Table 3–5). Chapter 2, Emissions Trends, has further discussion of trends in emissions from the Energy Industries category.

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 (CRF Category 1.B)).

Public Electricity and Heat Generation (CRF 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. 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.

Table 3–5 **Energy Industries GHG Contribution**

GHG Source Category	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
ENERGY INDUSTRIES TOTAL (1.A.1)	**143 000**	**207 000**	**195 000**	**193 000**	**193 000**	**180 000**	**183 000**	**180 000**
Public Electricity and Heat Generation	94 100	124 000	79 200	70 700	69 400	61 800	60 700	56 400
Petroleum Refining	17 400	20 000	14 600	14 800	15 600	13 600	13 800	14 200
Manufacture of Solid Fuels and Other Energy Industries[a]	31 500	63 600	102 000	108 000	108 000	104 000	108 000	110 000

Notes:
Totals may not add up due to rounding.
a. In accordance with the UNFCCC Common Reporting Format tables, Manufacture of Solid Fuels and Other Energy Industries includes stationary combustion emissions from coal mines. However, in Annexes 10 and 12, these emissions are included in the Coal Production category.

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 (CRF Category 1.A.1.b)

The Petroleum Refining subcategory includes 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 either internally generated fuels (such as still gas and petroleum coke) or purchased fuels (such as natural gas). 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 operations.

Manufacture of Solid Fuels and Other Energy Industries (CRF 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, and coal mining industries. Reported emissions from pipeline transmission appear in the Pipeline Transport subcategory (1.A.3.e.i) and off-road transport emissions in the mining and oil and gas extraction industries in the 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.

3.2.4.2. Methodological Issues

The methodology described in Annex 3.1 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 (CRF 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 Annex 3.1 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 CRF subcategories uses the RESD input data.[3] See Annex 3.1 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 CRF tables as a memo item.

Petroleum Refining (CRF 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, flaring emissions are calculated and reported separately in the Fugitive Emissions from Fuels category. Subtracting fuel-use and emission data associated with flaring avoids double counting. See Annex 3, section A3.2.2.8, for more details.

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

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

Calculated emissions for this subcategory use all fuel attributed to fossil fuel 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 Annex 3, 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 Annex 6), 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.

3.2.4.3. Uncertainties 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 fuels 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.

The estimated uncertainty for CH_4 (±111%) and N_2O (±276%) 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 3.2.4.5, 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 for natural gas production and processing, conventional crude oil production, and in-situ bitumen extraction. 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. Emissions estimates for the natural gas industry used provincially weighted natural gas emission factors since plant-level information on the composition of consumed unprocessed natural gas (which will vary from plant to plant) is unavailable.

3.2.4.4. QA/QC and Verification

The completed quality control checks 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.

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

As described in Chapter 1, Canada has a reporting program that 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 GHG reporting program 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.

3.2.4.5. Recalculations

Several improvements and activity data revisions have contributed to increased data accuracy and better comparability, as well as consistency with the 2006 IPCC Guidelines and UNFCCC reporting guidelines. Overall recalculation to the Energy Industries category, with estimates for 2021 increasing by 5.5 Mt CO_2 eq compared to the previous submission, due to:

- updated GWP to IPCC AR5 values, resulting in recalculations between 1990 and 2021 (emissions change ranged from +0.1 Mt in 1991 to +0.3 Mt in 2008 and 2021 saw a 0.24 Mt increase);
- revised RESD data, including updates to coal, diesel, heavy fuel oil, light fuel oil, natural gas, still gas, and petroleum coke, resulted in recalculations between 2005 and 2021 (emissions change ranged from -4.3 Mt in 2015 to +4.8 Mt in 2020 and 2021 saw a 4.7 Mt increase);
- revised CH_4 emission factors for producer-consumed natural gas in British Columbia, Alberta, and Saskatchewan caused increase emissions from 1990 to 2021 (emissions change ranged from +0.01 Mt in 1993 to +0.8 Mt in 2008 and 2021 saw a 0.5 Mt increase);
- revised CO_2 emission factors for petroleum coke resulted in recalculations between 2014 and 2021 (emissions change ranged from -0.05 Mt in 2021 to +0.11 Mt in 2015); and
- revised oxidation factors for all coal types resulted in recalculations between 1990 and 2021 (emissions change ranged from -0.62 Mt in 2000 to -0.02 Mt in 2021).

3.2.4.6. Planned Improvements

Environment and Climate Change Canada (ECCC), Natural Resources Canada (NRCan), and 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; and
2. improvements to data collection methods regarding the movement of fossils, and renewable fuels via rail and marine vessels.

Canada is focused on developing country-specific emission factors with improvements that prioritize fuels with 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. Annex 6 of this report presents the results of these improvement activities. Canada will continue to assess and identify additional fuels for improvement.

In addition, work is under way to investigate the possibility of developing a bottom-up inventory for the Public Electricity and Heat Generation subcategory, consistent with Tier 3 methods. Further research and investigations are necessary to ensure correct allocation of emissions from privately owned combined heat and power plants and heat plants.

3.2.5. Manufacturing Industries and Construction (CRF Category 1.A.2)

3.2.5.1. Source 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.

In 2022, the Manufacturing Industries and Construction category accounted for 67 Mt (9.6%) of Canada's total GHG emissions, with a 10% (7.7 Mt) decrease in overall emissions since 1990 (refer to Table 3–6 for more details). Within the Manufacturing Industries and Construction category, 39 Mt (58%) of the GHG emissions are from the Other subcategory, which is made up of mining, construction, off-road (associated with the manufacturing, mining and construction) along with other manufacturing activities. This subcategory is followed by, in order of decreasing contributions, the Chemicals (9.2 Mt, 13.7%), Pulp, Paper and Print (6.86 Mt, 10.2%), Iron and Steel (4.89 Mt, 7.3%), Non-ferrous Metals (3.79 Mt, 5.7%), and Non-metallic Minerals (3.23 Mt, 4.8%) 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.

Table 3–6 **Manufacturing Industries and Construction GHG Contribution**

GHG Source Category	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
MANUFACTURING INDUSTRIES AND CONSTRUCTION TOTAL (1.A.2)	**74 700**	**69 400**	**67 200**	**69 600**	**70 300**	**63 100**	**65 800**	**67 000**
Iron and Steel	4 940	5 510	6 000	6 380	6 060	4 560	5 140	4 890
Non-ferrous Metals	3 530	3 830	3 420	2 950	3 430	3 240	3 010	3 230
Chemicals	8 300	8 300	9 800	9 400	9 600	9 600	9 400	9 200
Pulp, Paper and Print	14 460	8 580	6 370	7 070	7 100	6 510	6 830	6 860
Food Processing, Beverages and Tobacco[a]	IE	IE	IE	IE	IE	IE	IE	IE
Non-metallic Minerals	3 940	5 380	4 240	4 310	4 200	3 670	3 690	3 790
Other	39 600	37 800	37 300	39 400	39 900	35 600	37 700	39 000
Mining (excluding fuels) and Quarrying[b]	4 160	3 980	4 010	5 460	5 440	4 830	5 640	5 650
Construction	1 880	1 440	1 300	1 380	1 440	1 430	1 460	1 590
Off-road Manufacturing, Mining and Construction	12 400	16 200	19 000	19 900	20 200	17 400	18 400	18 600
Other Manufacturing	21 200	16 200	13 000	12 600	12 800	11 900	12 200	13 100

Notes:
IE = Included elsewhere
Totals may not add up due to rounding.
a. Food Processing, Beverages and Tobacco emissions are included under Other Manufacturing.
b. In accordance with UNFCCC Common Reporting Format tables, combustion emissions from coal mines are excluded from Mining (excluding fuels) and Quarrying. However, in Annexes 9 and 11, these emissions are included in the Mining category.

GHG emissions resulting from fuel combustion for the generation of electricity or steam by an industry are assigned to the corresponding industrial subcategory (see Annex 3.1). 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.

3.2.5.2. Methodological Issues

Calculation of GHG emissions from fuel combustion for each subcategory within the Manufacturing Industries and Construction category uses the methodology described in Annex 3.1, including the off-road method, which is consistent with an IPCC Tier 2 approach. GHG emissions generated from the use 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. 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 appear separately in the UNFCCC CRF tables as a memo item.

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

Iron and Steel (CRF 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 the amount of fuel flared in the 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 as a reagent for the reduction of iron ore in blast furnaces.

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

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

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

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

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

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

Food Processing, Beverage and Tobacco (CRF 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 (CRF Category 1.A.2.f)

The RESD provides all fuel-use data for this subcategory, except for waste fuel, which comes from annual industry data supplied by the CEEDC.

Other (Mining, Construction and Other Manufacturing) (CRF 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.

3.2.5.3. Uncertainties 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. Section 3.2.4.5, Recalculations, presents a discussion on updated RESD fuel-use data.

3.2.5.4. QA/QC and Verification

The completed QC checks were consistent with the 2006 IPCC Guidelines. Elements of the QC checks included a review of the estimation model, activity data, emission factors, time-series consistency, transcription accuracy, reference material, conversion factors and unit labelling, and sample emission calculations.

QC checks completed on the entire stationary combustion GHG estimation model and time series included the following areas: emission factors, activity data and CO_2, CH_4 and N_2O emissions. No mathematical or reference errors were found during the QC checks. The data, methodologies and changes related to the QC activities are documented and archived.

3.2.5.5. Recalculations

There are revised emissions estimates for all years, with estimates for 2021 decreasing by 0.34 Mt CO_2 eq over the previous submission because of:

- updated GWP to IPCC AR5 values, resulting in recalculations between 1990 and 2021 (emissions change ranged from -0.07 Mt in 2019 to -0.04 Mt in 1993 and 2021 saw a 0.07 Mt decrease);
- revised RESD data, including coal, coal coke, diesel, heavy fuel oil, light fuel oil, natural gas, and propane, which affected 2007 to 2021 (emissions change ranged from -0.7 Mt in 2012 to -0.2 Mt in 2019 and 2021 saw a 0.5 Mt decrease);
- revised CO_2 emission factors for petroleum coke resulted in recalculations between 2014 and 2021 (emissions change ranged from -0.02 Mt in 2021 to +0.05 Mt in 2018); and
- revised oxidation factors for all coal types resulted in recalculations between 1990 and 2021 (emissions change ranged from -0.06 Mt in 2012 to -0.03 Mt in 2009 and 2021 saw a 0.4 Mt decrease).

3.2.5.6. 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 3.2.4.6, Planned Improvements for more detail on StatCan and the Trilateral Energy Working Group's activities.

There are several planned updates to off-road emissions modelling inputs. Refer to 3.2.6.6, Planned Improvements for further details.

In addition, the UNFCCC Expert Review Team (ERT) recommended reporting GHG emissions associated with the 1.A.2.e Food Processing, Beverage and Tobacco sector separately from subcategory 1.A.2.g, Other. However, StatCan does not currently have the needed information to further disaggregate fuel-use data to this level of detail. Investigations of additional data sources and methods continue, with the goal of reallocating the data where possible.

3.2.6. Transport (CRF Category 1.A.3)

In 2022, transport-related GHG emissions total 157 Mt, accounting for about 22% of Canada's total GHG emissions (Table 3–7). 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 28.7 Mt (116%) for LDGTs and 21.3 Mt (136%) 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 Mt since 1990. Since 1990, emissions from the Transport category have increased 32% and have contributed the equivalent of 38% of the total overall growth in emissions observed in Canada.

3

Table 3–7 **Transport GHG Emissions**

	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
TRANSPORT	**118 000**	**157 000**	**163 000**	**167 000**	**168 000**	**141 000**	**149 000**	**157 000**
Domestic Aviation[a]	7 270	7 450	7 700	8 410	8 340	4 560	5 400	7 490
Road Transportation	91 600	122 000	129 000	132 000	132 000	111 000	116 000	120 000
Light-Duty Gasoline Vehicles	44 200	40 600	33 600	33 000	32 300	25 000	24 100	23 400
Light-Duty Gasoline Trucks	24 700	40 900	51 600	53 300	55 000	47 200	50 500	53 400
Heavy-Duty Gasoline Vehicles	4 790	4 620	4 420	4 460	4 520	4 190	4 300	4 060
Motorcycles	204	459	898	922	952	773	765	721
Light-Duty Diesel Vehicles	367	665	613	587	504	310	325	339
Light-Duty Diesel Trucks	887	748	641	719	742	598	720	919
Heavy-Duty Diesel Vehicles	15 700	34 300	37 000	38 400	37 500	32 600	35 300	37 100
Propane and Natural Gas Vehicles	761	23	114	132	171	178	190	206
Railways	6 840	6 510	7 170	7 320	7 380	6 850	6 760	6 760
Domestic Navigation[a, b]	2 200	3 120	3 200	3 220	4 050	3 610	4 150	4 670
Other Transportation[c]	10 400	17 900	15 700	16 500	16 500	15 300	16 400	17 600
Off-Road	3 460	7 750	8 110	8 070	8 020	7 520	7 700	7 500
Pipeline Transport	6 920	10 100	7 570	8 400	8 500	7 760	8 740	10 100

Notes:
Totals may not add up due to rounding.
a. Excludes emissions from military equipment, reported in the Other (Not Specified Elsewhere) (CRF Category 1.A.5) categories.
b. Excludes emissionsfrom fishing vessel which are reported in the Agriculture/Forestry/Fishing categories.
c. Excludes off-road emissions reported in the Manufacturing Industries and Construction and Other Sectors categories.

3.2.6.1. Source Category Description

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

- Domestic Aviation
- Road Transportation
- Railways
- Domestic Navigation
- Pipeline Transport
- Other Transportation (Off-Road)

3.2.6.2. Methodological Issues

Fuel combustion emissions associated with the Transport category are calculated using various adaptations of Equation A3–1 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.

3

Domestic Aviation (CRF 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 (CRF 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 (CRF category 1.D.1.a).

The methodology for the Domestic Aviation subcategory follows a modified IPCC Tier 3 approach. Emissions 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 (CRF 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.

Railways (CRF 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 sales data from the RESD reported under railways are multiplied by country-specific emission factors.

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

Domestic Navigation (CRF 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 as international bunkers and are reported separately under Memo Items – International Bunkers (CRF Category 1.D.1.b). Emissions from fuel consumed by fishing vessels are reported under Agriculture/Forestry/Fishing – CRF Category 1.A.4.c. Emissions from fuel consumed by military vessels are reported under Other (Not specified elsewhere) – Mobile subcategory (CRF category 1.A.5.b).

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

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

Pipelines[4] represent the only non-vehicular transport in this sector. They use fossil-fuelled 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) (CRF 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. Emissions are based on country-specific emission factors, equipment populations and usage factors.

3.2.6.3. Uncertainties and Time-Series Consistency

Transport

The overall uncertainty of the 2022 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 ±5.4%. The Domestic Aviation subcategory only contributed approximately 5% to total Transport GHG emissions in 2022 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 within the range of ±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.

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

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. It is important to note that railway emissions only accounted for approximately 4% to total Transport GHG emissions in 2022 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 ±2.9%. The high N_2O emission factor uncertainty (-40% to +140%) represented the largest contribution to uncertainty, while CO_2 emission factor uncertainties were insignificant. Since domestic navigation emissions only made up 2% of the Transport category GHG inventory, they did not substantially alter the overall uncertainty results.

Emissions from Pipeline Transport

In general, the CH_4 emission uncertainty for pipeline transport ranges from ±15%. Table A2-1 and Table A2-2 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.

3.2.6.4. QA/QC and Verification

Tier 1 QC checks as elaborated in the framework for the QA/QC plan (see Chapter 1) were performed on all categories in Transport, not just those designated as "key." No significant mathematical errors were found.

In addition, certain verification steps were performed during the model preparation stage. Since MOVES uses national fuel data defined by type and region combined with country-specific emission factors, primary scrutiny is applied to the vehicle population profile, as this dictates the fuel demand per vehicle category and, hence, emission rates and quantities. Interdepartmental relationships exist among ECCC, Transport Canada, StatCan, and NRCan to facilitate the sharing of not only raw data but also derived information such as vehicle populations, fuel consumption ratios (FCRs) and kilometre accumulation rates (KARs). For example, KARs were validated using the Canadian Vehicle User Survey, and an independent survey of drivers managed by Transport Canada. This broader perspective fosters a better understanding of actual vehicle use and should promote better modelling and emission estimating.

3.2.6.5. Recalculations

Transportation estimates were revised for the 1990–2021 period as follows.

- **Updated GWP values**: Adoption of IPCC AR5 GWP values resulted in minor recalculations between 1990 and 2021. The transport category most impacted by this update was Railways, which resulted in emissions being revised downwards by approximately 1% for the entire time series.
- **RESD fuel**: Revisions include updating preliminary 2021 RESD data for all fuels as well as updating heavy fuel oil volumes for the 2020–2021 period. These revisions only had a notable impact on emissions associated with International Navigation.

3.2.6.6. Planned Improvements

Planned improvements have been identified for the Transport category. Current high priorities include updating on-road vehicle population estimates based on new vehicle registration data as well as updating renewable fuel content values for all applicable transportation fuels. Updates to off-road emissions modelling inputs are also planned, which include the provincial/territorial distributions used to allocate national off-road vehicles and equipment as well as the annual use rates for select vehicles and equipment.

3.2.7. Other Sectors (CRF Category 1.A.4)

3.2.7.1. Source 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.

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 CRF tables as memo items and not included in Energy sector totals.

In 2022, the Other Sectors category contributed 97.7 Mt (14%) of Canada's total GHG emissions, with an overall growth of about 12.7% (10.9 Mt) since 1990. Within the Other Sectors category, the Commercial/Institutional subcategory contributed 41 Mt (42%), followed by the Residential subcategory contributed 40 Mt (40.9%) and the Agriculture/Forestry/Fishing subcategory contributed 16.7 Mt (17.1%). Since 1990, GHG emissions have grown by 34.9% (10.9 Mt) in the Commercial/Institutional subcategory and 39.4% (4.7 Mt) in the Agriculture/Forestry/Fishing subcategory, while GHG emissions in the Residential subcategory have declined by about 9.8% (4.3 Mt). Refer to Table 3–8 for additional details. Chapter 2 has further discussion of trends for the Other Sectors category.

Table 3–8 **Other Sectors GHG Contribution**

GHG Source Category	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
OTHER SECTORS TOTAL (1.A.4)	**86 800**	**94 500**	**98 300**	**102 000**	**104 000**	**96 700**	**93 900**	**97 700**
Commercial/Institutional	30 400	36 900	41 700	43 100	44 100	40 600	38 900	41 000
Commercial and Other Institutional	26 200	32 400	36 000	37 100	38 100	35 200	33 000	35 000
Off-road Commercial & Institutional	4 240	4 510	5 690	5 930	6 040	5 450	5 950	6 030
Residential	44 300	44 700	39 900	41 500	42 200	39 700	38 400	40 000
Stationary Combustion	44 000	43 500	38 900	40 500	41 100	38 700	37 400	39 100
Off-road Residential	368	1 230	1 050	1 040	1 040	1 010	980	870
Agriculture/Forestry/Fishing	12 000	12 900	16 700	17 500	17 600	16 400	16 600	16 700
Agriculture and Forestry	2 410	2 180	3 080	3 180	3 340	3 030	3 100	3 320
Off-Road Agriculture/Forestry/Fishing	9 590	10 720	13 610	14 340	14 280	13 360	13 490	13 390

Note: Totals may not add up due to rounding.

3.2.7.2. Methodological Issues

Emission calculations for these source categories use the methodology described in Annex 3.1, which is an IPCC Tier 2 approach, with country-specific emission factors. See below for 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.

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

Emissions estimates in this category use RESD commercial and public administration fuel-use data. In the case of landfill gas (LFG), 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 CRF tables as a memo item. In the case of waste incineration for energy purposes, ECCC collects consumption quantities of municipal solid waste, and estimates quantities of medical waste. See section A3.6.3 of Annex 3 for further details. The CO_2, CH_4 and N_2O combustion emissions from the non-biogenic portion of the waste are included, along with CH_4 and N_2O emissions from the 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 CRF tables as a memo item.

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

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

Emissions estimates in this category use RESD residential fuel-use data, except for biomass data which StatCan, ECCC and NRCan collects using a periodic stand-alone survey. Annex 3.1 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.

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

Agriculture/Forestry/Fishing (CRF 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. Annex 3.1.4.2.3, 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 CRF categorization.

3.2.7.3. Uncertainties 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. The overall non-CO_2 emissions uncertainty is 6% for the Residential subcategory, compared to 2% for the Commercial subcategory; this is due to the higher uncertainty associated with residential firewood emission factors (CH_4 with -90% to +1500% and N_2O with -65% to +1000%) than with fossil-fuel-based CH_4 and N_2O emission factors (ICF Consulting 2004). As stated with respect to the Energy Industries category, for some of the emission factor uncertainty ranges and probability density functions, additional expert elicitation will improve the associated CH_4 and N_2O uncertainty estimates.

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.

3.2.7.4. QA/QC and Verification

The Other Sectors category underwent QC checks in a manner consistent with the 2006 IPCC Guidelines. QC checks found no mathematical, referencing or data errors. The data, methodologies, and changes related to the QC activities are documented and archived.

3.2.7.5. Recalculations

Revised methods and activity data contributed to recalculations and improved accuracy of the emissions for the Other Sectors category for all years, with estimates for 2021 decreasing by 1.5 Mt CO_2 eq over the previous submission, because of:

- updated GWP to IPCC AR5 values, resulting in recalculations between 1990 and 2021 (emissions change ranged from +0.09 Mt in 2021 to +0.22 Mt in 1992);
- revised RESD data, including diesel, heavy fuel oil, light fuel oil, natural gas, and propane, which affected 2016 to 2021 (emissions change ranged from -1.7 Mt in 2021 to +1.4 Mt in 2016);
- revised landfill gas data, which affected the entire time series (emissions change ranged from -0.06 kt to +0.03 kt);

- revised municipal solid waste and medical waste data, resulting in recalculations between 1990 and 2015 (emissions change ranged from -3.2 kt to -0.79 kt); and
- revised oxidation factors for all coal types resulted in recalculations between 1990 and 2021 (emissions change ranged from -1.9 kt in 2000 to +0.04 kt in 2017 and 2021 saw a 0.02 kt increase).

3.2.7.6. Planned Improvements

Although improvements were implemented to the RESD (as presented in the recalculation discussion in the overview section of 3.1), 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 3.2.4.6 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 3.2.6.6 for further details.

Additional improvement plans for the Other Sectors category include studies on biomass parameters, such as moisture content, energy content, and emission factors.

3.2.8. Other (Not Specified Elsewhere) (CRF Category 1.A.5)

The UNFCCC reporting guidelines assign military fuel combustion to this CRF category. Emissions generated by military aviation are estimated by AGEM and are included under this category (1.A.5.b). Emissions generated by military water-borne navigation are estimated by MEIT and are included under this category (1.A.5.b). As in previous submissions, 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 3.2.7) in accordance with the RESD fuel data. See Table 3–9 for additional data.

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Table 3–9 **Other (Not Specified Elsewhere) GHG Contribution**

GHG Source Category	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
OTHER (NOT SPECIFIED ELSEWHERE) TOTAL (1.A.5)	**262**	**286**	**335**	**333**	**342**	**267**	**282**	**310**

3.3. Fugitive Emissions from Fuels (CRF 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 categories reported in the inventory are fugitive releases associated with solid fuels (active and abandoned coal mines) and releases from activities related to the oil and natural gas industry.

In 2022, the Fugitive Emissions from Fuels category accounted for 75 Mt (11%) of Canada's total GHG emissions, with a 14% (9 Mt) growth in emissions since 1990. Fugitive emissions from oil and natural gas increased by 17% (11 Mt) and those from coal decreased by 52% (-1.6 Mt) since 1990. The oil and gas production, processing, transmission and distribution activities contributed 98% of the fugitive emissions. Refer to Table 3–10 for more details.

Table 3–10 **Fugitive GHG Contribution**

GHG Source Category	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
FUGITIVE EMISSIONS FROM FUELS (1.B)	**66 000**	**97 000**	**89 000**	**89 000**	**86 000**	**77 000**	**77 000**	**75 000**
Solid Fuels – Coal Mining (1.B.1)	3 200	1 600	1 400	1 500	1 600	1 300	1 400	1 500
a. Underground – Mining activities	1 700	100	70	110	170	80	NO	NO
b. Abandoned Underground Mines	210	190	120	70	70	120	110	100
c. Surface – Mining activities	1 300	1 300	1 200	1 300	1 300	1 100	1 200	1 400
Oil and Natural Gas (1.B.2)	63 000	95 000	88 000	88 000	85 000	75 000	76 000	74 000
a. Oil[a]	4 700	7 200	8 000	8 100	8 200	7 800	7 800	8 000
b. Natural Gas[a]	11 000	13 000	10 000	10 000	10 000	10 000	10 000	10 000
c. Venting and Flaring[b]	47 000	75 000	70 000	69 000	66 000	58 000	58 000	56 000
i. Venting	42 000	70 000	64 000	63 000	61 000	52 000	51 000	49 000
ii. Flaring	5 360	5 270	5 770	5 980	5 770	6 330	6 920	6 850

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 (CRF Category 1.B.1)

3.3.1.1. Source Category Description

The only reported fugitive emissions from solid fuel transformation in Canada come from active and abandoned coal mines. Combustion emissions in CRF category 1.A.2.a., include fugitive emissions from coke manufacturing (flaring). Other sources of solid fuel transformation emissions are unknown and assumed insignificant.

Coal Mining and Handling

Sources of mining emissions include exposed coal surfaces, coal rubble and the venting of CH_4 from within the deposit. Post-mining activities such as preparation, transportation, storage and final processing prior to combustion also release CH_4. Beginning in 2020, there were no operating underground mines in Canada.

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 2021, emissions from abandoned mines were approximately 60 kt CO_2 eq. The decrease in emissions between 2010 and 2015 reflected a return to production of a mine in Nova Scotia in 2014. The increase from about 56 kt CO_2 eq in 2015 to 72 kt CO_2 eq in 2016 resulted from two previously active underground mines that ceased operations at the beginning of 2016. See Table 3–10 for additional data.

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 plants 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 the 2019 Refinement to the 2006 IPCC Guidelines (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 UNFCCC Conference of the Party, Decision 24/CP19, Annex 1, paragraph 37.b., an NE notation key is reported in the CRF table 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, and this provides the basis for some of the coal mining fugitive emissions estimates. Dividing the emission estimates from King (1994) by the known coal production values provided appropriate emission factors. These factors are available in Annex 3.2.

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. The separate estimates of underground and surface mining activity emissions both include post-mining activity emissions. Annex 3.2, Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution, 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; and
- 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. Uncertainties 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 emissions estimates from abandoned coal mines is the IPCC (2006) default of -50% to +200%.

3.3.1.4. QA/QC and Verification

The CH_4 emissions from coal mining were a key category and underwent QC checks in a manner consistent with the 2006 IPCC Guidelines. Checks included a review of activity data, time-series consistency, emission factors, reference material, conversion factors and units labelling, as well as sample emission calculations. QC checks revealed no mathematical errors. All QC activities, data and methods were documented and archived.

Abandoned underground mines were also subject to QC checks as noted above.

3.3.1.5. Recalculations

Coal Mining and Handling

For years 2002 to 2015, the available set of production data lacked completeness. Newly available data from the Nova Scotia Environment Ministry and data in the RESD were used to construct a more representative production time series. Between 2002 and 2015, the increased emissions vary between 0.36 kt and 1.5 kt.

Abandoned Underground Mines

This category required no recalculations.

3.3.1.6. Planned Improvements

Coal Mining and Handling

There are currently no planned improvements.

Abandoned Underground Mines

There are currently no planned improvements.

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

3.3.2.1. Source 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 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), use of natural gas to produce hydrogen 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 Stationary 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 evaporative losses from storage facilities.

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.

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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 3–11 presents emission estimates from abandoned oil and gas wells.

Table 3–11 **GHG Emissions from Abandoned Oil and Gas Wells**

GHG Source Category	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
ABANDONED OIL AND GAS WELLS	**170**	**320**	**560**	**580**	**600**	**600**	**600**	**560**
Abandoned Oil Wells[a]	90	140	280	290	300	310	300	280
Abandoned Gas Wells[b]	80	180	280	290	300	300	300	280

Notes:
Totals may not add up due to rounding.
a. Included in CRF category 1.B.2.a – Fugitive emissions from fuels – Oil and natural gas – Oil
b. Included in CRF category 1.B.2.b – Fugitive emissions from fuels – Oil and natural gas – Natural Gas

Oil Sands / Bitumen

This component includes emissions from oil sand 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: There are three main sources of fugitive emissions from refineries: process, unintentional fugitive and flaring. Process emissions result from the production of hydrogen as well as from process vents. 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) and natural gas. The Energy Industries category reports GHG emissions from the combustion of fuel for energy purposes.

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 3–12 presents emission estimates from post-meter fugitives.

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Table 3–12 **GHG Emissions from Post-meter Fugitives**

GHG Source Category	kt CO_2 eq							
	1990	2005	2017	2018	2019	2020	2021	2022
POST-METER FUGITIVES[a]	**1 200**	**1 700**	**1 900**	**1 900**	**2 000**	**2 000**	**2 000**	**2 100**
Natural gas appliances in residential and commercial sectors	1 000	1 400	1 600	1 600	1 600	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	300	320	330	320	340	360

Notes:
Totals may not add up due to rounding.
a. Included in CRF category 1.B.2.b – Fugitive emissions from fuels – Oil and natural gas – Natural Gas

3.3.2.2. Methodological Issues

Upstream Oil and Gas

Fugitive emissions from the UOG industry are estimated using different methods depending on the emission source and data availability in the province or territory.

Direct estimation: where possible, emission estimates use facility reported volumetric data and detailed gas composition data. This applies to Alberta and Saskatchewan reported venting and flaring emissions, Newfoundland and Labrador offshore flaring (see Annex 3, section A3.2.2.1.2) and Alberta and British Columbia surface casing vent flow emissions (see Annex 3, section A3.2.2.1.4).

Modelling: when facility reported data is not available, emission estimates use annual facility counts, average number of components per facility, component-level EFs and gas composition data. This applies to 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. For a full description of modelled UOG fugitive emissions, see Annex 3, section A3.2.2.1.3.

Atmospheric measurements: source-resolved methane emission inventories, derived using atmospheric measurements, are the basis 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 aerial measurement campaigns conducted during 2020 in Saskatchewan and 2021 in all three western provinces (Conrad; 2023a, b; Johnson et al., 2023). For a full description of how atmospheric measurements are integrated into the inventory, see Annex 3, section A3.2.2.1.5.

Interpolation/Extrapolation: detailed inventory studies for the years 2000, 2005, and 2011 provide the basis to interpolate or extrapolate emissions for years without detailed inventory data based on changes in various activity data. This applies to all other fugitive emission sources and provinces and territories not mentioned above.

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 emissions 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. Annex 3, section A3.2.2.1.1 provides a more detailed description of the interpolation and extrapolation methodologies.

Abandoned Oil and Gas Wells

Emissions estimates for abandoned wells use an IPCC Tier 2 approach. The CH_4 emission factors are derived primarily from measured emissions from Canadian wells. Province-specific emission factors are used for abandoned wells in British Columbia, Alberta, and Ontario (Bowman et al., 2022; El Hachem and Kang, 2022; Williams et al., 2020). In the remaining provinces and territories, generalized Canadian emission factors are taken from the Williams study (Williams et al., 2020). Annual counts of abandoned wells are determined from provincial databases. See Annex 3, section A3.2.2.6, for more details.

Natural Gas Transmission and Storage

Fugitive emissions from natural gas transmission for 1990–1996 are 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 leakage rates developed using results from the original study. For 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 2012–2014 following an IPCC Tier 3 approach. Emission estimates for 2015–2022 are derived using length of natural gas transmission pipeline and the amount of gas deposited into and withdrawn from storage. Annex 3 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, 2017), 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 emissions estimates, and the oil sands study (ECCC, 2017) is the basis for the 2004–2020 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: A*lberta Mineable Oil Sands Plant Statistics* by the Alberta Energy Regulator (AER, 1990–) and annual reports for the Lloydminster Upgrader (Cenovus, 2022; Husky, 1998–2019). Annex 3 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 Greenhouse Gas Reporting Program (GHGRP). See Annex 3 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 estimates for this facility do not include the captured CO_2 transported and injected into storage.

Downstream Oil and Gas Production

Calculating fugitive emissions from refineries uses 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. Fugitive, venting and flaring 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. Annex 3 provides a detailed description of the methodology used to estimate emissions from 1991 to 1993 and 2003 onward.

Natural Gas Distribution

The emission estimates for the 1990–1999 period was derived from a study prepared for the Canadian Gas Association (CGA, 1997). The study estimated the emissions from the Canadian gas 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, emissions 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 2012–2014 following an IPCC Tier 3 approach. Emissions for 2015–2022 are estimated using length of natural gas distribution pipeline. Annex 3 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 were taken from data published by NRCan (2022) for the years 2000–2020 by province/territory. Appliance counts for 1990–1999 and 2021–2022 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 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 of Annex 3 for more details.

3.3.2.3. Uncertainties and Time-Series Consistency

Upstream Oil and Gas

The overall uncertainty for the 2022 upstream oil and gas fugitive emissions is -4.1% to +7.5%. Table 3–13 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 uncertainty.

The uncertainties were determined using the Tier 1 uncertainty approach presented in the IPCC Good Practice Guidance (IPCC, 2000). According to the IPCC (2000), there are 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.

Oil Sands/Bitumen

The overall uncertainty for the 2022 oil sands/bitumen fugitive emissions is -19.0% to +19.7%. An IPCC Good Practice Guidance 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, 2017). Table 3–13 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 2003–2022 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 3–14 presents these uncertainty results.

Table 3–13 **Uncertainty in Oil and Gas Fugitive Emissions (Excluding Petroleum Refining)**

Industry Segment	GHG Source Category Uncertainty (%)			
	Flaring	Fugitive	Venting	Total
Oil Production and Transport	± 7.9	-8.2 to +12.2	-7.0 to +8.4	-5.3 to +6.4
Oil Sands Mining and Bitumen / Heavy Oil Upgrading	-23.4 to +23.5	-31.3 to +34.2	-28.9 to +29.6	-19.0 to +19.7
Gas Production / Processing	-4.9 to +5.2	-1.4 to +2.2	-9.0 to +19.8	-6.9 to +15.2
Gas Transmission, Storage and Distribution	-15.0 to +19.4	-25.3 to +26.6	-19.6 to +22.1	-18.7 to +19.8
Accidents and Equipment Failures	—	± 28.0	—	± 28.0
Well Drilling, Servicing and Testing	-21.7 to +18.3	-25.0 to +28.4	-18.4 to +33.4	-18.3 to +16.0
Abandoned Oil and Gas Wells	—	-38.8 to +57.7	—	-38.8 to +57.7
Post-meter Fugitives	—	± 28.5	—	± 28.5

Table 3–14 **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

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3.3.2.4. QA/QC and Verification

The completed QC checks for all methods used to estimate fugitive oil and gas emissions 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.

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 that there were no errors, omissions or double counting. In addition, 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. First, was 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. 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 atmospheric measurements for Canada's main oil and gas producing provinces of Alberta, British Columbia and Saskatchewan (Chan et al., 2020; Conrad et al., 2023a, b; Johnson et al., 2023) were compared against inventory estimates to verify emission levels and trends.

3.3.2.5. Recalculations

Fugitive emissions from oil and natural gas were revised for the 1990–2021 period because of changes to activity data and methodologies. See Table 3–2 for a summary of the impact of the recalculations.

The most significant methodological update was the integration of atmospheric measurements of CH_4 emissions from key sources (compressor buildings, engine sheds, storage tanks, unlit flares, and wellheads) in the UOG industry, which resulted in revisions to emissions estimates. Previous CH_4 estimates for fugitive sources covered by the atmospheric measurements were removed to minimize double counting. In addition, the inclusion of unlit flares as a new source resulted in adjustments to flaring estimates, which involved revisions to flared gas volumes to account for gas unintentionally vented rather than combusted. Fugitive releases from storage tanks have been updated and reallocated to Venting, whereas storage losses had previously been included under the Oil or Natural Gas categories. For a full description of the methodology and how atmospheric measurements have been incorporated for the UOG sector, see Annex 3.2 section A3.2.2.1.5.

Additional methodological improvements resulted in recalculations with various impacts. Model parameters were updated to reflect reported emissions reductions from pneumatics in 2021, and corrections were made to modelled surface casing vent flow (SCVF) emissions that resulted in downward revisions in all years. Post-meter CO_2 emissions were removed entirely to eliminate double-counting with natural gas combustion estimates. Revised activity data (pipeline length) for 2021 also resulted in recalculated fugitive emissions for the natural gas transmission and storage, and natural gas distribution sectors.

The combined impact of recalculations on each fugitive category under oil and natural gas are as follows.

- **Oil:** recalculations due to methodological updates and reallocated emissions resulted in downward revisions in all years, ranging from -2.2 Mt in 1990 to -6.4 Mt in 2014.
- **Natural Gas:** recalculations cumulatively resulted in downward revisions in all years for the Natural Gas category, ranging from -1.4 Mt in 1990 to -3.7 Mt in 2006.
- **Venting:** cumulatively, recalculations due to all methodological updates and reallocation resulted in significant upward revisions to venting emissions for the entire time series, with changes ranging from +15.6 Mt in 1990 to a maximum of +27.4 Mt in 2014.
- **Flaring:** recalculations due to methodological updates and revised activity data resulted in changes in all years, with upward revisions from 1990 to 2001 followed by downward revisions from 2002 to 2021. These changes ranged from a maximum change of +0.4 Mt in 1991 to a minimum of -0.4 Mt in 2014.

In addition to these changes, the implementation of IPCC AR5 GWP values impacted fugitive emissions estimates in all years, resulting in upward revisions ranging from +5.5 Mt in 1990 to +9.1 Mt in 2014.

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 Manitoba, once results of aerial surveys in the province become available.
- Raw gas composition data collected by the British Columbia Energy Regulator (BCER) will be analyzed and assessed for incorporation into fugitive emission estimates from oil and gas facilities in British Columbia.
- Emissions for the natural gas transmission, distribution and storage industries provided by CEPEI for the years 2016-2022 will be assessed for integration into the inventory. Historical revisions between 1990 and 2015 may also be required.

3.4. CO_2 Transport and Storage (CRF 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 and its transport to a long-term storage (LTS) facility or enhanced oil recovery (EOR) operation. Table 3–15 summarizes existing sources of CO_2 captured, and transported, in Canada: CO_2 imported from the Dakota Gasification Company in North Dakota, United States; and domestically captured CO_2 from SaskPower's Boundary Dam power station, in Saskatchewan and Shell's Scotford bitumen upgrader, Agrium's fertilizer plant and North-West Redwater Partnership's Sturgeon refinery, in Alberta. Table 3–15 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.

In 2022, fugitive CO_2 emissions from the four active pipelines and four capture sites were approximately 0.65 kt, an increase of about 0.56 kt since 2000, as shown in Table 3–16. Of the four pipelines in Canada, three currently transport only CO_2 used for EOR. Some fugitive emissions associated with carbon capture cannot be disaggregated and fully reported under category 1.C. and, as such, do not appear in the data presented in Table 3–16. 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 in Canada's inventory 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.

Table 3–15 **CO_2 Import, Capture and Final Disposition**

	kt of CO_2										
	1990	2000	2005	2010	2015	2017	2018	2019	2020	2021	2022
CAPTURED CO_2 SOURCE											
Imported	NO	1 800	2 000	2 000	2 200	1 700	1 600	1 800	1 600	1 700	1 600
Domestic Capture – Total	NO	NO	NO	NO	800	1 600	1 700	1 700	2 700	2 800	2 800
Energy Industries (1.A.1)	NO	NO	NO	NO	400	500	600	600	700	400	700
Oil, Natural Gas (1.B.2)	NO	NO	NO	NO	400	1 100	1 100	1 100	1 800	2 200	1 900
Ammonia Production (2.B.1)	NO	NO	NO	NO	NO	NO	NO	NO	200	100	200
CAPTURED CO_2 USE AND STORAGE											
Enhanced Oil Recovery	NO	1 800	2 000	2 000	2 600	2 200	2 100	2 300	3 200	3 300	3 300
Cumulative EOR[b]	NO	NO	8 900	19 000	29 800	34 700	36 900	39 000	41 300	44 500	47 800
Long-term Geologic Storage	NO	NO	NO	NO	400	1 200	1 100	1 200	1 000	1 100	1 100
Cumulative LTS[a]	NO	NO	NO	NO	NO	1 600	2 700	3 900	5 100	6 100	7 200

Note:
Total quantities for capture source, and use and storage, may not be equal due to rounding.
NO = Not occurring
a. Cumulative LTS = On January 1st of the year, the total historic volume injected into long-term storage (LTS).
b. Cumulative EOR = On January 1st of the year, the total historic volume used for enhanced oil recovery (EOR).

Table 3–16 **CO_2 Emissions from Transport, Use and Storage Systems**

GHG Source Category	kt CO_2										
	1990	2000	2005	2010	2015	2017	2018	2019	2020	2021	2022
CO_2 EMISSIONS FROM TRANSPORT AND STORAGE (1.C)	**NO**	**0.09**	**0.09**	**0.09**	**0.22**	**0.27**	**0.28**	**0.28**	**0.49**	**0.65**	**0.64**
CO_2 Pipeline (1.C.1)	NO	0.09	0.09	0.09	0.22	0.27	0.27	0.27	0.46	0.60	0.60
CO_2 Injection Site (1.C.2)	NO	NO	NO	NO	0.00	0.01	0.01	0.01	0.02	0.04	0.04

Note:
NO = Not occurring

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 appear in the 1.C category 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. Carbon dioxide, purchased from the Dakota Gasification Company located in North Dakota and SaskPower's Boundary Dam coal-fired power station, arrives via pipeline. By the end of 2022, the Boundary Dam facility had captured approximately 7 Mt of CO_2 for shipment to the Weyburn site (SaskPower, 2023). While total annual injection volumes at this reservoir include the fresh supply of CO_2 and the recovered CO_2 from previous flooding cycles, Canada only reports the yearly fresh supply. The current CO_2 injection rate at the Weyburn-Midale operations is about 2 Mt per year, and from 2000 to 2022 the Weyburn and Midale sites have injected over 45 Mt of new CO_2.

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 (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 on the PTRC website.

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 governments Ministry of Environment and Parks that is described in available quantification documents (AEPa, 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 2022, on-going 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. Both sites began injecting CO_2 in 2015 with Quest having injected approximately 7.5 Mt and Aquistore approximately 500 kt, by 2022.

The Alberta governments Ministry of Environment and Parks has extensive quantification and MMV requirements related to carbon sequestration (AEP, 2022b). 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, on-going 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 2022, on-going 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. Transport of CO_2 – Pipelines (CRF Category 1.C.1.a)

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.

3.4.2.1. Source Category Description

The source is fugitive emissions from pipeline systems used to transport CO_2 to injection 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.

3.4.2.3. Uncertainties and Time-Series Consistency

Uncertainty estimates are 2006 IPCC defaults for Tier 1 methodologies of +200% to -50% (± a factor of 2).

3.4.2.4. QA/QC and Verification

Estimates underwent QC checks consistent with the 2006 IPCC Guidelines.

3.4.2.5. Recalculations

No recalculations were undertaken.

3.4.2.6. Planned Improvements

Future emissions 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 Greenhouse Gas Reporting Program. 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, 2021).

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3.5. Other Issues

3.5.1. CO_2 Emissions from Biofuels: Biodiesel and Ethanol

As per UNFCCC reporting guidelines, a memo item reports CO_2 from sustainably produced biomass fuels combusted to produce energy, and the energy sector totals exclude these 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.

3.5.1.1. Fuel Ethanol

Table 3–17 presents the quantities of fuel ethanol used in transportation. 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).

According to feedback from StatCan, ethanol is included in RESD gasoline fuel consumption data. Fuel ethanol is therefore introduced and modelled as if it were mixed into the total gasoline for the region(s). Total fuel ethanol available per province was allocated to each mode (on-road, by vehicle technology class, and off-road as a whole) as per the percentage of total gasoline. In lieu of developing specific emission factors for CH_4 and N_2O from ethanol, the representative gasoline emission factor was applied as per mode and technology class. CO_2 emission factors used are those based on true chemical characteristics mentioned previously and a 100% oxidation rate.

Table 3–17 **Ethanol Used for Transport in Canada**

	1990	2005	2017	2018	2019	2020	2021	2022
Ethanol Consumed (ML)	7	267	2 690	2 739	2 778	2 320	2 386	2 431

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*.

3.5.1.2. Fuel Biodiesel

Table 3–18 presents the quantities of biodiesel used in transportation. 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.

The RESD biodiesel consumption data is included in its diesel fuel oil total. On-going work to improve the quality and coverage while allowing for a better disaggregation biodiesel through the monthly collection and reporting of renewable fuel survey (RFLS) by StatCan (refer to section 3.2.4.6 for more information). Biodiesel was introduced and modelled as if it were mixed into the total fossil fuel-based diesel for the region(s). Total fuel available per province was allocated to each mode (on-road, by vehicle technology class, and off-road, railways and domestic marine as a whole) as per the percentage of total fossil fuel-based diesel fuel. In lieu of developing specific emission factors for CH_4 and N_2O for biodiesel, the representative fossil fuel-based diesel emission factor was applied as per mode and technology class. CO_2 emission factors used are those based on true chemical characteristics mentioned previously and a 100% oxidation rate.

Table 3–18 **Biodiesel Used for Transport in Canada**

	1990	2005	2017	2018	2019	2020	2021	2022
Biodiesel Consumed (ML)	NO	NO	859	904	897	800	865	911

Note:
NO = Not occurring

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CHAPTER 4

INDUSTRIAL PROCESSES AND PRODUCT USE (CRF SECTOR 2)

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. 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 51.3 Mt to the 2022 national GHG inventory (Table 4–1), compared with 55.4 Mt in 2005. IPPU emissions represented 7.3% of total Canadian GHG emissions in 2022. The contributing factors of the long-term and short-term trends in this sector are discussed in Chapter 2.

In line with the principle of continuous improvement and in response to comments made by the expert review teams (ERTs) on previous submissions, this submission has incorporated improvements/revisions to activity data, emission factors, and/or methods. Detailed explanations for the changes in estimates as a result of these improvements/revisions are described in the "Category-Specific Recalculations" sections of this chapter and are summarized in Table 4–2.

Table 4–1 **GHG Emissions from the Industrial Processes and Product Use Sector, Selected Years**

Greenhouse Gas Category	GHG Emissions (kt CO_2 eq)										
	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021	2022
INDUSTRIAL PROCESSES AND PRODUCT USE	**54 900**	**56 500**	**53 200**	**55 400**	**49 900**	**52 800**	**53 500**	**52 300**	**49 700**	**51 500**	**51 300**
Mineral Products	**8 490**	**9 180**	**10 060**	**10 270**	**7 830**	**8 000**	**8 710**	**8 850**	**8 220**	**9 000**	**8 400**
Cement Production	5 820	6 530	7 230	7 610	6 010	6 180	6 990	7 200	6 710	7 380	6 750
Lime Production	1 800	1 900	1 920	1 750	1 410	1 410	1 390	1 340	1 190	1 310	1 340
Mineral Product Use	860	750	910	910	410	410	330	320	310	310	310
Chemical Industry	**16 290**	**17 250**	**8 510**	**9 970**	**5 720**	**6 720**	**6 400**	**6 220**	**5 940**	**5 730**	**5 780**
Ammonia Production	2 740	2 920	2 950	2 700	2 470	2 920	2 420	2 500	2 290	2 540	2 590
Nitric Acid Production	870	860	1 050	1 070	430	200	240	230	170	190	130
Adipic Acid Production	9 160	9 170	770	2 260	-	-	-	-	-	-	-
Petrochemical and Carbon Black Production (includes Carbide Production)	3 520	4 300	3 740	3 930	2 830	3 600	3 740	3 490	3 480	3 000	3 070
Metal Production	**23 100**	**22 920**	**22 950**	**19 880**	**15 860**	**14 530**	**14 900**	**14 110**	**13 210**	**14 140**	**13 630**
Iron and Steel Production	10 480	11 470	11 820	10 310	8 980	8 670	9 300	8 550	7 270	8 220	7 810
Aluminium Production	9 560	9 370	8 390	8 300	6 680	5 620	5 450	5 250	5 840	5 770	5 660
SF_6 Used in Magnesium Smelters and Casters	3 050	2 070	2 740	1 270	190	240	150	300	100	140	170
Production and Consumption of Halocarbons, SF_6 and NF_3	**820**	**460**	**2 630**	**4 820**	**7 300**	**10 430**	**11 530**	**11 470**	**11 270**	**10 770**	**10 630**
Non-Energy Products from Fuels and Solvent Use	**5 830**	**6 330**	**8 440**	**9 940**	**12 770**	**12 630**	**11 320**	**11 050**	**10 390**	**11 200**	**12 210**
Other Product Manufacture and Use	**360**	**370**	**570**	**510**	**410**	**510**	**650**	**620**	**660**	**660**	**650**

Note: Totals may not add up due to rounding.

Table 4–2 **Impact of Recalculations from Revisions and Improvements**

Greenhouse Gas Categories	GHG Emissions or Change in Emissions (Mt CO_2 eq), Selected Years										
	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
INDUSTRIAL PROCESSES AND PRODUCT USE											
Current (2024) submission	54.9	56.5	53.2	55.4	49.9	52.8	52.3	53.5	52.3	49.7	51.5
Previous (2023) submission	57.0	58.4	54.0	56.5	50.6	53.4	52.4	53.9	52.9	50.4	51.9
Net change in emissions	-2.1	-1.9	-0.9	-1.1	-0.7	-0.6	-0.1	-0.4	-0.6	-0.7	-0.4
Mineral Products											
Current (2024) submission	8.5	9.2	10.1	10.3	7.8	8.0	8.6	8.7	8.9	8.2	9.0
Previous (2023) submission	8.5	9.2	10.1	10.3	7.8	8.0	8.6	8.7	8.8	8.2	9.0
Net change in emissions	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	+0.0	+0.0	+0.0	+0.0
Chemical Industry											
Current (2024) submission	16.3	17.2	8.5	10.0	5.7	6.7	6.3	6.4	6.2	5.9	5.7
Previous (2023) submission	17.5	18.5	8.7	10.4	5.8	6.7	6.3	6.4	6.2	5.9	5.7
Net change in emissions	-1.2	-1.2	-0.2	-0.4	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
Metal Production											
Current (2024) submission	23.1	22.9	23.0	19.9	15.9	14.5	15.1	14.9	14.1	13.2	14.1
Previous (2023) submission	23.8	23.5	23.4	20.2	16.0	14.4	14.6	14.5	13.9	13.1	13.9
Net change in emissions	-0.7	-0.6	-0.4	-0.3	-0.2	+0.1	+0.5	+0.4	+0.2	+0.1	+0.2
Production and Consumption of Halocarbons, SF_6 and NF_3											
Current (2024) submission	0.8	0.5	2.6	4.8	7.3	10.4	10.5	11.5	11.5	11.3	10.8
Previous (2023) submission	1.0	0.5	2.8	5.1	7.7	11.1	11.1	12.2	12.2	12.0	11.5
Net change in emissions	-0.2	-0.0	-0.2	-0.3	-0.4	-0.7	-0.6	-0.7	-0.7	-0.7	-0.7
Non-Energy Products from Fuels and Solvent Use											
Current (2024) submission	5.8	6.3	8.4	9.9	12.8	12.6	11.1	11.3	11.1	10.4	11.2
Previous (2023) submission	5.8	6.3	8.5	10.0	12.8	12.6	11.1	11.3	11.0	10.4	11.0
Net change in emissions	+0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	+0.0	-0.0	+0.2
Other Product Manufacture and Use											
Current (2024) submission	0.4	0.4	0.6	0.5	0.4	0.5	0.6	0.6	0.6	0.7	0.7
Previous (2023) submission	0.4	0.4	0.6	0.5	0.4	0.5	0.6	0.7	0.7	0.7	0.7
Net change in emissions	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.1	-0.1

Note: Totals may not add up due to rounding.

In addition, this submission includes the implementation of the IPCC Fifth Assessment Report (AR5) Global Warming Potential (GWP) values and its impact on the recalculations for the IPPU category are depicted in Table 4–3.

Table 4–3 **Impact of Implementation of IPCC AR5 GWP on Overall Recalculations**

	Activity Data and Method Change Recalculations VS. GWP Recalculations (Mt CO_2 eq), Selected Years										
	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021
INDUSTRIAL PROCESSES AND PRODUCT USE											
2023 submission	57.0	58.4	54.0	56.5	50.6	53.4	52.4	53.9	52.9	50.4	51.9
2024 submission	54.9	56.5	53.2	55.4	49.9	52.8	52.3	53.5	52.3	49.7	51.5
Recalculations											
Activity data and method change recalculations	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.4	0.2	0.1	0.4
GWP recalculations	-2.1	-1.9	-0.8	-1.1	-0.7	-0.8	-0.7	-0.8	-0.8	-0.8	-0.8
Total Recalculations	**-2.1**	**-1.9**	**-0.9**	**-1.1**	**-0.7**	**-0.6**	**-0.1**	**-0.4**	**-0.6**	**-0.7**	**-0.4**

4.2. Cement Production (CRF Category 2.A.1)

4.2.1. 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 located 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 6752 kt (or 1.0%) of Canada's total emissions in 2022, an 11% decrease from 2005.

Emissions resulting 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.

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4.2.2. 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 2017–2022, CO_2 emission estimates came directly from the CO_2 emissions reported by Canadian cement production facilities to the Greenhouse Gas Reporting Program (GHGRP) (ECCC, 2023). 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

1 Natural Resources Canada, Personal communication on Canada's Minerals subsector.

Equation 4–2

$$\mathbf{E}_{CO_2} = \sum_{m}^{12}[Q_{CLI_m} \times \mathbf{EF}_{CLI_m}] + \sum_{q}^{4}[Q_{CKD_q} \times \mathbf{EF}_{CKD_q}] + [\mathbf{TOC}_{RM} \times RM \times 3.664]$$

E_{CO2}	=	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 2017–2022 (ECCC, 2023). 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 (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.[2]

The 2006 IPCC Tier 3 method for Cement Production sums CO_2 emissions from all carbonates consumed in the kiln and CO_2 emissions from organic carbon oxidation in raw materials, and subtracts the CO_2 emissions from uncalcined carbonate in CKD not recycled to the kiln. In contrast, 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. Unlike the 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 2017–2022. For the unknown data years (1991–1999, 2001, 2015–2016), an average is taken from the years before and after the unknown data point.

2 [ECCC] Environment and Climate Change Canada. Canada's greenhouse gas quantification requirements / Greenhouse Gas Reporting Program. 2022. [accessed 2023 Jan 23]. Available online at: http://publications.gc.ca/site/eng/9.866467/publication.html.

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 on the basis of 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.[3] For 2014–2016, the Mining and Processing Division of ECCC provided clinker production capacity via personal communication.[4] For 2017–2022, provincial/territorial emission estimates are based on the emissions reported to the GHGRP by cement production facilities in each province/territory.

4.2.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty estimate has been developed on the basis of 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 2017–2022. 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 4.2.2.

To address time-series consistency between the Tier 2 method applied for 1990–2016 and modified Tier 3 method applied for 2017–2022, 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}.

4

4.2.4. Category-Specific Quality Assurance/Quality Control and Verification

This key category in the IPPU sector has undergone checks as outlined in *Canada's General Quality Control (QC) (Tier 1) Checklist Guidance* (Environment Canada, 2015). The checks performed were consistent with quality assurance (QA)/QC requirements as promoted by Volume 1, Chapter 6 (IPCC, 2006).

4.2.5. Category-Specific Recalculations

CO_2 emissions for this category were recalculated due to updated facility-reported data from the GHGRP for 2019 and 2021, which resulted in a decrease of -0.35 kt CO_2 in 2019 and -1.6 kt CO_2 in 2021.

4.2.6. Category-Specific Planned Improvements

During the 2023 ERT review, an activity data outlier in 2018 was identified, which impacts the Implied Emission Factor (IEF) for that year. Activity data is currently under review to determine if corrections are required, to resolve or explain this discrepancy.

3 Panagapko D. 2008–2014. Personal communications (emails to EC, last email September 16, 2014).

4 Sunstrum J. 2020. Personal communications (emails to ECCC, last email July 9, 2020).

4.3. Lime Production (CRF Category 2.A.2)

4.3.1. 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 4–4 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 located 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 1342 kt (0.2%) to Canada's total emissions in 2022, a 23% decrease from 2005.

Emissions from the regeneration of lime from spent pulping liquors at pulp mills are not accounted for in the IPPU sector. CO_2 emissions 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 4.4).

4.3.2. 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[5] and from annual averages of all lime production facilities in Canada that reported to the GHGRP for 2017–2022, which 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)[6] for the period up to and including 2006. In subsequent years, information was provided directly by Natural Resources Canada via personal communication.[7] For 2017–2022, CO_2 emissions came directly from the CO_2 emissions reported by lime production facilities in Canada to the GHGRP (ECCC, 2023). The CO_2 emissions reported by lime production facilities to the GHGRP were calculated using a modified Tier 3 method (IPCC, 2006) in accordance with section 3 of Canada's Greenhouse Gas Quantification Requirements.[8]

4

Equation 4–4

$$E_{CO2} = \sum_i (Q_i \times EF_i) \times CF_{LKD} \times CF_{hydrated}$$

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, fraction

$CF_{hydrated}$ = correction factor that corrects for hydrated lime, fraction

Table 4–4 **Split between Dolomitic and High-Calcium Lime Production in Canada (1990–2016)**

Year	% Split	
	Dolomitic Lime	High-Calcium Lime
1990–1992	14%	86%
1993–1999	16%	84%
2000–2002	8%	92%
2003–2008	9%	91%
2009–2010	7%	93%
2011–2016	8%	92%

5 Kenefick W. 2008. Personal communication (email from Kenefick W to Shen A, Environment Canada, dated October 7, 2008). Canadian Lime Institute.

6 [NRCan] Natural Resources Canada. 1990–2006. *Canadian Minerals Yearbook. Minerals and Metals Sector* (Annual). Natural Resources Canada (discontinued).

7 [NRCan] Natural Resources Canada. 2007–2018. Canada, Production of Limestone – Stone. Unpublished data. Natural Resources Canada, Mineral & Mining Statistics Division

8 [ECCC] Environment and Climate Change Canada. Canada's greenhouse gas quantification requirements / Greenhouse Gas Reporting Program. 2022. [accessed 2023 Jan 23]. Available online at: http://publications.gc.ca/site/eng/9.866467/publication.html.

Canadian lime plants are classified into three types based on their final products: dolomitic lime only, high-calcium lime only, and both dolomitic lime and high-calcium. In the absence of disaggregated data on the breakdown of lime types for 1990–2016, a 15/85 value for dolomitic lime/high-calcium lime was assumed for lime plants that produced both high-calcium lime and dolomitic lime. Table 4–4 provides the breakdown between dolomitic lime and high-calcium Lime Production in Canada. 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%.[9] 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 all lime production facilities in Canada as reported to the GHGRP for 2017–2022 and is applied for 1990–2016.

Provincial CO_2 emission estimates are apportioned from national emission estimates on the basis of the 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.[10] For 2014–2016, the Mining and Processing Division of ECCC provided calcining capacity via personal communication.[11] For 2017–2022, provincial/territorial emission estimates are based on the emissions reported to the GHGRP by lime production facilities in each province/territory.

The decline in the share of dolomitic lime between 1999 and 2000 is the result of operational changes at two Ontario plants in that period. First, Guelph DoLime Limited, which produced only dolomitic lime up to 1999, ceased operations in 2000. Second, the Lafarge Canada quarry in Dundas switched from producing only dolomitic lime to both high-calcium lime and dolomitic lime in 1999–2000.[12] 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.

4.3.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty estimate has been developed on the basis of 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 2017–2022. 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 2017–2022, 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 2017–2022 values calculated from the GHGRP facility-reported data. 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 2017–2022 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, as described in section 4.3.2.

4.3.4. Category-Specific Quality Assurance/Quality Control and Verification

The Lime Production category has undergone checks as outlined in Canada's General Quality Control (QC) (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with quality assurance (QA)/QC requirements as promoted by Volume 1, Chapter 6 (IPCC, 2006).

9 Kenefick W. 2008. Personal communication (email from Kenefick W to Shen A, Environment Canada, dated October 22, 2008). Canadian Lime Institute.

10 Panagapko D. 2013. Personal communication (email to Edalatmanesh M, Environment Canada, dated November 6, 2013).

11 Sunstrum J. 2020. Personal communications (emails to ECCC, last email July 9, 2020).

12 Panagapko D. 2013. Personal communication (email to Edalatmanesh M, Environment Canada, dated November 6, 2013).

4.3.5. Category-Specific Recalculations

Recalculations for this category include updates to the LKD correction factor, EF_{dol} and $EF_{h\text{-}c}$ for 1990–2016, and revised activity data for 2008 and 2021. The magnitude of the recalculations ranged from -0.6 kt CO_2 to -0.9 kt CO_2 for 1990–2007 and 2009–2016, -21 kt CO_2 for 2008, and -0.02 kt CO_2 for 2021.

4.3.6. Category-Specific Planned Improvements

During the 2023 ERT review, activity data outliers were identified for 2019 and 2021, impacting the Implied Emission Factors (IEFs) for these years. Activity data is currently under review to determine whether corrections are required, or if a new data source is necessary.

4.4. Mineral Product Use (CRF Categories 2.A.3 and 2.A.4)

4.4.1. Category Description

The categories discussed in this section, under the aggregate title of "Mineral Product Use," include Glass Production (CRF category 2.A.3), Ceramics Production (CRF category 2.A.4.a), Other Uses of Soda Ash (CRF category 2.A.4.b), Non-Metallurgical Magnesia Production (i.e., magnesite use) (CRF category 2.A.4.c) and Other Limestone and Dolomite Use (CRF category 2.A.4.d).

In 2022, the aggregate category accounted for 311 kt (or 0.04%) of Canada's total GHG emissions, with a decrease of approximately 66% in total emissions since 2005. Non-metallurgical Magnesia Production accounted for 37% of Mineral Product Use emissions, whereas Other Limestone and Dolomite Use, Other Uses of Soda Ash, and Glass Production contributed 32%, 16% and 15% of emissions, respectively.

Glass Production (CRF 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.

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Ceramics Production (CRF 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.

To assess the significance of CO_2 emissions from Ceramics Production, emissions were estimated for 2005 to 2007 and for 2011 to 2022. For 2005 to 2007, national total annual amounts of clay used for ceramics were obtained from the *Canadian Minerals Yearbook* (NRCan, 1990–2008). Equation 2.14 of Volume 3, Chapter 2, Section 2.5.1.1 (IPCC, 2006), which is a Tier 1 method, was used to assess the emissions for these years. 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 2022, 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 2022 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. As of the 2020 inventory submission, they are reported in the CRF Reporter as "NE" ("not estimated") with an explanation provided, in accordance with the ERT's recommendation.

Other Uses of Soda Ash (CRF 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) (CRF Category 2.A.4.c)

Three magnesia production facilities in Canada reported magnesite consumption in their processes at various times over the years 1990–2007. Two of the three facilities have closed, one in 1991 and the other in 2007; one facility remains in production.

Other Limestone and Dolomite Use (CRF 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.

4.4.2. Methodological Issues

Glass Production (CRF 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.[13]

Ceramics Production (CRF Category 2.A.4.a)

CO_2 process emissions from Ceramics Production was determined to be insignificant under paragraph 32 of the MPGs, as described in section 4.4.1.

Other Uses of Soda Ash (CRF 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 on the basis of 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, 2023). The total quantities of soda ash used have been distributed by application type, on the basis of 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) (CRF 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.

Magnesite use activity data was obtained or derived from various sources. One of the three plants operated between 1990 and 1991 and did not have publicly available data on magnesite use. The activity data has been back-calculated from the amount of magnesia produced, which has been assumed to be half of the 1990 capacity reported in the *Minerals and Metals Foundation Paper, 1999* (AMEC, 2006).

A second plant operated between 1990 and 2007. Its production data for 1990–2005 was sourced from Environment Canada, Quebec Region, Environmental Protection Branch.[14] The activity data for 2006 and 2007 has been estimated from the average ratio of magnesite consumed to magnesia produced between 1990 and 2005.

The third plant has been operational for the full reporting period (1990–2022) and its annual activity data is sourced from British Columbia's Ministry of Energy and Mines (British Columbia Geological Survey, 2023).

Other Limestone and Dolomite Use (CRF 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 4–5) and emission factors, as described below.

13 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.

14 Banville J. 2006. Personal communication (email from Banville J to Zaremba R, Environment Canada, dated March 3, 2006). Environment Canada, Environmental Protection Branch, Quebec Region.

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 CRF Category 2.C.1.f.

For the years 1990–2016, a Tier 2 methodology is used to estimate emissions from limestone and dolomite in iron and steel production, multiplying quantities of stone consumed (Table 4–5) 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). As of the 2024 submission, the raw stone data is 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 2017–2022.

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 2017–2022, calculated from the facility-reported data to the GHGRP.

As of the 2024 submission, a Tier 3 methodology is 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, 2023). 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 is used to estimate emissions from limestone used in pulp and paper mills, by multiplying quantities of limestone consumed (Table 4–5) 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.

As of the 2024 submission, an IPCC Tier 3 methodology is 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 (1990–2022).

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 4–5) 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 (CRF category 2.A.3) and Other Limestone and Dolomite Use (CRF category 2.A.4.d).

Table 4–5 High Calcium 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	186	T2
2021	248		T3	0	T2	35	T3	21	T2	191	T2
2022	174		T3	0	T2	30	T3	17	T2	194	T2

Note: Quantities of limestone and dolomite for 2017–2022 are aggregated to protect confidentiality.

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,[15] only limestone is used for FGD processes in Canadian coal power plants.

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.

15 Cook S. 2013. Personal communication to Edalatmanesh M, Environment Canada, November 18, 2013. Canadian Electricity Association.

4.4.3. Uncertainties and Time-Series Consistency

Glass Production (CRF Category 2.A.3)

The Tier 1 uncertainty assessment of the Glass Production category considers uncertainties associated with the consumption data, emission factors, and assumptions for soda ash and limestone used in glass production. The overall uncertainty associated with the 2022 estimate is ±10.2%.

The same emission factors have been consistently applied over the time series, and the activity data sources are described in section 4.4.2.

Ceramics Production (CRF Category 2.A.4.a)

No uncertainty assessment was performed for this category because this category was determined to be insignificant under paragraph 32 of the MPGs, as described in section 4.4.1.

Other Uses of Soda Ash (CRF Category 2.A.4.b)

A Tier 1 uncertainty assessment was performed for the category of Other Uses of Soda Ash. It considered the uncertainties associated with the production data (for years before 2001) and import and export data. The uncertainty associated with the category as a whole for the time series ranged from ±5.9% to ±7.5%.

The same emission factor has been consistently applied over the time series. The activity data source is provided in section 4.4.2.

Non-Metallurgical Magnesia Production (Magnesite Use) (CRF Category 2.A.4.c)

A Tier 1 uncertainty assessment was performed for the category of Non-metallurgical Magnesia Production. It considered the uncertainties associated with the activity data and emission factor. The uncertainty associated with the category as a whole for the time series ranged from ±4.3% to ±8.1%, with data on the use of magnesite being the largest contributor.

The same emission factor has been consistently applied over the entire time series. The activity data source varied across the time series, as described in section 4.4.2.

Other Limestone and Dolomite Use (CRF Category 2.A.4.d)

The Tier 1 uncertainty assessment for the category of Other Limestone and Dolomite Use considers the uncertainty associated with the activity data and emission factors. The uncertainty for the whole time series ranged from ±15.4% to ±38.0%, with activity data on chemical uses being the largest contributor to the uncertainty estimate.

To address time-series consistency between the Tier 2 method applied for 1990–2016 and Tier 3 method applied for 2017–2022 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 2017–2022. Activity data sources and emission factors are described in section 4.4.2.

For limestone used in pulp and paper mills, the Tier 2 method applied for 1990–2017 and the Tier 3 method applied for 2018–2022 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 4.4.2.

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 4.4.2.

4.4.4. Category-Specific Quality Assurance/Quality Control and Verification

Categories under Mineral Product Use have undergone informal quality control checks throughout the emission estimation process. The Other Limestone and Dolomite Use category has also undergone checks as outlined in Canada's General Quality Control (QC) (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with quality assurance (QA)/QC requirements as promoted by Volume 1, Chapter 6 (IPCC, 2006).

4.4.5. Category-Specific Recalculations

For the Other Uses of Soda Ash category, updates to the activity data for 1990–2021 resulted in an increase of less than 1 kt CO_2 for each impacted year.

For Other Limestone and Dolomite Use, a method change in the calculation of emissions from the use of limestone in pulp and paper mills resulted in recalculations from 2018–2021. Revisions and updates to activity occurred for limestone used in nonferrous smelters and other chemical uses for 2019–2021. These updates resulted in recalculations for the 2.A.4.d category for 2018–2021, ranging from +2 kt CO_2 in 2021 to +7 kt CO_2 in 2020.

A method change in the calculation of emissions from the use of limestone and dolomite as flux in iron and steel production resulted in recalculations for 2017–2021. The impact of these recalculations is seen in CRF Category 2.C.1.

4.4.6. Category-Specific Planned Improvements

During the 2023 ERT review, potential activity data discrepancies were identified for Other Limestone and Dolomite Use activity data, particularly for 2010 and onwards. Activity data is currently under review to investigate the potential discrepancies, and to determine whether corrections are required.

4.5. Ammonia Production (CRF Category 2.B.1)

4.5.1. Category Description

Ammonia Production (CRF category 2.B.1) accounted for 2600 kt (0.3%) of Canada's emissions in 2022. This category accounts for CO_2 emissions from the 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, the majority of carbon in natural gas ends up as CO_2 emissions. It should be noted that 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[16] operating in Canada, located in Alberta, Saskatchewan, Manitoba and Ontario. 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 over-estimation 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 2006 IPCC Guidelines (box 3.2 on page 3.16). Emissions from use of urea-based additives in catalytic converters are discussed in section 4.15 and reported in CRF 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 CRF category 2.B.10.

Two SMR facilities recover CO_2 emissions for long-term storage through 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 the 2006 IPCC Guidelines (Box 3 of Figure 3.1 on page 3.14).

4.5.2. Methodological Issues

The Ammonia Production category includes CO_2 emissions resulting from the feedstock use of natural gas and considers emissions that are recovered for use in urea production and in long-term storage activities. A Tier 3 country-specific method is applied in accordance with the 2006 IPCC Guidelines (IPCC, 2006) for the years 2018 to 2022, while a Tier 2 country-specific method was applied for years 1990–2017. Collection of facility-reported data from the federal Greenhouse Gas Reporting Program (GHGRP) allowed for sufficient information to transition into a Tier 3 approach for years 2018 and after. Since disaggregated activity data (i.e., natural gas used as feedstock and that used 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.

To calculate the net national emissions from ammonia production, Equation 4–6 below is used.

16 Fertilizer Canada. Ammonia Production Greenhouse Gas Emissions Benchmarking. [last updated 2023 Oct; accessed 2024 Feb 01]. Available online at https://fertilizercanada.ca/wp-content/uploads/2023/10/Nitrogen-Benchmarking-Report-Final.pdf.

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, 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 annual ammonia production data for 1990–2004 were gathered in a study conducted by Cheminfo Services (2006); that for 2005–2009 was collected by Environment Canada through a voluntary data submission process with the fertilizer industry; and that for 2008–2017 was obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey (Statistics Canada, n.d.[c]). 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. For the years 2018 and after, the natural gas quantity used as feedstock reported by facilities through the GHGRP was directly used in the CO_2 emission estimation.

All of the eight active facilities that use steam methane reformation have voluntarily confirmed or provided natural gas carbon content values used for estimating 1990 to 2017 emissions. Table 4–6 below provides a summary of description of the natural gas carbon content of each facility. In general, it is observed that 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 2018 and after, facility-reported natural gas carbon content values obtained through the GHGRP were applied.

For 1990 to 2017, it is assumed that the urea production process consumes a stoichiometric quantity of CO_2 of 0.733 kg CO_2/kg urea. For 1990–2007, plant-specific urea production was estimated on the basis of actual ammonia production and the respective average ratio of ammonia-to-urea production for each plant taken over data years 2008 to 2013. Urea production data for 2008–2017 was retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. For 2018 and after, CO_2 recovered for urea production was directly reported by facilities through the GHGRP.

Table 4–6 **Description of 1990–2017 Natural Gas Carbon Content Values used in Ammonia Production Emission Estimation**

Active Facility	Time Period	Natural Gas Carbon Content Description
A	1990 to 2017	Facility confirmed the use of the average of 2018 to 2020 carbon contents reported to the GHGRP to be suitable.
B	1990 to 2017	Facility provided facility-specific average carbon content value (based on 1998 to 2017 values).
C	1990 to 2017	Facility provided facility-specific average carbon content value (based on 2003 to 2017 values).
D	1990 to 2017	Facility provided facility-specific average carbon content value (based on 2004 to 2017 values).
E*	1990 to 2009	Facility confirmed the use of the average of 2018 to 2020 carbon contents reported to the GHGRP to be suitable.
	2010 to 2017	Facility provided facility- and year-specific carbon content values.
F	1990 to 2007	Facility provided facility-specific average carbon content value (based on 2008 to 2012 values).
	2008 to 2018	Facility provided facility- and year-specific carbon content values.
G	1990 to 2017	Facility confirmed the use of the average of 2018 to 2020 carbon contents reported to the GHGRP to be suitable.
H	1990 to 2017	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.

Note:
*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.

Table 4–7 **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

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 long-term storage of recovered CO_2 through enhanced oil recovery (EOR). Table 4–7 summarizes the CCS and other carbon recovery activities for each facility using SMR. The facilities were contacted again in 2023 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).

4.5.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Ammonia Production. The assessment took into account the uncertainties associated with the ammonia and urea production data, ammonia-to-feed fuel conversion factor and carbon content of natural gas. The uncertainty values associated with CO_2 emissions from the category as a whole vary over time from 6.4% to 8.8% in accordance with changes in natural gas volumes consumed for ammonia production and with changes in urea production.

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 4.5.2 above.

4.5.4. Category-Specific Quality Assurance/Quality Control and Verification

This category has undergone informal quality control checks throughout the emission estimation process.

4.5.5. Category-Specific Recalculations

The update of the feedstock use of natural gas value from one facility for 2021 contributed to a minute recalculation.

4.5.6. Category-Specific Planned Improvements

There are currently no improvements planned for estimating CO_2 emissions from Ammonia Production.

4.6. Nitric Acid Production (CRF Category 2.B.2)

4.6.1. Category Description

Nitric acid is a chemical intermediate that is commonly used to produce ammonium nitrate fertilizers or explosives. 14 nitric acid production lines (plants) at 9 facilities have been active over the time series (Cheminfo Services, 2006) (Table 4–8). Since 2005, national nitric acid production has decreased by 26%, mainly due to the closure of all plants at the Dyno Nobel Nitrogen Inc. facility in Maitland, ON in 2010. In 2022, 8 plants were operational at 5 facilities.

The Nitric Acid Production category accounted for 128 kt CO_2 eq of Canada's emissions in 2022, an 88% decrease from 2005. This decrease is driven by the installation of secondary and tertiary 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 (NO_x), notably, nitrogen dioxide (NO_2). In the second stage, the NO_2 is then absorbed into water in an absorption tower to produce nitric acid (HNO_3). 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 4–8, 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 4–8 (Cheminfo Services, 2006).

The most commonly used N_2O abatement technology type at Canadian plants are non-selective catalytic reduction (NSCR) 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 (SCR) system uses ammonia, which selectively reacts only with nitrogen oxide (NO) and nitrogen dioxide (NO_2) gases, and not with N_2O, hence a higher N_2O emission factor. NSCR 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 NSCR systems since 1990 or since their startup (Cheminfo Services, 2006). In 2021, a tertiary catalyst abatement system (believed to be an NSCR system) was retroactively installed at plant 1 at the Orica Canada Inc. Carseland Works site (Orica, 2021, 2023). This installation is the main driver for an emission decrease of 33% in this category between 2021 and 2022.

Process-gas catalytic decomposition (PGCD) 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. PGCD systems were installed retroactively in the two plants at Orica Canada Inc.'s Carseland Works in 2008[17] and 2012[18]. These installations are responsible for the majority of the emission decrease observed between 2005 and 2022 in this category. Figure 4–1 shows the production and emission trends for the category.

4.6.2. Methodological Issues

A mix of Tier 1, Tier 2 and Tier 3 methods were used in the estimation of N_2O from Nitric Acid Production, the predominance being with Tier 2, where plant-level production values were applied to technology-level EFs:

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; or
2. Tier 2 method: use of facility-specific (combined from multiple nitric acid plants at the same facility) or plant-specific production data and production technology-specific emission factors that are provided by plant technology vendors or national technology-specific average values; or
3. Tier 1 method: use of estimated production data and either plant-specific or technology-specific emission factors.

17 Orica Canada Inc. 2016. *Nitrous Oxide Abatement from Nitric Acid Production Offset Project Plan*. Available online at: https://alberta.csaregistries.ca/GHGR_Listing/AEOR_ListingDetail.aspx?ProjectId=204.

18 Orica Canada Inc. 2014. *Orica Nitric Acid Plant 2 – Nitrous Oxide Abatement from Nitric Acid Production Offset Project Plan.* Available online at: https://alberta.csaregistries.ca/GHGR_Listing/AEOR_ListingDetail.aspx?ProjectId=205.

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Figure 4–1 **Nitric Acid Production and N_2O Process Emission Trends**

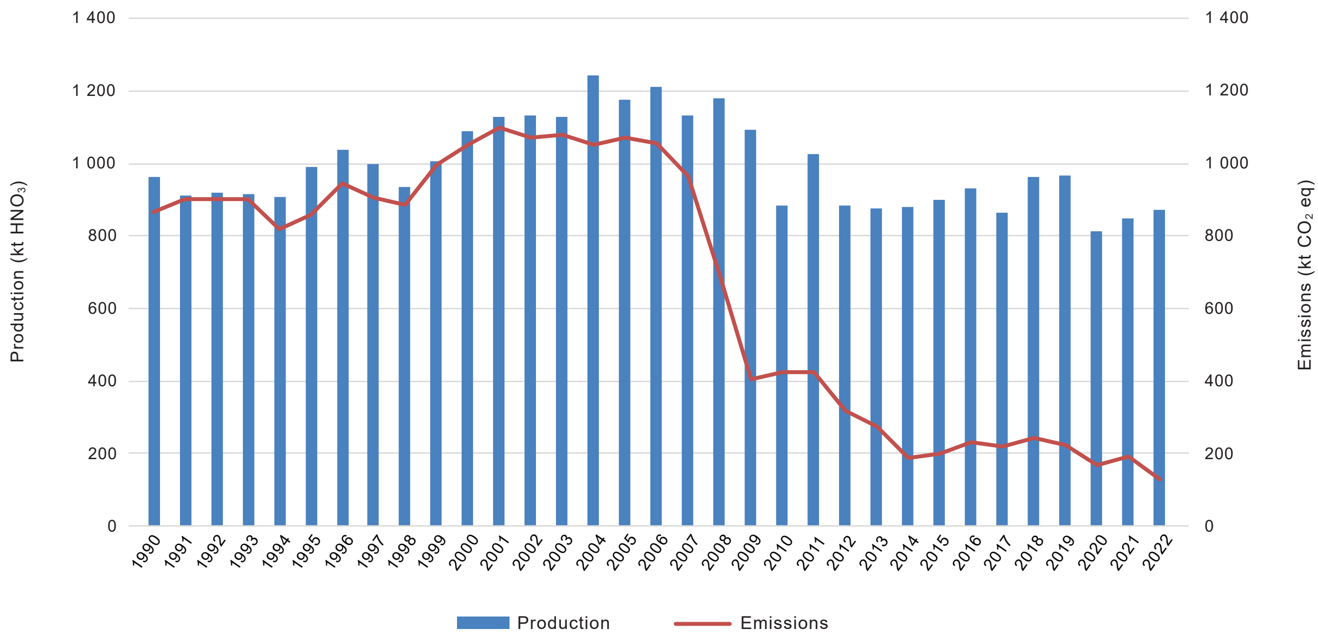

Table 4–8 describes the nitric acid industry in Canada and the methods used in compiling the estimates on a facility-specific basis.

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 using Equation 4–7 (Cheminfo Services, 2006).

Equation 4–7

$$\begin{aligned}\textit{Estimated Production, plant } i &= \left(\textit{National production} - \sum \textit{reported plant data}\right) \\ &\times \frac{\textit{Production capacity of plant } i}{\sum \textit{Production capacities for nonreporting plants}}\end{aligned}$$

For 2005–2009, activity data was reported by companies to Environment and Climate Change Canada 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 2010–2022, facility-level production data was primarily obtained from the ICSR survey. In certain cases, plant-level production data from the 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 Continuous Emissions Monitoring Systems (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 PGCD 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 Greenhouse Gas Reporting Program (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. It should be noted that in order to ensure that confidential plant- or facility-specific production data is fully protected, it is not possible for Canada to specifically associate emission factors with the plants. A weighted average emission factor for 2022 is available in Table A6.2–3.

Table 4–8 **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 & NSCR (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 2021 installation of a tertiary catalyst abatement (believed to be an NSCR system) at plant 1 of the Carseland, AB site was collected from company media releases (Orica, 2021, 2023).

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).

4.6.3. Uncertainties 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 from the category vary from 8.8% to 9.7% between 1990–1998, drop to 6.9% to 7.5% between 2000–2007, and drop again to 3.3% to 4.5% from 2012–2022. The first decrease is due partly to the closure of the Orica Canada Beloeil plant in 1999, which had a very uncertain technology-specific emission factor (± 45%). As well, the activity data uncertainty decreased due to more readily available facility-level production data from 2000 onwards. The second decrease is due to the use of less uncertain Tier 3 CEMS data from Orica Canada Inc. Carseland Works. The emission factors are the largest contributors to the uncertainty for this category.

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.

Plant equipment vendor or technology-specific emission factors (Tier 2) are used for estimating facility emissions for all years unless plant- and year-specific Tier 3 emission factors are available. These Tier 3 emission factors are used to increase the accuracy of the estimates. 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.

4.6.4. Category-Specific Quality Assurance/Quality Control and Verification

The Nitric Acid Production category has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with quality assurance/quality control (QA/QC) requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

In addition, the following checks were done to supplement the Tier 1 QC Checklist for this category:

- ensure that activity data are for 100% HNO_3 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 (EFDB)

4.6.5. Category-Specific Recalculations

There were no recalculations for this category.

4.6.6. Category-Specific 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 NSCR and SCR systems. These systems are in widespread use at Canadian nitric acid plants to abate N_2O and NO_x process emissions, and their use may contribute some process emissions.

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4.7. Adipic Acid Production (CRF Category 2.B.3)

4.7.1. 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 CRF.

4.7.2. 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 estimation method calculated emissions that occur when the abator is operating (Equation 4–9) separately from emissions that occur when the abator is not operating (Equation 4–10) due to maintenance or technical problems. The total emissions for the category are the sum of both operational modes, as shown in Equation 4–8.

Equation 4–8

$$\text{Total Emissions (t)} = N_2O \text{ Emissions (t) with abator} + N_2O \text{ Emissions (t) without abator}$$

N_2O Emissions with Abator:

Equation 4–9

$$N_2O\ Emissions\ (t)\ with\ Abator = (Production(t)) \times \left(\frac{0.3t\ N_2O}{t\ adipic\ acid}\right) \times (1 - Destruction\ Efficiency) \times (Abatement\ Utilization\ Ratio)$$

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%.
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

$$N_2O\ Emissions\ (t)\ without\ Abator = (Production(t)) \times \left(\frac{0.3t\ N_2O}{t\ adipic\ acid}\right) \times (1 - Abatement\ Utilization\ Ratio)$$

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 is not capable of measuring 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).

4.7.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Adipic Acid Production. It takes into account 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 as a whole 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 4.7.2, 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.

4.7.4. Category-Specific Quality Assurance/Quality Control and Verification

Adipic Acid Production is a key category that has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories.*

4.7.5. Category-Specific Recalculations

There have been no recalculations for this category.

4.7.6. Category-Specific Planned Improvements

There are currently no improvements planned specifically for this category.

4.8. Soda Ash Production (CRF Category 2.B.7)

4.8.1. Category Description

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.

4.8.2. Methodological Issues

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 CRF Reporter category 2.B.7 (AMEC, 2006).

4.8.3. Uncertainties and Time Series Consistency

The method, emission factor and activity data are consistent across the time series. The Tier 1 uncertainty associated with the recovered emissions is 14%.

4.8.4. Category-Specific Quality Assurance/Quality Control and Verification

The Soda Ash Production category has undergone informal quality control checks throughout the emission estimation process.

4.8.5. Category-Specific Recalculations

There have been no recalculations for this category.

4.8.6. Category-Specific Planned Improvements

There are currently no improvements planned specifically for this category.

4.9. Carbide Production, Titanium Dioxide Production, Petrochemical and Carbon Black Production, Fluorochemical Production and Other Uses of Urea (CRF Categories 2.B.5, 2.B.6, 2.B.8, 2.B.9.a, and 2.B.10)

4.9.1. Category Description

Carbide Production (CRF 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 (CRF Category 2.B.6)

Titanium dioxide (TiO_2) is one of the most commonly used white pigments. Its main use is in paint manufacture followed by paper, plastics, rubber production and other miscellaneous uses.

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.[19] The titanium slag products are shipped as process inputs for

19 Weidenhammer, Erich. 2021. *Developments in Canadian Hydrometallurgy Since 1950.* Ottawa: Ingenium – Canada's Museums of Science and Innovation. Transformation Series: 20.2. 80pp. Available online: https://publications.gc.ca/collections/collection_2021/mstc-cstm/NM33-1-20-eng-2.pdf.

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.[20]

Methanol Production (CRF Category 2.B.8 and CRF 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 containing CH_4 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 CRF category 2.B.10 Other (Methanol Production – N_2O Emissions).

Ethylene Production (CRF Category 2.B.8 and CRF Category 2.B.10)

There were five ethylene facilities in operation in Canada between 1990 and 2022, 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 CRF category 2.B.8.b and N_2O emissions are reported in CRF category 2.B.10 Other (Ethylene Production – N_2O Emission).

Ethylene Dichloride Production (CRF Category 2.B.8)

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 for the production of 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 (CRF Category 2.B.8)

Ethylene Oxide is a chemical intermediate that is used in the manufacture of glycols, including monoethylene glycol. Table 4–9 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). Process emissions from ethylene oxide production in 2022 are 8.8% higher than 2005 and 153% higher than 1990 levels due to increased production.

Table 4–9 **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.

20 Environment Canada. 1996. *Tioxide Canada Inc.*.Montreal: Environment Canada. Catalogue En153-6/27-1996E-PDF. 4pp. Available online: https://publications.gc.ca/site/eng/9.816961/publication.html.

Carbon Black Production (CRF Category 2.B.8 and CRF Category 2.B.10)

Four facilities produced carbon black in Canada between 1990 and 2022, three of which are currently operating. CO_2, CH_4 and N_2O emissions can arise from carbon black production. It should be noted that N_2O emissions are reported in CRF category 2.B.10 Other (Carbon Black Production – N_2O Emissions), whereas CO_2 emissions are included in CRF category 2.D (Non-Energy Products from Fuels and Solvent Use). Because CRF category 2.D cannot be disaggregated, CO_2 emissions from carbon black production are reported as "IE" ("included elsewhere") in the CRF Reporter.

Styrene Production (CRF Category 2.B.8)

Three styrene facilities produced styrene in Canada between 1990 and 2022, one of which closed in 1998. CO_2 and CH_4 emissions can arise from styrene production. It should be noted that CO_2 emissions are included in CRF category 2.D (Non-Energy Products from Fuels and Solvent Use) and CRF category 2.D cannot be disaggregated. Therefore, CO_2 emissions from styrene production are reported as "IE" in the CRF Reporter.

Fluorochemical Production (By-product Emissions, CRF 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 814 kt, 885 kt and 695 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 (CRF Category 2.B.10 Other [Other uses of Urea – CO_2 Emissions])

The Other Uses of Urea category takes into account 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.

4.9.2. Methodological Issues

Carbide Production (CRF 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 on the basis of 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

Total CH_4 emissions (t) =

$$\sum^{y}[(\boldsymbol{SiC\ capacity} \times \boldsymbol{capacity\ utilization} \times \boldsymbol{Emission\ Factor\_SiC}) + (\boldsymbol{CaC_2\ capacity} \times \boldsymbol{capacity\ utilization} \times \boldsymbol{Emission\ Factor\_CaC_2})]$$

y	=	companies
SiC or CaC_2 capacity	=	data collected from the industry, kt
Capacity utilization	=	based on Cheminfo Services' knowledge of the industry, %
Emission Factor_SiC	=	see Annex 6
Emission Factor_CaC_2	=	see Annex 6

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Titanium Dioxide Production (CRF Category 2.B.6)

Generally, the titanium dioxide facilities have reported their process inputs to the Report on Energy Supply and Demand (RESD) as energy inputs rather than process inputs. Therefore, quantities of process inputs and process emissions are mainly included in the Energy sector estimates (Table 4–10). To reflect this situation, CO_2 emissions from the Titanium Dioxide Production category are reported as "Included Elsewhere" (notation key "IE") in the CRF.

Table 4–10 **Titanium Dioxide Production in Canada, and Location of Activity Data & Process Emissions in the CRF**

Company	Location	Product	Primary Process Input	Years	Location of Process Emissions in the CRF
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.D.3 – Non-Energy Products from Fuels and Solvent Use – Other (Other and Differentiated)

Note: 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).

Methanol Production (CRF Category 2.B.8 and CRF 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). The methanol production data is considered confidential from 1990–2006 and as such has been aggregated for those years under Category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) and Category 2.B.10 Other (Confidential Petrochemicals – N_2O Emissions).

Methanol production restarted in Canada in 2011 in a facility that had previously been included in the inventory. The same country-specific emission factors were applied to the facility's publicly reported production data for 2011 (Cheminfo Services 2015). For 2012–2022, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

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Ethylene Production (CRF Category 2.B.8 and CRF 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 (CRF category 2.B.8) from the emissions associated with non-energy uses of fuels (CRF 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 2008–2022, 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. N_2O emissions for 2007 and 2008 were reported under Category 2.B.10 Other (Confidential Petrochemicals – N_2O Emissions) due to confidentiality of carbon black production data.

Ethylene Dichloride Production (CRF Category 2.B.8)

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). Due to the confidentiality of activity data, CH_4 emissions are reported under CRF Category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions).

Ethylene Oxide (CRF Category 2.B.8)

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 4–11.

No more than 2 companies producing ethylene oxide were operational in any year (Table 4–9). To protect confidential ethylene oxide activity data, CH_4 emissions are reported in Category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) for the entire time series. In addition, 1990–2006 CO_2 emissions are reported in Category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) to protect confidential methanol activity data.

Table 4–11 **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 (ISCR) 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.
	2019–2021	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.
	2022	1 plant: Plant-level data reported the ICSR. 1 plant: Outlier plant-level data exceeding the production capacity was reported to the ICSR. The data was corrected by Statistics Canada by imputing the average of 2019 and 2020 production levels. 2021 production levels were not used for the imputation because the facility reported an event affecting production levels that year. 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 (CRF Category 2.B.8 and CRF 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 is 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 2010–2022 are obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

To protect confidential carbon black activity data, CH_4 emission values are reported under 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) and N_2O emissions values are reported under 2.B.10 Other (Confidential Petrochemicals – N_2O Emissions) from 1990 to 2008.

Styrene Production (CRF Category 2.B.8)

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).

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. For the purpose of emission estimation at the provincial level, the annual styrene production is allocated to each plant on the basis of capacity share for years 1990–2009. Due to the unavailability of 2010 and 2011 production data, these data years are assumed to be equal to 2009 production. For years 2012–2022, 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 emission values 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 for several petrochemical categories contain confidential data that needs to be protected for certain years within the time series. Table 4–12 summarizes, by period of the time series, the categories that need to have their associated GHG emission estimates aggregated in the CRF 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) and N_2O emissions are aggregated under category 2.B.10 Other (Confidential Petrochemicals – N_2O Emissions).

Fluorochemical Production (By-product Emissions, CRF 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 was collected by Environment Canada from HCFC producers.[21]

Other Uses of Urea (CRF Category 2.B.10 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 (see Equation 4–12) was derived from that described in the U.S. National GHG Inventory.[22]

21 Bovet Y and Guilbault Y. 2004–2006. Personal communications (emails received from Bovet Y and Guilbault Y to Au A, Environment Canada, during the years 2004–2006). UPCIS.

22 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016 (2018 release). Available online at: https://www.epa.gov/sites/production/files/2018-01/documents/2018_complete_report.pdf, pg.4-28.

Table 4–12 **Categories Included in Confidential CRF Node**

	1990–2006	2007–2008	2009–present
Methanol	CO_2, CH_4, N_2O	-	-
Ethylene	-	N_2O	-
Ethylene dichloride and vinyl chloride monomer	CH_4	-	-
Ethylene oxide	CO_2, CH_4	CH_4	CH_4
Carbon black	CH_4, N_2O	CH_4, N_2O	-
Styrene	CH_4	CH_4	CH_4

Note:
- indicates no aggregation is occuring

Equation 4–12

Total CO_2 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 4.5.

Nationally complete 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.[23]

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 was calculated based on the estimated emissions, which are discussed in section 4.15 and reported in CRF category 2.D.3.

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. A complete urea balance was provided to and reviewed by the ERT to respond to an ERT comment during the inventory review that took place in 2021.

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.

4.9.3. Uncertainties and Time-Series Consistency

Carbide Production (CRF Category 2.B.5)

A Tier 1 uncertainty assessment was performed for the Carbide Production category (Cheminfo Services 2010) using expert knowledge following the 2006 IPCC Guidelines.

Regarding the carbide capacity data, an uncertainty of ±5% is applied when survey uncertainties are not provided. The uncertainty associated with the category as a whole for the time series where emissions occurred (1990–2001) ranges from ±16% to ±27% (Cheminfo Services, 2010).

23 Statistics Canada, Canadian International Merchandise Trade Web Application. Available online at: https://www150.statcan.gc.ca/n1/pub/71-607-x/71-607-x2021004-eng.htm.

Methanol Production (CRF Category 2.B.8 and CRF Category 2.B.10)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the Methanol Production subcategory following the 2006 IPCC Guidelines.

As no plant-specific uncertainty estimates could be collected (Cheminfo Services, 2010), uncertainties based on expert knowledge were used in the analysis.

The uncertainty associated with the category as a whole for the time series ranged from ±8% to ±15% for CH_4 emissions, from ±11% to ±20% for N_2O emissions and from ±4% to ±11% for CO_2 emissions.

Ethylene Production (CRF Category 2.B.8 and CRF Category 2.B.10)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010, 2015) for the Ethylene Production subcategory following the 2006 IPCC Guidelines.

In the Cheminfo Services (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided any uncertainty estimates for their data. Uncertainties based on expert knowledge of the industry were therefore used in the analysis.

The uncertainties for the time series range from ±7% to ±12% for CH_4 emission estimates, from ±12% to ±21% for N_2O emission estimates and from ±4% to ±7% for CO_2 emission estimates.

Ethylene Dichloride Production (CRF Category 2.B.8)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the Ethylene Dichloride Production subcategory following the 2006 IPCC Guidelines. As no plant-specific uncertainty estimates could be collected by Cheminfo Services (2010), uncertainties based on expert knowledge of the industry were used in the analysis. The uncertainty associated with the category as a whole for the time series is estimated at ±21% (Cheminfo Services, 2010).

Ethylene Oxide (CRF Category 2.B.8)

A Monte Carlo uncertainty assessment was performed for the Ethylene Oxide Production subcategory following the 2006 IPCC Guidelines and all years of the time-series have been assessed. As no plant-specific uncertainty estimates could be collected by Cheminfo Services (2010), uncertainties based on expert knowledge of the industry were used in the Monte Carlo analysis. Uncertainties related to the plant-level and national-level activity data, the plant allocation of national-level activity data, imputed or interpolated data, and the plant-level emission factors were included in the assessment.

The uncertainty associated with the estimates in 1990 are ±8.0% and ±37.8% for CO_2 and CH_4 emissions, and in 2022, the uncertainties are ±7.4% and ±30.8% for CO_2 and CH_4 emissions. The uncertainty of the estimates generally decreases over time due to the increase in operational facilities, as well as due to the use of plant-level activity data instead of allocation based on capacity. An exception to this trend occurs during the activity data interpolation period from 2010 to 2015. 2016 is the year with the lowest uncertainty, since all plant-level activity data was provided by facilities. The emission factors are the largest contributor to the overall uncertainty of the estimates.

The interpolation and imputation methods used for missing data gaps are consistent with the 2006 IPCC Guidelines, Volume 1, Chapter 5 (IPCC, 2006).

Carbon Black Production (CRF Category 2.B.8 and CRF Category 2.B.10)

A Tier 1 uncertainty assessment was performed by Cheminfo Services for the Carbon Black Production subcategory following the 2006 IPCC Guidelines. In the Cheminfo Services (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.

Uncertainties associated with this category range from ±6% to ±11% for CH_4 emissions, from ±11% to ±13% for N_2O emissions and from ±2% to ±7% for CO_2 emissions.

Styrene Production (CRF Category 2.B.8)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the Styrene Production subcategory following the 2006 IPCC Guidelines.

As no plant-specific uncertainty estimates could be collected by Cheminfo Services, uncertainties based on expert knowledge of the industry were used in the analysis. The Tier 1 uncertainty associated with CH_4 emissions from styrene production ranges from ±20% to ±22%.

Fluorochemical Production (By-product Emissions, CRF Category 2.B.9.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.

Other Uses of Urea (CRF Category 2.B.10 Other [Other Uses of Urea – CO_2 Emissions])

A Tier 1 uncertainty assessment was completed for the Other Uses of Urea category following the 2006 IPCC Guidelines.

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. The overall uncertainty associated with CO_2 emission estimates from other uses of urea ranged from ± 6.5% to ± 9.6%.

4.9.4. Category-Specific Quality Assurance/Quality Control and Verification

CO_2 and HFC emission estimates for categories under Petrochemical and Carbon Black Production and the Fluorochemical Production category have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Emission estimates of the other two GHGs (i.e., CH_4 and N_2O) for the same categories have undergone informal quality control checks.

In addition to the Tier 1 QC Checklist, 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 is 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

The following informal check is also done for Other Uses of Urea in addition to the Tier 1 QC Checklist:

- compare the sum of facility-reported urea production received through the Greenhouse Gas Reporting Program (ECCC, 2023) to the published national production totals from Statistic Canada's Industrial Chemicals and Synthetic Resins survey to ensure that activity data is complete

4.9.5. Category-Specific Recalculations

Other Uses of Urea (CRF Category 2.B.10 Other [Other Uses of Urea – CO_2 Emissions])

Other Uses of Urea emissions estimates were recalculated downwards for 2009 through 2021, with a maximum change of -2.6 kt (-6.2%) in 2021. These recalculations were caused by revised estimates for urea used as diesel exhaust fluid in selective catalytic reduction (SCR) vehicles for 2008 to 2021 due to Energy (Transport) methodological updates as well as minor changes to Statistics Canada import data for urea and urea-ammonium-nitrate fertilizer mixes for 2020.

4.9.6. Category-Specific Planned Improvements

Titanium Dioxide Production (CRF Category 2.B.6)

In past inventory submissions, the Titanium Dioxide Production category was assessed to be insignificant and reported as "Not Estimated" ("NE") in the CRF reporter based on a Tier 1 estimate conducted in 2010 that included TiO_2 produced using the chloride process at one facility. It was discovered upon a recent in-house review that titanium slag production has also taken place in Canada throughout the time-series at one facility and as a result, emissions from the category are now potentially greater than 500 kt CO_2 eq.

As noted in section 4.9.2 of this inventory submission, industrial process emissions from the facilities in this category are currently reported as part of the Energy sector's CO_2 emissions from Manufacturing Industries and Construction (CRF Category 1.A.2) and as part of the IPPU sector's Non-Energy Products from Fuels and Solvent Use (CRF Category 2.D.3). Therefore, Titanium Dioxide Production is currently reported in the CRF using the "Included Elsewhere" ("IE") notation key.

Data sources for estimating industrial process emissions in CRF Category 2.B.6 are being explored. Efforts will also be made to ensure that process input quantities are reconciled with the other inventory categories to avoid double-counting.

4.10. Iron and Steel Production (CRF Category 2.C.1)

4.10.1. Category Description

The Iron and Steel Production category contributed 7811 kt (1.1%) to Canada's total emissions in 2022, a 24% 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 is 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
- CH_4 emissions from metallurgical coke use (as a reductant)

4

4.10.2. Methodological Issues

An IPCC Tier 2 methodology is used to estimate emissions from Iron and Steel Production (IPCC, 2006). The method reflects the operation of Canadian facilities with country-specific emission factors for coke (EF_{met_coke}) and carbon content of pig iron. For more specific information on the Canadian Iron and Steel sector, refer to Annex 3.3.

Pig Iron Production (CRF Category 2.C.1.b)

CO_2 emissions from the production of pig iron from the blast furnace are reported under the CRF category 2.C.1.b Pig Iron. These emissions were estimated using the following Equation 4–13:

Equation 4–13

$$E_{CO2\_PI} = (EF_{met\_coke} \times M_{met\_coke}) - (P_{PI} \times CC_{PI}) \times (44/12)$$

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_i	=	mass of i used or produced, kt; where i is metallurgical coke, ore
CC_i	=	carbon content of i, %; where i is 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

For the purposes of calculating emission estimates for this category, it was assumed that the reductant used in the Canadian industry is 100% metallurgical coke (Cheminfo Services, 2010). Pig iron producers in Canada have recently confirmed the use of natural gas as reductant in their blast furnaces for the entire time series, and the GHG emissions associated with the use of natural gas are currently estimated under CRF Category 1.A.2.a. As such, the implied emission factor associated with Category 2.C.1.b Pig Iron is lower than the IPCC default value of 1.35 tonne CO_2 per tonne of pig iron produced. Work is ongoing to re-allocate the natural gas emissions to Category 2.C.1.b. Table 4–13 summarizes the different sources of activity data and other variables used in the calculation of Equation 4–13.

The emission factors for coke use (EF_{met_coke}) was 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. Facility reported 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 4–13.

CH_4 emissions were estimated on the basis of the mass of metallurgical coke used (Statistics Canada 1990–2022) multiplied by an 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.

Table 4–13 **Sources of Iron production activity data and other variables used in Equation 4–13**

Variable	Year	Source
M_i – metallurgical coke used	1990–present	RESD, Statistics Canada (Cat. No. 57-003)
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, 2023)
EF_{met_coke} – metallurgical coke used	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, 2023)
	2017–present	GHGRP (ECCC, 2023)
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, 2023)
	2017–present	GHGRP (ECCC, 2023)

Direct Reduced Iron (CRF 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 (CRF 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. In addition, any other material used in the sinter process containing carbon is reported under category 2.D.3 Other and Undifferentiated, through data reported to the RESD.

Steel Production (CRF Category 2.C.1.a)

CO_2 emissions from the production of steel and ferroalloys are reported under CRF 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_j	=	carbon content of i, % 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 4–14 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 4–14 **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, 2023)
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, 2023)
	2017–present	GHGRP (ECCC, 2023)
EFk – 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, 2023)
	2017–present	GHGRP (ECCC, 2023)

Pellet Production (CRF Category 2.C.1.e)

In Canada, there are two iron ore pellet producing facilities, for which emissions are currently not estimated due to lack of suitable activity data for the entire time-series. Work is ongoing to identify potential sources of activity data for eventual inclusion in the inventory.

Limestone use in Iron and Steel Furnaces (CRF 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 4.4.2.

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.

4.10.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Iron and Steel Production. It took into account the uncertainties associated with all the parameters used in estimating emissions of each source in this category, such as data on metallurgical coke use, the emission factor of coke, data on pig iron and steel production, the carbon content of pig iron and steel, limestone data 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 ±5.61% and ±405%, respectively.

4.10.4. Category-Specific Quality Assurance/Quality Control and Verification

Iron and Steel Production (CO_2) is a key category that has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

4.10.5. Category-Specific Recalculations

CO_2 emissions for this category were recalculated due to updated production data for Pig Iron production from 2017 to 2021, GHGRP data revisions and a method change in the calculation of emissions from the use of limestone in Iron and Steel furnaces. The magnitude of the recalculations ranged from +1.0 to +616 kt CO_2 eq and impacted the entire time series from 1990–2021.

4.10.6. Category-Specific Planned Improvements

As noted earlier, a smaller part of the process CO_2 emissions associated with iron and steel production originates from the use of reductants other than metallurgical coke, namely natural gas and coal. This fuel data is from the RESD, and owing to its aggregated format, it is currently not possible to allocate the appropriate portion to CRF category 2.C.1, Iron and Steel Production.

Natural gas used as a reductant in the production of direct-reduced iron (DRI) and within the blast furnace, are currently reported in the Energy sector (as combustion emission sources in Iron and Steel Production). Also, a fraction of coal (aggregated with non-energy fuels in RESD) used in iron and steel making is currently reported under the Non-Energy Products from Fuels and Solvent Use category (section 4.14).

As supporting information (to disaggregate RESD fuel data) becomes available, it is planned to allocate the aforementioned emissions to CRF category 2.C.1, Iron and Steel Production.

4.11. Ferroalloy Production (CRF 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 2021, 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 CRF category 2.C.1.a Steel since they cannot be disaggregated due to confidentiality concerns.

4.12. Aluminium Production (CRF Category 2.C.3)

4.12.1. Category Description

The Aluminium Production category accounted for 5655 kt (0.8%) of Canada's emissions in 2022, representing an overall decrease in emissions of 32% since 2005.

Emissions from the combustion of fossil fuels used in the production of baked anodes are covered in the Energy sector, but emissions arising specifically from the combustion of volatile matter released during the baking operation and from the combustion of baking furnace packing material are accounted for under the Aluminium Production category (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), both of 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.[24] 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.

24 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,[25] and the 10 plants currently in operation have focused on modernizing their facilities and improving production efficiency.

4.12.2. 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 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 receives the same data sets as those provided by AAC member companies in the provinces. As of the data year 2018, aluminium companies have been reporting their emissions directly to ECCC's GHGRP (ECCC 2023), methods of which are also consistent with the 2006 IPCC Guidelines.

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 4–15 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 4–15 **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

25 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.

4.12.3. Uncertainties 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.

4.12.4. Category-Specific Quality Assurance/Quality Control and Verification

CO_2 and PFC emissions from Aluminium Production are key categories that have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

4.12.5. Category-Specific Recalculations

There were no recalculations for this category.

4.12.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

4.13. Magnesium Production (CRF Category 2.C.4)

4.13.1. Category Description

SF_6 is emitted during magnesium production and casting, where it is used as a cover gas to prevent oxidation of the molten metals. SF_6 is not manufactured in Canada and is solely imported.

During the 1990–2006 period, there were two major magnesium producers in Canada: Norsk Hydro and Timminco Metals. Norsk Hydro closed in the first quarter of 2007 and Timminco closed in August 2008. Another magnesium producer, Métallurgie Magnola, operated between 2000 and 2003, but closed in April 2003. Between 1990 and 2004, Norsk Hydro had invested in research and development projects designed to find a substitute for SF_6 and eventually eliminate the use of SF_6 as a cover gas at its plant.[26] This research, as well as the use of substitute gas mixtures, produced significant reductions in SF_6 emissions in the mid- to late 1990s. The significant increase in magnesium production across 1999–2000, noted in an ERT's review comment, was the consequence of a new facility beginning operation in 2000 and the other two facilities increasing their SF_6 use by more than 30% between 1999 and 2000. For 2005–2007, Norsk Hydro's SF_6 emissions were significantly reduced as a result of the gradual reduction in production and the plant's closure in 2007. Regular review is conducted in-house to ensure magnesium production activities from any new facilities are included in emissions estimates. From this review, it was identified that one magnesium production company began operations in 2020. However, this company does not contribute to any SF_6 emissions, as it does not use SF_6 as cover gas.

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. Two companies shut down their magnesium casting operations at different times in 2009 (one in June and one in December), one of which moved its operations to the United States.

It is estimated that the remaining five magnesium casting companies in operation released about 167 kt CO_2 eq in 2022 (< 0.1% of Canada's emissions).

Following comments received from the ERT in 2017, emissions from magnesium casting previously reported in CRF category 2.C.7 are reported altogether with SF_6 emissions coming from primary magnesium production in CRF category 2.C.4 since the 2018 inventory submission.

26 Laperrière J. 2004. Personal communication (email from Laperrière J to Au A, Environment and Climate Change Canada, dated October 27, 2004). Norsk Hydro.

4.13.2. Methodological Issues

SF_6 emissions from magnesium production for 1999–2007 were directly reported by the companies (Norsk Hydro, Timminco Metals and Métallurgie Magnola Inc.) to Canada's National Pollutant Release Inventory (NPRI). Emission estimates used in this report are obtained from the NPRI's online database (Environment Canada, 1990–2007). For previous years (i.e., 1990–1998), the data was provided voluntarily by the producers to Environment Canada through personal communication. Since there was no reported 2008 data for Timminco, its 2008 SF_6 value was estimated on the basis of its 2007 data and the number of months of operation in 2008 (i.e., seven months). For 2009 onwards, since there have been no magnesium production plants operating in Canada, there has been no need to perform any data collection.

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. However, they used different methods for estimating their SF_6 consumption. Norsk Hydro confirmed the use of the weight difference method,[27] 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.[28] 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 taken into account.

The technique applied to estimate emissions from magnesium production is considered to be a Tier 2 type method, as it is based on the reporting of facility-specific emission data.

The approach for estimating SF_6 emissions from casting companies assumes all SF_6 used as a cover gas is emitted to the atmosphere. SF_6 use data for the 1990–2022 time series came from a combination of data sources. There were 11 casting companies that operated over 1990–2004. Two companies closed in 2000 and two other companies closed in 2003. The majority of the companies have provided SF_6 consumption data through the Cheminfo Services study (2002) and the Cheminfo Services (2005b) study. Interviews were also conducted with companies that did not complete the Cheminfo studies to collect data.

For 2005–2007, SF_6 consumption data was provided by all seven operating casting companies through a voluntary data submission process. They were used for the calculation of emissions. For 2008, data was made available by six of the seven casting companies through the voluntary data submission process. For the remaining company, it was assumed that its 2008 SF_6 use stayed at the 2007 level. For 2009, communication was established with all seven companies. Two of the companies, for which magnesium casting operations had shut down in 2009, were not able to report their 2009 SF_6 use data, but provided reasonable assumptions that could be used to estimate the 2009 SF_6 use. SF_6 use data for 2009 was provided by the other five companies. For 2014 to 2019, SF_6 use data was provided by four out of five operating magnesium casting companies through a voluntary data collection. For 2022, two out of five companies provided SF_6 data through a voluntary data collection, while two other companies reported their SF_6 emission data through the GHGRP. Facilities that reported to the GHGRP confirmed that the SF_6 emission values reported for the 2020 data year were solely for emissions coming from the use of SF_6 as cover gas. It is assumed that the situation stays the same for subsequent years. In the case where SF_6 use data was not available for a company during the years 2010 to 2022, SF_6 emissions were estimated based on provincial gross output data. More specifically, a ratio of "provincial gross output for a year with no facility-specific SF_6 use data" to "provincial gross output for the most recent year for which the facility provided SF_6 use data" was calculated. SF_6 emissions (for the years with no SF_6 use data) were then estimated by multiplying the ratio by the most recent facility-specific SF_6 emission value.

SF_6 consumption was estimated by companies using a variety of methods, with the accounting method being the most common. 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 time period within the year. The technique applied to estimate emissions from magnesium casting for 1990–2004, 2008–2009 and 2010–2022 for facilities where SF_6 use data was estimated based on provincial gross output data or derived from reported magnesium casting production values is considered to be of Tier 2 type (IPCC, 2006). For 2005–2007 and 2010–2022 for facilities that provided SF_6 data directly, the emission estimation method is of Tier 3 type.

4.13.3. Uncertainties and Time-Series Consistency

A combined Tier 1 uncertainty assessment was performed for Magnesium Production and Magnesium Casting. It took into account the uncertainty associated with the SF_6 data reported by each facility. The uncertainty varied from ±2.6% to ±20.8% from 1990 to 2022.

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 methodology section.

27 Laperrière J. 2006. Personal communication (email from Laperrière J to Au A, Environment and Climate Change Canada, dated October 4, 2006). Norsk Hydro.

28 Katan R. 2006. Personal communication (emails from Katan R to Au A, Environment and Climate Change Canada, dated March 16–22, 2006). Timminco.

4.13.4. Category-Specific Quality Assurance/Quality Control and Verification

The Magnesium Production category has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as outlined in Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* There is a step (step 4.4) in Canada's current QC process for detecting large fluctuations (e.g., in production or in implied emission factors).

The Magnesium Casting category has undergone informal quality control checks.

4.13.5. Category-Specific Recalculations

Emission estimates for 2010 to 2021 were recalculated for Magnesium Casting due to updates in gross output data.

The changes were between -5.1 kt to +3.2 kt.

4.13.6. Category-Specific Planned Improvements

There are no planned improvements for magnesium production.

4.14. Lead and Zinc Production (CRF Category 2.C.5 and 2.C.6)

4.14.1. 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.

A Tier 1 emission estimate was completed for both lead and zinc based on national production data. However, upon further investigation, the use of reductants accounts for most of these emissions. The fuel and reductant use data is reported to the RESD and owing to its aggregated format, it is currently not possible to allocate the appropriate portion of emissions to CRF category 2.C.5 for Lead Production and 2.C.6 for Zinc Production. Thus, emissions are currently accounted for as part of CRF 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.

4.15. Non-Energy Products from Fuels and Solvent Use and Use of Urea in Selective Catalytic Reduction Vehicles (CRF Category 2.D.3)

4.15.1. Category Description

Non-Energy Products from Fuels and Solvent Use (CRF Category 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. 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 to avoid double counting. Additional details on the method used to calculate emissions from this category can be found in Annex 3, section A3.3.3.

The Non-Energy Products from Fuels and Solvent Use category contributed 12 213 kt (1.7%) to Canada's total emissions in 2022, a 23% increase from 2005.

Efforts have been made to examine the possibility of disaggregating lubricating oils and greases from the Non-Energy Products from Fuels and Solvent Use category and reporting the associated CO_2 emissions under CRF category 2.D.1, instead of CRF category 2.D.3. However, results of the examination show that reporting CO_2 emissions coming from use of lubricating oil and greases as a separate CRF category can lead to disclosure of confidential activity data. Hence, these emissions are kept in CRF category 2.D.3.

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles (CRF 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.

4.15.2. Methodological Issues

Non-Energy Products from Fuels and Solvent Use (CRF Category 2.D.3)

Emission factors for non-energy use of fuels were developed on the basis of 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 4–16.

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.

This technique is consistent with the method described in the 2006 IPCC Guidelines and is considered to be a Tier 1 type method as it is based on the use of national consumption data and average national emission factors. Emissions of CH_4 and N_2O for CRF category 2.D.3 are not estimated because there is no methodological guidance provided in the 2006 IPCC Guidelines.

Table 4–16 **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 (CRF 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.

For estimating emissions from this source, road transportation activity data must be considered. More specifically, vehicle population, fuel consumption ratios and kilometre accumulation rates are 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 catalyst. For more information on the sources of this information, refer to Annex 3.1.

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. Additionally, the default DEF purity of 32.5% 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.[29]

4.15.3. Uncertainties and Time-Series Consistency

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).

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. The overall uncertainty was found to be ±50%.

4.15.4. Category-Specific Quality Assurance/Quality Control and Verification

Non-Energy Products from Fuels and Solvent Use is a key category that has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

The category of CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles has undergone informal quality control checks throughout the emission estimation process.

4.15.5. Category-Specific Recalculations

For the Non-Energy Products from Fuels and Solvent Use category, CO_2 emissions were recalculated for the entire time series (1990–2021) due to updates to the RESD, updates to the use of lubricating oils and greases used in off-road two-stroke engines and updates made to the Iron and Steel model that impacted the amount or petroleum coke assumed to be used as electrodes in Electric Arc Furnaces. The overall impact of all the revisions ranges from a maximum of +156 kt in 2021 to a minimum -38.6 kt in 2001.

Revised activity data from 2009 to 2021 caused recalculations ranging from 0.0002 kt in 2009 to 2.6 kt in 2021, for the category of use of urea in SCR vehicles.

4.15.6. Category-Specific Planned Improvements

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.

There is no planned improvement for estimating CO_2 from use of urea in SCR vehicles.

29 Rideout G. 2014. Personal communication (email to McKibbon S. November 4, 2014). Pollution Inventories and Reporting Division, Environment and Climate Change Canada.

4.16. Electronics Industry (CRF Categories 2.E.1 and 2.E.5)

4.16.1. 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 as a dielectric coolant, as these are included under Other Product Manufacture and Use (CRF subsector 2.G).

It is estimated that emissions from the electronics industry in Canada accounted for about 49 kt CO_2 eq in 2022, a 492% 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.

4.16.2. Methodological Issues

PFC Emissions from Semiconductor Manufacturing (CRF 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 (CRF category 2.F; refer to section 4.18). 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 and 2022 in the absence of a 2021–2022 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_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:

4

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)
$E_{C_2F_6}$	=	C_2F_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 A6.2–10.

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 and 2022, emission control use rates and destruction efficiencies were held constant at 2020 levels for 2021 and 2022, resulting in a constant emissions trend.

NF_3 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

In 2013, Environment and Climate Change Canada (ECCC) commissioned a study to determine the extent of NF_3 usage in Canada, including a survey of all potential NF_3 gas suppliers as well as seven identified potential users (Cheminfo Services, 2014). In the survey, only one semiconductor manufacturing facility indicated usage of NF_3 in 2013, and a gas distributor identified an additional unidentified purchaser between 2010 and 2013. The results of the study are considered to be complete, as both Canadian fabrication plants in the SEMI World Fab Watch database responded to the survey (Cheminfo Services, 2014). Additionally, previous research conducted by ECCC using the Domestic Substances List indicated that between 33 and 199 kg of NF_3 were sold in 1986 (ECCC, 1986). All NF_3 usage in Canada is believed to occur in the semiconductor manufacturing industry.

The use of NF_3 in the plasma cleaning of CVD chambers can produce by-product emissions of CF_4 (a PFC). The IPCC Tier 2 methodology, as shown in Equation 4–16, was used to estimate NF_3 and by-product CF_4 emissions from the semiconductor manufacturing industry:

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)

To determine NF_3 use and emissions throughout the time series, various assumptions needed to be made. For the unidentified 2010–2013 purchaser, the use of the purchased quantity of NF_3 was assumed to be evenly distributed amongst the years since no information on annual use was available. Emissions for this purchaser were estimated using Tier 2a emission factors (EFs) and the default heel value of 10%. It was assumed that no emission control technologies were employed. The identified 2013 user stated that the NF_3 was used in an etching process and provided a purchase quantity and an amount fed into the process, so the heel value was not applied. Emissions for this facility were estimated using Tier 2b EFs representative of the etching process. The company indicated that no emission control technologies were employed. It was assumed that 2010–2012 use levels for this company were at 2013 levels, and emissions were calculated using the same method.

To estimate emissions for years 1990–2009, emissions for 1986 were first calculated using the midpoint value of the range from the Domestic Substances List using Tier 2a EFs and the default heel value, and it was assumed that no emission control technologies were used. Then, the 1990–2009 emissions were calculated by linearly interpolating the 1986 and 2010 NF_3 and by-product CF_4 emissions values. The emissions were interpolated, rather than interpolating the use of NF_3 and calculating emissions independently, because this latter approach would have induced a discontinuity with the by-product emissions of CF_4 from the application of different sets of EFs (Tier 2a EFs were used for 1986, and a combination of Tier 2a and 2b EFs were used for 2010).

Voluntary surveys were collected from major gas distributors and the identified 2013 user for data years 2014–2020. Other than the identified 2013 user, gas distributors did not sell any NF_3, so the unidentified 2010–2013 user is assumed to have stopped using NF_3 after 2013. Emissions for 2014–2020 are therefore estimated using annual use data for the etching process as collected from the sole facility based on weighing the gas canisters before and after process use along with Tier 2b emission factors. The facility states that they have emission control technology on-site capable of abating NF_3 and CF_4 emissions, but that the process gases from this part of production are not fed into the abatement technology (a_i is equal to 0 for 2014–2020). In the absence of a 2021–2022 data collection, NF_3 use data and the emission control use rate were held constant at 2020 levels for 2021 and 2022, yielding a constant emissions trend.

For all years where a Tier 2a method is applied (1990–2013), NF_3 usage was assumed, as opposed to NF_3 remote usage, based on the definitions stated in the 2006 IPCC Guidelines. Remote usage only applies to remote plasma cleaning of the reaction (CVD) chamber, which can also be done in-situ. 2014–2022 emissions are estimated using a Tier 2b method for etching processes, where remote NF_3 use is not applicable.

SF_6 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

The method applied to estimate SF_6 Emissions from Semiconductor Manufacturing was similar to what was used to estimate PFC and NF_3 emissions. However, use of SF_6 as a process gas in etching and CVD processes does not produce any fluorocarbon by-product emissions. A Tier 2a estimate was conducted using IPCC 2006 Volume 3, Equation 6.2.

Quantities of SF_6 sold to semiconductor manufacturers for 1995–2003 were obtained from major Canadian gas suppliers. Since 1990–1994 sales data is unavailable, it was assumed that the quantity sold per year during 1990–1994 was at the 1995 level.

From 2004 onwards, the total amount of SF_6 used in the semiconductor manufacturing industry was estimated by multiplying the total SF_6 imported (from Statistics Canada) by the proportion of gas distributor SF_6 sales data attributed to semiconductor manufacturing (in %) (Cheminfo Services, 2005a and several ECCC surveys). No SF_6 sales data was collected for the years 2010–2013, so the proportions of gas distributor SF_6 sales data attributed to semiconductor manufacturing were linearly interpolated between 2009 and 2014. In the absence of the collection of 2021 or 2022 SF_6 sales data, sales data characteristics were held constant at 2020 levels. SF_6 import data was available until 2011 from Statistics Canada. For 2012–2022 data years, the gross output (GO) economic data for NAICS 334 (Computer and Electronic Products Manufacturing) was used as a proxy variable to scale the annual imports of SF_6 to the 2011 import data.

Due to the two different sources of SF_6 data (i.e., Canadian gas suppliers for 1995–2003 and Statistics Canada for 2004–2009), there was a significant difference among these periods. To ensure a consistent trend over the entire time series, an overlap technique (IPCC 2006, Volume 1, Chapter 5) was applied for 1990–2003 (both data sources had SF_6 import data for years 1998–2000).

Emissions were calculated using the heel value (h) of 12% provided and confirmed by two major SF_6 gas distributors, Air Liquide and Praxair.[30] The IPCC 2006 default emission factor (1-U) of 0.2 was used. From 1990 to 2013, it was that assumed no emissions control technologies were used by the industry since no data is available. For 2014 to 2020, some SF_6 users in the semiconductor manufacturing industry provided annual facility-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). It was assumed that all other facilities had no emissions control technologies operating from 2014 to 2020. The facility-specific shares (s_f) of the gas distributor SF_6 sales data attributed to semiconductor manufacturing were used in Equation 4–17 to calculate the total emissions from SF_6 use in semiconductor manufacturing. The use rates, destruction efficiencies, and market penetration rates of emission control technologies were held constant at 2020 levels in 2021 and 2022 in absence of a data collection. Equation 4–17 is an expanded country-specific version of IPCC 2006 Volume 3, Equation 6.2:

4

Equation 4–17

$$E_{SC,SF_6} = (1-\mathbf{h}) \times [\mathbf{FC} \times (1-U) \times \left(1-\sum_{f=1}^{n}(s_f \times a_f \times d_f)\right)]$$

E_{SC,SF_6}	=	total emissions from SF_6 use in semiconductor manufacturing
h	=	heel value of 12%, as provided by gas distributors Air Liquide and Praxair
FC	=	total amount of SF_6 used in the semiconductor manufacturing industry (SF_6 imported multiplied by the proportion of gas distributor sales data attributed to semiconductor manufacturing)
U	=	U is the fractional use rate of SF_6 (fraction destroyed or transformed in process), equal to 0.8 (see IPCC 2006 Volume 3, Table 6.3)
s_f	=	facility-specific share of the gas distributor sales data attributed to semiconductor manufacturing
a_f	=	facility-specific fraction of SF_6 volume fed into process types with emission control technology
d_f	=	facility-specific fraction of SF_6 destroyed by the emission control technology

30 Rahal H and Tardif A. 2006. Personal communications (emails from Rahal H and Tardif A to Au A, Environment and Climate Change Canada, dated November 22, 2006, and November 13, 2006, respectively). Praxair and Air Liquide, respectively.

PFC Emissions from Other Emissive Applications (CRF 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 (CRF category 2.F; refer to section 4.18). 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.

4.16.3. Uncertainties and Time-Series Consistency

PFC Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

A Tier 1 uncertainty assessment was performed for the category of PFC Emissions from Semiconductor Manufacturing. PFC emissions in the base year are only from NF_3 usage, so the base year activity data uncertainty was assumed to be the same as NF_3. The base year emission factor uncertainty is from IPCC 2006, Volume 3, Table 6.9. The current year activity data uncertainty is assumed to be the same as other facility and gas distributor data (2%), and the current year emission factor uncertainty is based on an assessment that took into account all of the process-specific emission factors (Japan Ministry of the Environment, 2009). The base year uncertainty is 321%, and the current year uncertainty is 19%.

NF_3 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

A Tier 1 uncertainty assessment was performed for the category of NF_3 Emissions from Semiconductor Manufacturing. The base year NF_3 activity data uncertainty is based on the 1986 NF_3 use range that was provided by the Domestic Substances List (33 to 199 kg). The base year activity data uncertainty was calculated by determining the error if the true value was the minimum of the provided range instead of the midpoint that was used for interpolating 1990 activity data. The current year NF_3 activity data uncertainty of 78% was calculated by combining the 2020 facility data uncertainty (2%) and the uncertainty of holding the 2020 activity data constant for 2022. The uncertainty of holding the 2020 data constant for 2022 was determined using the variance of the 2013 to 2020 use rates reported by the facility. The NF_3 emission factor uncertainties (Tier 2a for base year, Tier 2b for current year) are from IPCC 2006, Volume 3, Table 6.9. The base year uncertainty is 261%, and the current year uncertainty is 310%.

SF_6 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

A Tier 1 uncertainty assessment was performed for the category of SF_6 Emissions from Semiconductor Manufacturing that took into account the uncertainty of the SF_6 import data, the total reported SF_6 sales data, the proportion attributed to semiconductor manufacturing, and the emission factors (± 45%). This uncertainty value is assumed to be representative of the entire time series.

PFC Emissions from Other Emissive Applications (CRF Category 2.E.5)

A Tier 1 uncertainty assessment was performed for the category of PFC Emissions from Other Emissive Applications. The base year uncertainty is zero since there are no emissions until 1995. The current year activity data uncertainty from facility and gas-distributor reported data is 2%, and the emission factor uncertainty was assessed to be 50% (Japan Ministry of the Environment, 2009). Therefore, the current year uncertainty is 50%.

4.16.4. Category-Specific Quality Assurance/Quality Control and Verification

Categories under the Electronics Industry subsector have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories.*

In addition to the Tier 1 QC Checklist, 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.

4.16.5. Category-Specific Recalculations

SF_6 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

Emissions were recalculated for years 2012–2021 due to the revision of gross output data for the Computer and Electronic Products Manufacturing NAICS (334), which are used to extrapolate 2012 to 2021 SF_6 imports from 2011 levels. The effects of these recalculations range from -0.20 kt CO_2 eq (-0.76%) in 2016 to +1.4 kt (+4.1%) in 2021.

4.16.6. Category-Specific Planned Improvements

Voluntary data surveys for 2021 and 2022 were not collected, and 2021 and 2022 use levels and emissions were held constant at 2020 levels. A voluntary data collection of 2021–2022 data is planned in 2024 to obtain updated PFC, SF_6, and NF_3 use data.

The SF_6 Emissions from Semiconductor Manufacturing estimate uses discontinued SF_6 import data from Statistics Canada as input. This data has been extrapolated using economic proxy variables since 2011. The inventory team is exploring other data options for revising the model to eliminate the use of discontinued data.

4.17. Product Uses as Substitutes for Ozone-Depleting Substances (CRF Category 2.F, HFCs)

4.17.1. Category Description

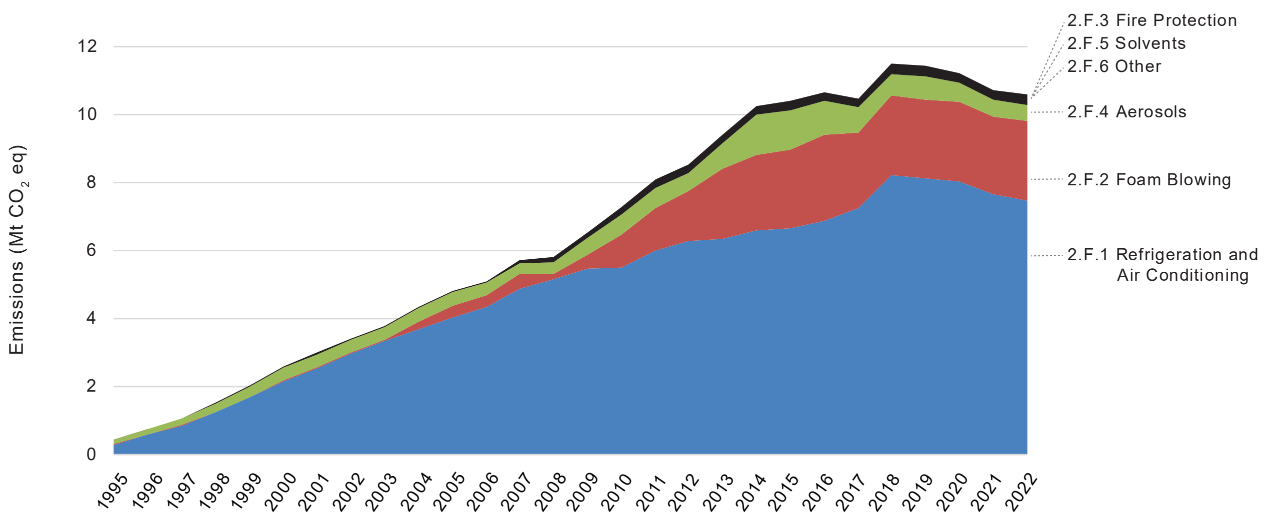
In order to provide a clear representation of the Canadian category of Product Uses as Substitutes for Ozone-Depleting Substances, explanations on hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) have been divided into two separate sections in this report (sections 4.17 and 4.18, respectively).

Before the Montreal Protocol ban on the production and use of chlorofluorocarbons (CFCs) came into effect in 1996, very few HFCs were produced and used globally. In Canada, HFC-23 was emitted as a by-product of HCFC-22 production, which ended in 1992. There has never been production of HFCs in Canada. Also, Canadian emissions from HFC consumption were considered negligible for the 1990–1994 period (IPCC/OECD/IEA, 1997). HFC consumption in Canada began in 1995. HFCs are used in a variety of applications, including refrigeration, air conditioning, fire protection, aerosols, solvent cleaning, and foam blowing. All HFCs consumed in Canada are imported in bulk or in manufactured items and products (e.g., refrigerators).

HFC releases contributed approximately 10.6 Mt CO_2 eq (1.5%) to Canada's total emissions in 2022, a 120% increase from 2005 that can be explained by their phase-in as substitutes for CFCs and hydrochlorofluorocarbons (HCFCs). HFC emission trends and contributions from applications are presented in Figure 4–2. Refrigeration and air conditioning applications comprise the majority of HFC emissions in Canada. Use as foam blowing agents and in aerosol products are also significant contributors. Since a peak in 2018 at 11.5 Mt, HFC emissions have begun to decline, in part due to reduced imports of bulk HFCs. This reduction coincides with the implementation of the Ozone-depleting Substance and Halocarbon Alternatives Regulations, which for calendar years 2019 to 2023 limited total net HFC imports (expressed in CO_2 equivalent mass) to 90% of average annual net imports in 2014 and 2015.[31]

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

Figure 4–2 **Emissions from HFCs used as Substitutes for Ozone-Depleting Substances, by Application**



4.17.2. Methodological Issues

Activity Data

Canadian HFC use data is derived from bulk imports, and imports and exports of manufactured items (MIs). Canada occasionally exports small quantities of HFCs in bulk. Up to the year 2005, activity data of bulk gases and MIs was gathered via periodic, mandatory surveys for the data years 1995 through 2004; additional mandatory bulk gas activity data collection took place in 2014 and 2016, covering activity data of years 2008 through 2015. Bulk gas activity data for 2017–2022 was collected annually from 2018–2023 through mandatory surveys under the *Ozone-depleting Substances and Halocarbon Alternatives Regulations* (ODS Regulations).

Note that the 1996 survey did not include information on imports and exports of manufactured items for the 1995 data year, and the activity data was therefore estimated on the basis of the 1996–1998 survey data.

Voluntary surveys for bulk sales and imports and exports of MIs by market segment were collected from 2006 to 2011 covering activity data of years 2005 through 2010. The surveys had varying response rates and application aggregation levels.

The 2014, 2016, and 2018–2023 mandatory surveys of HFC bulk imports and exports by HFC type and market segment forms the foundation for the 2008 through 2015 and 2017 through 2022 portion of the HFC inventory. Some incomplete activity data for the imports and exports of MIs was voluntarily reported through the 2014 and 2016 surveys for the 2008–2015 data years and is included in the inventory. Reporting of HFCs to the 2014 and 2016 mandatory surveys was done on a application and sub-application level so that the quantities for manufacture and servicing could be split. When there were overlaps between the voluntary and the mandatory surveys, the mandatory surveys took precedence.

Imports and exports of MIs have been extrapolated since 2010. The extrapolation process involves using proxy variables such as deflated economic data to estimate the growth or decline in HFC consumption for a given sub-application. In addition, no activity data on imports or exports of bulk gases was collected for 2016, so this year was extrapolated from the 2015 activity data.

All chemical activity data has been provided at a Tier 2a sub-application level or is broken down to a sub-application level using the trends of the importer or company research. More information on the received data, the applications and sub-applications, the disaggregation methodology and the extrapolation methodologies are available in Annex 3.3.3.

The full list of HFCs and the activity data years in which they appeared are shown in Table 4–17.

Table 4–18 shows the breakdown of 2022 bulk HFC import data by type per 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.[32] PureSphera in Bécancour, Quebec may also recover and/or destroy HFCs from end-of-life refrigeration equipment.[33] However, no data is publicly available on the amount of HFCs destroyed or reclaimed in Canada.

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. [EHS], 2013; Environment and Climate Change Canada [ECCC], 2015). Additional information on survey results and quality control procedures can be found in Annex 3.3.3.3. The country-specific emission factors were applied for the entire time-series.

For the aerosols, foam blowing, fire extinguishing, solvents, and 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 using 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 Annex 3.3.3 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 are 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 Annex 3.3.3.

Table 4–17 **HFCs Used in Canada and Years of Appearance in Activity Data**

HFC Type	Years	HFC Type	Years
HFC-125	1995–2015, 2017–2022	HFC-23	1995–2004, 2008–2015, 2017–2022
HFC-134	2008–2009, 2015, 2017–2022	HFC-236fa	1996–1998, 2000–2004, 2008, 2010, 2012–2013, 2020–2021
HFC-134a	1995–2015, 2017–2022	HFC-245fa	2001–2015, 2017–2022
HFC-143	2013	HFC-32	1995–2015, 2017–2022
HFC-143a	1995–2015, 2017–2022	HFC-365mfc	2008–2015, 2017–2020
HFC-152a	1995–2015, 2017–2022	HFC-41	1999–2000 and 2010
HFC-227ea	1995–2015, 2017–2022	HFC-4310mee	1998–2015, 2018–2020

32 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 on April 12, 2021). Heating, Refrigeration and Air Condiitoning Institute of Canada - Refrigerant Management Canada.

33 PureSphera's recovery process is described here: https://www.puresphera.com/en/technologies-propres

Table 4–18 **2022 Bulk HFC Imports by Type per Application**

HFC Type	2.F.1 Refrigeration and Air Conditioning	2.F.2 Foam Blowing	2.F.3 Fire Protection	2.F.4 Aerosols	2.F.5 Solvents	2.F.6 Other	Total bulk HFC imports
HFC-23	0.0%	-	-	-	-	0.6%	0.0%
HFC-32	16.9%	-	0.0%	-	-	99.3%	10.8%
HFC-125	24.9%	-	100.0%	-	-	-	17.1%
HFC-134	-	2.6%	-	-	-	-	0.6%
HFC-134a	46.6%	17.3%	-	5.8%	100.0%	0.2%	33.3%
HFC-143a	9.0%	-	-	-	-	-	5.5%
HFC-152a	0.0%	55.2%	-	94.2%	-	-	25.7%
HFC-227ea	0.0%	-	-	-	-	-	0.0%
HFC-245fa	2.6%	25.0%	-	-	-	-	7.1%
Application share of total bulk imports	61.4%	22.0%	1.8%	14.4%	0.0%	0.4%	

Notes:
2022 bulk HFC import data was provided by Marianne Racine of the Chemicals Production Division of ECCC.
Totals may not add up due to rounding.
""-"" indicates that there were no imports of the HFC type for the application.
0.0% indicates that imports occurred, but were small and are truncated due to rounding.

4.17.3. Uncertainties and Time-Series Consistency

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. To determine the uncertainty for a sub-application, the uncertainties related to activity data (Cheminfo Services, 2005c) and emission factors from Volume 3, Chapter 7 (IPCC, 2006) were used. It should be noted that the overall category uncertainty can vary throughout the time-series because it is dependent on the magnitude of each of the sub-application emission estimates, which changes from year-to-year. The uncertainty associated with the category as a whole was ± 11%.

4.17.4. Category-Specific Quality Assurance/Quality Control and Verification

HFC emissions from Product Uses as Substitutes for Ozone-Depleting Substances is a key category that has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Volume 1, Chapter 6 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

4.17.5. Category-Specific Recalculations

There are downward recalculations for this category for 2011–2021 from the use of updated proxy variables in extrapolating manufactured item imports and exports from 2010 onwards for all sub-applications. Small revisions to 2017 and 2021 activity data were also included in this year's submission. The maximum impact of these recalculations is -42 kt (-0.4%) in 2021.

4.17.6. Category-Specific Planned Improvements

A data gap exists with the manufactured item (MI) 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. During the 2023 in-country review of the inventory, the ERT recommended that the inventory team should prioritize filling this gap and should collect data on imports of HFCs in MIs through cooperation with other exporting countries or by surveying importers. The inventory team is investigating existing statistical data on the imports, exports and sales of MIs that can contain HFCs, and is working on developing sets of surveys to send to importers to achieve information necessary for integration into the inventory.

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). During the 2023 in-country review of the inventory, the ERT recommended that the inventory team carry out an investigation with the goal of updating or verifying the end-of-life emission factors for refrigeration, air conditioning, and foam blowing applications. This will be explored through communications with the HRAI Refrigerant Management Canada program, or directly through surveying the reclamation and destruction facilities.

4.18. Product Uses as Substitutes for Ozone-Depleting Substances (CRF Category 2.F, PFCs)

4.18.1. Category Description

Perfluorocarbon (PFC) consumption in Canada began in 1995. Like Hydrofluorocarbons (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.

PFC releases contributed to about 7.8 kt CO_2 eq in 2022, a 287% increase from 2005.

4.18.2. Methodological Issues

The 2006 IPCC Tier 1a/2a methodologies were used to estimate emissions from the consumption of PFCs in various applications for the years 1995 to 2022. 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 and 2022 in the absence of a 2021 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 2017–2022 HFC/PFC blend activity data was collected through mandatory HFC surveys in 2018, 2019, 2020, 2021, 2022 and 2023. 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 A6.2-12.

4

Refrigeration and Air Conditioning (CRF 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 A6.2-12.

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 continue to occur.

Uses of PFCs in commercial refrigeration and stationary air-conditioning contribute a total of 5.2 kt CO_2 eq in 2022.

Foam Blowing Agents (CRF 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 (CRF 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 (CRF 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 (CRF 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 2022, emissions from the uses of CF_4 and C_2F_6 in solvent applications contributed 2.6 kt CO_2 eq.

4.18.3. Uncertainties and Time-Series Consistency

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 uncertainty is zero since the use of PFCs as ODS substitutes did not begin until 1995.

4.18.4. Category-Specific Quality Assurance/Quality Control and Verification

The category of PFC consumption has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories.*

In addition, checks have been performed 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.

4.18.5. Category-Specific Recalculations

There were no recalculations for PFCs used as substitutes for ODS in this submission.

4.18.6. Category-Specific Planned Improvements

Voluntary data surveys for 2022 and 2021 were not collected, and 2022 and 2021 use levels were held constant at 2020 levels for most applications. A voluntary data collection of 2021–2022 data is planned for 2024 to obtain updated PFC distribution and use data.

Solvents (CRF 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).

4.19. Other Product Manufacture and Use (CRF Category 2.G)

4.19.1. Category Description

The Other Product Manufacture and Use category includes emissions from the use of Sulphur Hexafluoride (SF_6) in electrical equipment (CRF category 2.G.1), Nitrous Oxide (N_2O) emissions from medical applications (CRF category 2.G.3.a), N_2O emissions from use as a propellant (CRF category 2.G.3.b) and Perfluorocarbon (PFC) Emissions from Other Contained Product Uses (CRF 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 that occur during equipment use are a result of leakages during gas transfer and handling operations and leakages during normal operation of the equipment. In order 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 to 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 used in whipped cream being considered as significant. None of the N_2O is 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.

Note that emissions from use of solvents in dry cleaning, printing, metal degreasing and a variety of industrial applications, as well as household use, are not estimated.

The Other Product Manufacture and Use category contributed about 646 kt (<0.1%) to Canada's total emissions in 2022, a 27% increase from 2005.

4.19.2. Methodological Issues

Sulphur Hexafluoride Emissions from Electrical Equipment (CRF Category 2.G.1)

A modified Tier 3 method was used to estimate SF_6 emissions from electrical equipment in utilities for certain years (i.e., 2006–2022) of the time series, 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 2006–2022 are provided by the Canadian Electricity Association (CEA), and BC Hydro, which collectively represent electricity companies across Canada. CEA and BC Hydro 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 and BC Hydro do 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 2006–2022 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 on the basis of 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 (CRF Category 2.G.3.a) and Propellant Usage (CRF Category 2.G.3.b)

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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 2006–2022 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 (CRF Category 2.G.4)

The activity data on PFCs used in Other Contained Products was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRF category 2.F; refer to section 4.18). 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 is 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.

4.19.3. Uncertainties and Time-Series Consistency

Sulphur Hexafluoride Emissions from Electrical Equipment (CRF 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 as a whole 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 4.19.2 (Methodological Issues).

Nitrous Oxide Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF 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 (CRF 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.

4.19.4. Category-Specific Quality Assurance/Quality Control and Verification

The categories of N_2O Emissions from Medical Applications and Propellant Usage, and PFC Emissions from Other Contained Product Uses have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories.*

The category of SF_6 Consumption in Electrical Equipment has undergone informal quality control checks throughout the emission estimation process.

4.19.5. Category-Specific Recalculations

There were no recalculations for the Other Product Manufacture and Use category.

4.19.6. Category-Specific Planned Improvements

Sulphur Hexafluoride Emissions from Electrical Equipment (CRF 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 (CRF 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 (CRF Category 2.G.2)

This category is a catch-all for product uses of SF_6 and PFCs that are not covered under other CRF categories and is currently reported as "Not Estimated" using notation key "NE" in the CRF 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 past ERT recommended that the inventory team perform a significance assessment on this category. This recommendation was re-iterated in the 2023 in-country review, and the ERT suggested that the inventory team could base a first approach on a top-down methodology based on import/export data.

The inventory team is investigating potential sources of top-down import/export data, including the United States Environmental Protection Agency's Greenhouse Gas Reporting Program. If information cannot be collected from existing data sources, a survey will be sent to SF_6 and PFC gas and manufactured item suppliers. Once data is collected, a Tier 1 emissions estimate will be performed to assess the significance of emissions in this category. If emissions are significant (i.e., more than 500 kt CO_2 eq or greater than 0.05% of the national emissions total), efforts will be made to develop and publish emissions estimate for the whole time series.

Nitrous Oxide Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF Category 2.G.3.b)

There are plans to develop an updated Canadian N_2O sales pattern by application in future inventory submissions in the emissions estimates of the N_2O Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF category 2.G.3.b) categories. The current sales breakdown is assumed to be the same as 2005.

Perfluorocarbon Emissions from Other Contained Product Uses (CRF Category 2.G.4)

This category is country-specific. A past ERT recommended the re-allocation of all activity data in this category to other categories to improve the comparability of the inventory. This recommendation was re-iterated in the 2023 in-country review. Legacy data sources are being investigated to ensure that emissions estimates are re-attributed to the correct category(ies).

CHAPTER 5

AGRICULTURE (CRF SECTOR 3)

5.1. Overview

The Agriculture sector contributed 7% of Canada's total greenhouse gas (GHG) emissions annually from 1990 until 2020, when this contribution rose to 8% through 2022. Emissions in the sector increased by 32% between 1990 and 2022. 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 76% 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. Since 2005, beef populations have decreased to 11 million head, while swine populations decreased to 12.5 million head in 2010 and rebounded to 14 million head in 2016, and have remained stable since then. Since 1990, poultry populations increased to 154 million in 2016 and decreased to 151 million in 2022, while dairy cattle populations have decreased until recently, with some fluctuations, stabilizing at just under 1 million head in 2022.

As a result of changes in cropping practices in Canada, canola production increased from 3.3 Mt in 1990 to 19 Mt in 2020 before declining to 14 Mt in 2021 and rebounding to 19 Mt in 2022, corn production increased from 7 Mt to 14 Mt, and soybean production from 1.3 Mt to 6.5 Mt. From 1990 to 2002, wheat production fell off sharply, decreasing from 32 Mt to 16 Mt, but has increased, to 35 Mt in 2020 before declining again to 22 Mt in 2021 and rebounding to 34 Mt in 2022. With the changes in crop production, inorganic nitrogen (N) fertilizer consumption has more than doubled, from 1.2 Mt in 1990 to 2.8 Mt in 2022, while land under conservation tillage has increased by 17 million hectares (Mha).

1 In the Common Reporting Format (CRF) tables, 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.

As a result of these combined changes in livestock and crop production, Canada's GHG emissions from the Agriculture sector rose from 42 Mt CO_2 eq in 1990 to 56 Mt CO_2 eq in 2022 (Table 5–1). This 32% increase is mainly due to emissions associated with the greater use of inorganic N fertilizers (130% increase in N shipments), recent declines in the proportion of perennial cropland, larger swine populations (37% increase), and changes in animal weight, feed and manure handling practices in the beef, dairy and swine industries.

Emissions of CH_4 from livestock accounted for 28 Mt CO_2 eq in 1990 and 31 Mt CO_2 eq in 2022, with an uncertainty range of -6% to +20% for the mean estimates. Over the 1990 to 2022 time series, mean CH_4 emissions are estimated to have increased by 3.6 Mt CO_2 eq, a 13% increase, which is associated with an uncertainty range of -10% to +17%. Emissions of N_2O from agricultural soils and livestock represented 13 Mt CO_2 eq in 1990 and 22 Mt CO_2 eq in 2022, with an uncertainty range of approximately -27% to +29% of the mean estimates. Over the time series, mean N_2O emissions increased by 8.3 Mt CO_2 eq, an increase of 62%.

Table 5–1 **Short- and Long-Term Changes in Greenhouse Gas Emissions from the Agriculture Sector**

GHG Source Category		GHG Emissions (kt CO_2 eq)								
		1990	2005	2016	2017	2018	2019	2020	2021	2022
Agriculture TOTAL[a]		**42 000**	**56 000**	**54 000**	**53 000**	**54 000**	**54 000**	**56 000**	**55 000**	**56 000**
Enteric Fermentation (CH_4)		**25 000**	**35 000**	**27 000**	**27 000**	**27 000**	**27 000**	**27 000**	**27 000**	**27 000**
Dairy Cattle		4 400	3 600	3 600	3 700	3 800	3 900	3 900	4 000	4 000
Beef cattle[b]		20 000	29 000	22 000	22 000	22 000	22 000	22 000	22 000	22 000
Others[c]		820	1 500	1 200	1 200	1 200	1 200	1 200	1 200	1 200
Manure Management		**6 000**	**8 700**	**7 800**	**7 900**	**7 900**	**7 900**	**7 800**	**7 900**	**7 800**
Dairy Cattle	CH_4	480	760	990	1 000	1 000	1 100	1 100	1 100	1 100
	N_2O	460	310	230	230	240	240	240	240	240
Beef cattle[b]	CH_4	910	1 400	1 100	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	2 100	2 100	2 100
Swine	CH_4	1 100	2 000	1 900	1 900	1 900	1 900	1 900	1 900	1 900
	N_2O	90	60	50	50	50	50	50	50	40
Poultry	CH_4	180	220	230	230	220	220	220	220	220
	N_2O	380	480	550	540	530	530	520	510	510
Others[d]	CH_4	40	60	50	50	50	40	40	40	40
	N_2O	80	150	110	110	100	100	100	90	90
Indirect Source of N_2O		520	640	550	540	540	540	540	530	530
Agricultural Soils (N_2O)		**10 000**	**12 000**	**16 000**	**15 000**	**16 000**	**16 000**	**18 000**	**17 000**	**18 000**
Direct sources		7 800	8 900	13 000	12 000	13 000	13 000	14 000	13 000	15 000
Synthetic nitrogen fertilizers		3 900	4 700	8 000	7 400	8 200	8 300	9 200	9 100	8 700
Organic nitrogen fertilizers		1 000	1 300	1 400	1 400	1 400	1 400	1 400	1 400	1 400
Crop residue decomposition		2 200	2 700	3 900	3 900	3 800	3 800	4 000	3 100	3 900
Cultivation of organic soils		50	50	50	50	50	50	50	50	50
Mineralization of soil organic carbon		200	170	260	260	180	270	420	430	1 500
Conservation tillage[e]		-360	-1 100	-2 000	-2 000	-2 100	-2 200	-2 300	-2 100	-2 200
Irrigation		490	690	1 100	980	1 000	1 100	1 200	1 000	1 200
Manure on pasture, range and paddock		200	230	180	180	180	180	170	170	170
Indirect sources		2 300	2 700	3 500	3 300	3 500	3 500	3 700	3 500	3 600
Field Burning of Agricultural Residues (CH_4 & N_2O)		240	50	50	50	50	50	60	40	50
Liming and Urea Application (CO_2)		**1 200**	**1 400**	**2 500**	**2 400**	**2 600**	**2 700**	**3 000**	**3 100**	**2 900**

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, 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.

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Emissions from the Agriculture sector peaked in 2005, and decreased to 50 Mt CO_2 eq 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 CO_2 in 2022.

In this submission, 1990 emissions were revised upward by 1.3 Mt CO_2 eq; 2005 emissions by 2.1 Mt CO_2 eq ; and 2021 emissions by 0.8 Mt CO_2 eq compared to the previous submission, representing recalculations of +3.3%, +3.9%, and +1.5%, respectively (Table 5–2).

Recalculations are the result of (i) the inclusion of new GWP values from the IPCC AR5, (ii) refinements to time series 2021 *Census of Agriculture* activity data reflecting high resolution land use data sources; (iii) and minor improvements and error corrections. 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 is not a source of 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 **Quantitative Summary of Recalculations for the Agriculture Sector in the 2024 National Inventory Report**

		Recalculations							
		1990	2005	2016	2017	2018	2019	2020	2021
Previous submission (2023 NIR), kt CO_2 eq		41 000	54 000	53 000	52 000	53 000	54 000	55 000	54 000
Current submission (2024 NIR), kt CO_2 eq		42 000	56 000	54 000	53 000	54 000	54 000	56 000	55 000
CHANGE DUE TO CONTINUOUS IMPROVEMENT OR REFINEMENT									
Implementation of IPCC AR5 Global Warming Potentials									
Enteric Fermentation	kt CO_2 eq	2 700	3 700	2 900	2 900	2 900	2 900	2 900	2 900
	%	0.066	0.069	0.055	0.056	0.055	0.054	0.053	0.054
Manure Management	kt CO_2 eq	-110	-64	15	20	21	27	29	34
	%	-0.003	-0.001	0.000	0.000	0.000	0.001	0.001	0.001
Agricultural Soils	kt CO_2 eq	-1 300	-1 500	-2 000	-1 900	-2 100	-2 100	-2 200	-2 100
	%	-0.032	-0.028	-0.038	-0.037	-0.040	-0.039	-0.040	-0.039
Field Burning of Agricultural Residues	kt CO_2 eq	15	3	3	3	3	3	4	2
	%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Activity Data Updates and Error Correction									
Manure Management	kt CO_2 eq	-0.02	-0.48	-0.25	0.8	1.6	2.4	3.2	3.8
	%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Agricultural Soils	kt CO_2 eq	5.5	-87	-89	-83	-240	-220	-200	-74
	%	0.000	-0.002	-0.002	-0.002	-0.005	-0.004	-0.004	-0.001

Table 5–3 **Qualitative Summary of the Revisions to Methodologies, Corrections and Improvements Carried out for Canada's 2024 Submission**

Correction or Improvement	Recalculation Categories Affected	Years Affected
Implementation of IPCC AR5 Global Warming Potentials	All CH_4 and N_2O emissions	Complete time series
Activity Data Updates and Error Correction	Manure Management CH_4 Manure Management N_2O Agricultural Soils – Direct N_2O Emissions Agricultural Soils – Indirect N_2O Emissions	Complete time series

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5.2. Enteric Fermentation (CRF Category 3.A)

5.2.1. Source Category Description

Methane is produced during the normal digestive process of enteric fermentation in herbivores including species raised in agricultural animal production. Micro-organisms in the gastrointestinal tract break down 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 that is 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 both 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 take into account 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 1990–2020 time period, 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, as a consequence, 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 slaughter animal weights have continued to increase, but at a lower rate. Emission factors have since decreased as a result 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. 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 A3–1). 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. Uncertainties 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. Details of this analysis can be found in Annex 3.4, 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 2019, 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 in 1990 and 2022, and mean estimates in 2022 lie within a range of -14% to +17% (Table 5–4). Over the time series of 1990 to 2022, mean emissions are estimated to have increased by 2.1 Mt CO_2 eq, an 8% increase. The observed increase falls within an uncertainty range of +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 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 (1990–2022), with the exception of 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 on the basis of 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)		972	921 (-5.2%)	1 023 (+5.2%)
	Tier 2 emission factor (kg/head/year)		146	124 (-15%)	174 (+19%)
	Emissions (Mt CO_2 eq)		4	3.3 (-16%)	4.8 (+20%)
Non-Dairy Cattle	Population (1000 head)		10 953	10 743 (-1.9%)	11 176 (+2.0%)
	Tier 2 emission factor (kg/head/year)		72	60 (-15%)	84 (+18%)
	Emissions (Mt CO_2 eq)		22	18 (-16%)	27 (+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%)
		2022	27	23 (-14%)	32 (+17%)
	Trend	1990–2022	2.1 (+8.2%)	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 2022.
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 2022.

5.2.4. Quality Assurance / Quality Control and Verification

Enteric Fermentation, as a key category, has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. 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 2010–2011 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 take into account specific regional management influences on emissions, replacing IPCC defaults currently used in the emission model, as has been done for Dairy Cattle. 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

Recalculations occurred in the Enteric Fermentation category in the 2024 NIR submission as a result of the inclusion of new GWP values from the IPCC AR5, and refinements to the activity data updates (Table 5–5).These changes resulted in upward revisions of emissions by 2.7 Mt in 1990, 3.7 Mt in 2005 and 2.9 Mt in 2021. The short term and long-term trends remained unchanged at -21% and +9 %, respectively.

Table 5–5 **Recalculations of Emission Estimates and Their Impact on Emission Trends and Total Agricultural Emissions from Enteric Fermentation, Manure Management CH_4 and Manure Management N_2O**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change Category Emissions (%)	Old Trend (%)	New Trend (%)
Enteric Fermentation	1990	2023	22 347	2 682	12	Long term (1990–2021)	
		2024	25 029			9	9
	2005	2023	30 821	3 698	12		
		2024	34 519			Short term (2005–2021)	
	2021	2023	24 449	2 934	12	-21	-21
		2024	27 383				
Manure Management CH_4	1990	2023	2 461	295	12	Long term (1990–2021)	
		2024	2 757			59	59
	2005	2023	3 908	469	12		
		2024	4 377			Short term (2005–2021)	
	2021	2023	3 911	470	12	0	0
		2024	4 381				
Manure Management – Direct N_2O	1990	2023	3 042	-337	-11	Long term (1990–2021)	
		2024	2 705			10	10
	2005	2023	4 088	-453	-11		
		2024	3 636			Short term (2005–2021)	
	2021	2023	3 336	-370	-11	-18	-18
		2024	2 967				
Manure Management – Indirect N_2O	1990	2023	586	-65	-11	Long term (1990–2021)	
		2024	521			2	3
	2005	2023	721	-80	-11		
		2024	641			Short term (2005–2021)	
	2021	2023	598	-63	-11	-17	-17
		2024	535				

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, in order 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 (CRF 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, poorly aerated manure management systems generate high CH_4 emissions but relatively low N_2O emissions, whereas well-aerated 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 pastured 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 (CRF Category 3.B [a])

5.3.1.1. Source 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 on 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 Manure Management 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 emission estimates (section 5.2.2). Methane emission factors for Manure Management are estimated using the IPCC Tier 2 methodology (IPCC, 2006).

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. 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 in order to better capture trends in feeding practices and/or animal weights, as described in Annex 3.4. In particular, 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 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 on the basis of ash content and digestible energy derived from expert consultations. Urinary energy (UE) coefficients were applied according to the 2006 IPCC Guidelines. 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 and AWMS proportions were taken from Marinier et al. (2005) for each province, taking into account regional differences in production practices and manure storage systems. For swine and dairy cattle, a manure storage system time series was developed in order to track changes in the proportion of manure in AWMS subsystems with and without crust and covers. Values of MCF taken from the 2006 IPCC Guidelines 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 Annex 3.4, section A3.4.3.3.

Increases in cattle emission factors over the 1990–2022 period (see Annex 3.4.3) reflect higher gross energy intake for dairy cattle due to changes in feed, herd characteristics and increased milk productivity. Most importantly, for dairy, emission factors 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 Annex A3.4.3.6) for sows is related to the shift in swine production from eastern to western Canada and for growing swine are a result of increases in growth rates and final carcass weights.

5.3.1.3. Uncertainties 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 Annex 3.4, section A3.4.3.8.

The CH_4 emission estimate of 4.3 Mt CO_2 eq from the management of livestock manure in Canada in 2022 lies within an uncertainty range of -28% to +23% (Table 5–6). The emission estimate for 1990, 2.8 Mt CO_2 eq, 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 57% increase in mean emissions between 1990 and 2022 lies within an uncertainty range of +45% to +66%.

As was the case with the Enteric Fermentation category, most uncertainty in the emission estimate was associated with the calculation of the emission factor. The uncertainty range around the mean emission factor was as high as 110% in the case of dairy cattle. The uncertainty in emissions was most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular the MCF that was applied to all regions of Canada and all animal types and the maximum methane production capacity (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, it is not expected that changes to these models would have a large impact on national manure management uncertainty. The introduction of an AWMS time series for the dairy and swine sectors may, however, play an important role in influencing the trend uncertainty for manure management emissions.

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2022), with the exception of 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 5–6 **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)		972	921 (-5.2%)	1 023 (+5.2%)
	Tier 2 emission factor (kg/head/year)		40	22 (-45%)	54 (+37%)
	Emissions (Mt CO_2 eq)		1.1	0.6 (-45%)	1.47 (+37%)
Non-Dairy Cattle	Population (1000 head)		10 953	10 743 (-1.9%)	11 176 (+2.0%)
	Tier 2 emission factor (kg/head/year)		3.6	2.7 (-25%)	5.3 (+45%)
	Emissions (Mt CO_2 eq)		1.1	0.8 (-27%)	1.67 (+51%)
Swine	Population (1000 head)		14 040	13 707 (-2.4%)	14 379 (+2.4%)
	Tier 2 emission factor (kg/head/year)		4.8	2.2 (-54%)	7.0 (+45%)
	Emissions (Mt CO_2 eq)		1.9	1.0 (-49%)	2.70 (+42%)
Other Livestock	Emissions (Mt CO_2 eq)		0.3	0.17 (-31%)	0.29 (+14%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	2.8	1.5 (-44%)	3.7 (+36%)
		2022	4.3	3.1 (-28%)	5.3 (+23%)
	Trend	1990–2022	1.6 (+57%)	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 2022.

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 2022.

5.3.1.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data and methodologies are documented and archived in electronic form. 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 Annex 3.4, section A3.4.3.7.

5.3.1.5. Recalculations

Recalculations were made to manure management CH_4 emissions in all years due to the use of IPCC AR5 GWP values and refinements to the 2021 *Census of Agriculture* activity data. These changes resulted in an upward revision to emission estimates of 295 kt CO_2 eq in 1990, 469 kt CO_2 eq in 2005, and 470 kt CO_2 eq in 2021. The recalculations caused no change in the short-term or long-term emission trends (Table 5–5).

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). Those data, combined with Canadian publications on livestock management (Sheppard et al., 2009a, 2009b, 2010, 2011a, 2011b; Sheppard and Bittman, 2011, 2012), have provided the basis for a new manure management time series for dairy and swine production in Canada, and work is being considered for other major livestock categories. 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.

5.3.2. N_2O Emissions from Manure Management (CRF Category 3.B [b])

5.3.2.1. Source Category Description

The production of N_2O during storage and treatment of animal waste occurs during nitrification and denitrification of nitrogen 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, 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 (Annex 3.4.3.3), 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 (Annex 3.4.3.3), 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.

The animal characterization data are the same as those used for the Enteric Fermentation (section 5.2) and Manure Management (section 5.3.1) estimates. The 2006 IPCC default emission factors 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. Uncertainties 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 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 defined in sections 5.2.3 and 5.3.1.3. Details of this analysis can be found in Annex 3.4, section A3.4.6.

The estimate of direct N_2O emissions of 2.9 Mt CO_2 eq from Manure Management in 2022 lies within an uncertainty range of 1.7 Mt CO_2 eq (-43%) to 4.4 Mt CO_2 eq (+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 (1990–2022).

5.3.2.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. 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

Direct N_2O emissions from manure management were recalculated for all years (Table 5–5) due to the use of IPCC AR5 GWP values and 2021 *Census of Agriculture* activity data updates. The net impact of these changes was a revision in emissions of 0.38 Mt CO_2 eq in 1990, 0.45Mt CO_2 eq in 2005, and 0.37 Mt CO_2 eq in 2021. The recalculations did not change short and long-term emission trends (-18%, and +10%, respectively; Table 5–5).

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, implementation of 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 nitrogen excretion rates. These data have been integrated for dairy cattle, but 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 (CRF Category 3.B [c])

5.3.3.1. Source 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 nitrogen in manure that is stored 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 nitrogen that is transported from the manure storage site in this manner is assumed to undergo subsequent nitrification and denitrification elsewhere in the environment and, as a consequence, to 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 nitrogen 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 nitrogen 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. 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, whereas the N_2O emission factors for N leached from manure storage and handling are taken from the 2006 IPCC Guidelines, for all livestock categories.

5.3.3.3. Uncertainties and Time-Series Consistency

A full uncertainty analysis using a Monte Carlo technique has not been carried out on the estimation of 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 (1990–2022).

5.3.3.4. Quality Assurance / Quality Control and Verification

This category underwent Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines. The activity data, methodology and databases have been documented and archived in electronic form.

5.3.3.5. Recalculations

Indirect N_2O emissions from manure management were recalculated were due to the inclusion of new GWP values based on IPCC AR5 and refinements to 2021 *Census of Agriculture* activity data on animal populations. The net impact of these changes was a downward revision in emissions of 65 kt CO_2 eq in 1990, 80 kt CO_2 eq in 2005, and 63 kt CO_2 eq in 2021. The recalculations had no impact on the short-term trend but the long-term emission trend was revised upward slightly from +2% to +3%; Table 5–5).

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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 (CRF Category 3.D)

N_2O emissions from agricultural soils occur in both 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 nitrogen, nitrification and denitrification. Indirect emissions occur through two pathways: (1) the volatilization of nitrogen 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 (CRF Category 3.D.1)

Direct sources of N_2O from soils include the application of organic and inorganic nitrogen 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 on the basis of nitrogen inputs from the application of organic and inorganic nitrogen fertilizers and crop residue nitrogen.

5.4.1.1. Inorganic Nitrogen Fertilizers

5.4.1.1.1. Source Category Description

Inorganic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen 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 nitrogen fertilizer application on agricultural soils, which takes into account moisture regimes, soil texture, nitrogen 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 nitrogen applied to the land is estimated from yearly nitrogen fertilizer shipments to Canadian agriculture markets. All inorganic nitrogen 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.

5.4.1.1.3. Uncertainties 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, included all direct and indirect emissions from soils (Table 5–7). For N_2O emissions from fertilizer, the analysis considered 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. As a consequence, 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 8.7 Mt CO_2 eq from the application of inorganic fertilizers on agricultural soils in 2022 lies within a range of 5.7 Mt CO_2 eq (-35%) to 12 Mt CO_2 eq (+43%) (Table 5–7).

The same methodology and emission factors were used for the entire time series (1990–2022).

Table 5–7 **Uncertainty in the Estimates of N_2O Emissions from Manure Management and Agricultural Soils in 2021**

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	8.7	5.7 (-35%)	12 (+43%)
	Organic N fertilizers	1.4	0.91 (-33%)	1.9 (+41%)
	Crop residues	3.9	2.5 (-35%)	5.6 (+45%)
	Cultivation of organic soils	0.054	0.011 (-79%)	0.11 (+96%)
	Mineralization associated with loss of soil organic matter	1.5	0.95 (-35%)	2.1 (+45%)
	Urine and dung deposited by grazing animals	0.17	0.068 (-60%)	0.30 (+75%)
	Soil N mineralization/immobilization	-1.1	-0.61 (-44%)	-1.7 (+55%)
Indirect N_2O emissions from managed soils		3.6	1.4 (-60%)	6.1 (+70%)
	Atmospheric Deposition	0.87	0.22 (-75%)	1.8 (+110%)
	Leaching and runoff	2.7	0.54 (-80%)	5.4 (+100%)

Notes:
a. Mean value reported from database.
b. Values in parentheses represent the uncertain percentage of the mean.

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5.4.1.1.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. 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 nitrogen applications on agricultural soils in Canada vary on a site-by-site basis. There is, however, 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 revised methodology.

5.4.1.1.5. Recalculations

Recalculations in this submission resulted from the integration of new GWP values from IPCC AR5, and to a lesser extent, minor activity data updates and error corrections. The decrease in the GWP value for N_2O is the main driver for the reductions in emissions.

Emissions were revised downward by 0.48 Mt CO_2 eq in 1990, 0.60 Mt CO_2 eq in 2005, and by 1.31 Mt CO_2 eq in 2021 (Table 5–8). The recalculations caused revisions in the short-term and long-term emission trends (96% to 93%, and 136% to 133%, respectively).

Table 5–8 **Recalculations of N_2O Emission Estimates and Their Impact on Trends in Greenhouse Gas Emissions from Fertilizer Application, Crop Residue Decomposition, and Urine and Dung Deposited by Grazing Animals**

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 (%)
Inorganic N fertilizers	1990	2023	4 423	-497	-11	Long term (1990–2021)	
		2024	3 926			136	133
	2005	2023	5 322	-600	-11		
		2024	4 722			Short term (2005–2021)	
	2021	2023	10 443	-1313	-13	96	93
		2024	9 131				
Organic N fertilizers	1990	2023	1 158	-129	-11.14	Long term (1990–2021)	
		2024	1 029			24	33
	2005	2023	1 487	-165	-11.12		
		2024	1 322			Short term (2005–2021)	
	2021	2023	1 441	-70	-5	-3	4
		2024	1 371				
Crop residue decomposition	1990	2023	2 507	-281	-11.23	Long term (1990–2021)	
		2024	2 225			37	37
	2005	2023	3 077	-343	-11.15		
		2024	2 734			Short term (2005–2021)	
	2021	2023	3 435	-378	-11	12	12
		2024	3 057				
Urine and dung deposited by grazing animals	1990	2023	224	-25	-11.07	Long term (1990–2021)	
		2024	199			-13	-14
	2005	2023	258	-28	-11		
		2024	230			Short term (2005–2021)	
	2021	2023	194	-22	-11.22	-25	-25
		2024	172				

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 nitrogen application and nitrogen 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

5.4.1.2.1. Source Category Description

The application of organic nitrogen 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 was the case for N_2O emissions from inorganic nitrogen fertilizers, a Tier 2 methodology was used to estimate N_2O emissions from organic manure applied to agricultural soils using country-specific emission factors that take into account 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 that is 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. Uncertainties and Time-Series Consistency

In the case of N_2O emissions from the application of organic nitrogen fertilizer, the uncertainty analysis considered 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, in order to quantify the uncertainty in the updated country-specific soil N_2O emission factors, including the ratio factor used for organic nitrogen. 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 nitrogen fertilizers (Rochette et al., 2018; Liang et al., 2020), which provides improved probability distributions for parameters.

On the basis of past analyses, it is estimated that N_2O emissions of 1.4 Mt CO_2 eq from application of organic nitrogen fertilizers in 2022 lies within an uncertainty range of 1.4 Mt CO_2 eq (-33%) to 1.9 Mt CO_2 eq (+41%) (Table 5–7). The main source of uncertainty in the calculation of emissions from organic nitrogen 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 (1990–2022).

5.4.1.2.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies have been documented and archived in electronic form.

5.4.1.2.5. Recalculations

The recalculations in emissions from organic fertilizers applied to agricultural soils are primarily due the integration of IPCC AR5 based GWP values. Minor changes resulted from other activity data updates and error correction.

Emissions were revised downward by 129 kt CO_2 eq in 1990, 165 kt in 2005, and 70 kt CO_2 eq in 2021 (Table 5–8). The short-term trend was revised upward from -3% to +4%, and the long-term trend, from +24% to +33%.

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 fertilizer 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 (CRF Category 3.D.1.4)

5.4.1.3.1. Source 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 nitrogen fertilizer application (section 5.4.1.2.2).

5.4.1.3.3. Uncertainties and Time-Series Consistency

For N_2O emissions from crop residue decomposition, the uncertainty analysis considered 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 CO_2 eq from crop residue decomposition in 2022 is associated with an uncertainty range of -35% to +45%, or 2.5 Mt CO_2 eq to 5.6 Mt CO_2 eq 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, in order to account for the uncertainty in the updated country-specific soil N_2O emission factors, including the ratio factor used for organic nitrogen.

The same methodology and emission factors are used for the entire time series (1990–2022).

5.4.1.3.4. Quality Assurance / Quality Control and Verification

This category underwent Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.3.5. Recalculations

Recalculations are primarily due to the implementation of the new GWP values based on the IPCC AR5. Minor recalculations occurred from other activity data updates and error corrections.

Emissions were revised downward by 0.28 Mt CO_2 eq in 1990, 0.34 Mt CO_2 eq in 2005 and by 0.38 Mt CO_2 eq in 2021, respectively (Table 5–8). There was no impact to the long-term or short-term emission trend as a result of these changes.

5.4.1.3.6. Planned Improvements

Future improvements will focus on differentiating organic nitrogen 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 (CRF Category 3.D.1.3)

5.4.1.4.1. Source Category Description

When urine and dung are deposited by grazing animals, the nitrogen 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 Annex 3.4, section A3.4.5. Emissions are calculated for each animal category by multiplying the number of grazing animals for that category by the appropriate nitrogen excretion rate and by the fraction of manure nitrogen available for conversion to N_2O.

5.4.1.4.3. Uncertainties and Time-Series Consistency

The uncertainty associated with the new estimates of N_2O emissions from urine and dung deposited by grazing animals was estimated on the basis of the previous uncertainty analysis using the parameters and uncertainty distributions defined in the Tier 1 methodology in the 2006 IPCC Guidelines, with the exception of new emission factors. Livestock populations, the proportion of animals on pasture systems and their characterizations were 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 CO_2 eq from pasturing Canadian livestock in 2022 lies within an uncertainty range of -60% to +75%, or 0.068 Mt CO_2 eq to 0.30 Mt CO_2 eq, respectively (Table 5–7).

The same methodology and emission factors are used for the entire time series (1990–2022).

5.4.1.4.4. Quality Assurance / Quality Control 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

Revisions to the distribution of livestock populations resulted in slight changes to N_2O emissions from urine and dung deposited by grazing animals. Emissions were revised downward by 25 kt CO_2 eq in 1990, 28 kt CO_2 eq in 2005, and 22 kt CO_2 eq in 2021 (Table 5–8). As a result of these changes, the short-term emission trend stayed unchanged at -25% and the long-term trend was revised downward slightly from -13% to -14%.

5.4.1.4.6. Planned Improvements

No immediate plan is in place to improve emission estimates for this source. Further uncertainty work will be carried out to take into account 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 (CRF Category 3.D.1.5)

5.4.1.5.1. Source Category Description

Carbon loss in soils as a result 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 nitrogen, once in an inorganic form, is prone to loss in the form of N_2O during either nitrification or denitrification and consequently must be taken into account 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 as a result 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 2022 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 nitrogen 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. Uncertainties 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 to be the same as those for emissions from crop residue decomposition. According to these assumptions, the estimate of N_2O emissions of 1.5 Mt CO_2 eq from mineralization associated with the loss of soil organic matter in 2022 lies within an uncertainty range of -35% to +45%, or 0.95 Mt CO_2 eq to 2.1 Mt CO_2 eq, respectively (Table 5–7).

5.4.1.5.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.5.5. Recalculations

Recalculations occurred in all years from 1990 to 2021 due to revisions to activity data including adjustments to crop yields and GWP values based on the IPCC AR5. Emissions were recalculated downward by 6 kt CO_2 eq in 1990, 102 kt CO_2 eq in 2005, and by 43 kt CO_2 eq in 2021. The long-term trend was revised downward from +127% to +113%, and the short-term trend upward from +71% to +147%.

5.4.1.5.6. Planned Improvements

As was 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 (CRF Category 3.D.1.6)

5.4.1.6.1. Source 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 nitrogen 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. 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 of cultivated organic soils in Canada, a constant level for the period 1990–2022 (Liang et al., 2004a).

5.4.1.6.3. Uncertainties and Time-Series Consistency

For N_2O emissions from organic soils, the uncertainty analysis considered the uncertainty in the area of cultivated organic soils and in the default emission factor.

The N_2O emission estimate of 0.05 Mt CO_2 eq from organic soils in 2022 lies within an uncertainty range of -79% to +96%, or 0.01 Mt CO_2 eq to 0.11 Mt CO_2 eq, respectively (Table 5–7). The main source of uncertainty is the IPCC Tier 1 default emission factor.

The same methodology and emission factors are used for the entire time series (1990–2022).

5.4.1.6.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.6.5. Recalculations

The implementation of the IPCC AR5 GWP values decreased the N_2O GWP by 11% from 298 to 265, and as a result, emissions in 1990, 2005 and 2021 were recalculated downward by 7 kt (11%). This change did not alter the long-term or short-term trend.

5.4.1.6.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.7. Changes in N_2O Emissions from Adoption of No-Till and Reduced Tillage

5.4.1.7.1. Source 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 - namely 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-tillage, 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 nitrogen 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). Following an expert review process with Canadian agricultural research scientists, the tillage factor for prairie regions from Liang et al. (2020) was implemented, while the factor for non-prairie regions was 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 5–7).

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 nitrogen applied to cropland, and crop residue nitrogen 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. Uncertainties and Time-Series Consistency

For N_2O emissions from the adoption of conservation tillage practices, the uncertainty analysis considered 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 reductions of 2.2 Mt CO_2 eq from conservation tillage practices in 2022 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 (1990–2022).

5.4.1.7.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.7.5. Recalculations

Minor recalculations occurred in this submission from the implementation of IPCC AR5 GWP values and from refinements to activity data and error corrections that resulted in spatial reallocation of N between ecodistricts.

These changes led to a downward recalculation in N_2O emissions of 46 kt CO_2 eq in 1990, 133 kt CO_2 eq in 2005 and 252 kt CO_2 eq in 2021. These recalculations decreased the trend from -485% to -489% in the long term, and from -99% to -100% in the short term (Table 5–9).

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.

Table 5–9 **Recalculations of N_2O Emission Estimates and Their Impact on Trends in Greenhouse Gas Emissions from Conservation Tillage Practices and Irrigation**

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 (%)
Conservation tillage practices	1990	2023	-405	45.57	-11.24	Long term (1990–2021)	
		2024	-360			-485	-489
	2005	2023	-1193	133.20	-11.17		
		2024	-1059			Short term (2005–2021)	
	2021	2023	-2371	252	-10.6	-99	-100
		2024	-2119				
Irrigation	1990	2023	556	-61.9	-11.14	Long term (1990–2021)	
		2024	494			111	108
	2005	2023	782	-87.8	-11.23		
		2024	694			Short term (2005–2021)	
	2021	2023	1 172	-143	-12.2	50	48
		2024	1 029				

5.4.1.8. N_2O Emissions from Irrigation

5.4.1.8.1. Source Category Description

As in the case of tillage practices, the effect of irrigation on N_2O emissions is not derived from additional nitrogen 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.

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5.4.1.8.3. Uncertainties and Time-Series Consistency

For N_2O emissions from irrigation, the uncertainty analysis considered 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 1.2 Mt CO_2 eq from irrigated land in 2022 has 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). The reporting of summer fallow emissions by using a country-specific methodology was discontinued in this submission to avoid double-counting due to the introduction of a methodology for estimating soil organic carbon from changes in crop productivity. 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 (1990–2022).

5.4.1.8.4. 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) in a manner consistent with the 2006 IPCC Guidelines. The activity data and methodology are documented and archived in electronic form.

5.4.1.8.5. Recalculations

Emissions from irrigation are linked to all soil emission calculations. Recalculations are due to the implementation of new IPCC AR5 GWP values and refinements to the 2021 *Census of Agriculture*, and general activity data updates.

These changes resulted in downward revisions in emissions of 62 kt CO_2 eq in 1990, 88 kt CO_2 eq in 2005 and 143 kt CO_2 eq in 2021. These recalculations revised the short-term trend slightly from +50% to +48%, and the long-term trend from +111% to +108% (Table 5–9).

5.4.1.8.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source. Further uncertainty work will be carried out to establish updated level and trend uncertainty estimates over the medium term.

5.4.2. Indirect N_2O Emissions from Managed Soils (CRF Category 3.D.2)

A fraction of the nitrogen 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 nitrogen that is transported off-site from agricultural fields results in eventual nitrogen accumulation in other ecosystem sites and subsequently undergoes nitrification or denitrification to produce N_2O.

5.4.2.1. Atmospheric Deposition of Nitrogen

5.4.2.1.1. Source Category Description

When organic or inorganic fertilizer is applied to cropland, a portion of the nitrogen 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 nitrogen depends on a number of factors, such as rates of fertilizer and manure nitrogen application, fertilizer types, methods and timing of nitrogen application, soil texture, rainfall, temperature, and soil pH.

5.4.2.1.2. Methodological Issues

There are few published scientific data that actually 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.

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.

For dairy cattle and swine, the amount of manure nitrogen 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 were used to estimate N loss as NH_3.

5.4.2.1.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N_2O emissions from the atmospheric deposition of N considered the uncertainty surrounding the parameters defined in the Tier 1 methodology in the 2006 IPCC Guidelines, as well as the uncertainty in the estimate of NH_3.

The estimate of N_2O emissions of 0.87 Mt CO_2 eq from volatilization and redeposition in 2022 has an uncertainty range of -75% to +110, or 0.22 Mt CO_2 eq to 1.8 Mt CO_2 eq 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, with the climate-specific factors from the 2019 IPCC guidelines, 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 (1990–2022).

5.4.2.1.4. Quality Assurance/ Quality Control and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.2.1.5. Recalculations

Recalculations occurred mainly due to IPCC ARR_5 GWP values, and to a minor extent due to activity data updates and error correction. These recalculations revised emissions downward by 80 kt CO_2 eq in 1990, by 96 kt CO_2 eq in 2005 and by 103 kt CO_2 eq in 2021 (Table 5–10). The short-term trend and long-term increased slightly from +13% to +14% and +37% to +38% respectively.

5.4.2.1.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

Table 5–10 **Recalculations of N_2O Emission Estimates and Their Impact on Trends in Greenhouse Gas Emissions from Atmospheric Deposition and Leaching and Runoff**

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 (%)
Atmospheric deposition	1990	2023	724	-79.66	-11.00	Long term (1990–2021)	
		2024	645			37	38
	2005	2023	874	-96.44	-11.03		
		2024	778			Short term (2005–2021)	
	2021	2023	990	-102.9	-10.40	13	14
		2024	887				
Nitrogen leaching and runoff	1990	2023	1 836	-203.93	-11.11	Long term (1990–2021)	
		2024	1 632			61	61
	2005	2023	2 203	-245.30	-11.134		
		2024	1 958			Short term (2005–2021)	
	2021	2023	2 963	-329.3	-11.11	35	35
		2024	2 634				

5.4.2.2. Nitrogen Leaching and Runoff

5.4.2.2.1. Source Category Description

When organic and inorganic fertilizers, and crop residues, are added to cropland, a portion of the nitrogen from these sources is lost through leaching and runoff. The magnitude of this loss depends on a number of factors, such as the application rate and method, crop type, soil texture, rainfall and landscape. This portion of lost nitrogen 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.

A modified IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from leaching and runoff of fertilizers, manure, and crop residue nitrogen from agricultural soils. Indirect N_2O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using the fraction of nitrogen that is lost through leaching and runoff ($FRAC_{LEACH}$) multiplied by the amount of inorganic fertilizer nitrogen and crop residue nitrogen 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 through October), the maximum $FRAC_{LEACH}$ value of 0.3 recommended by the 2006 IPCC Guidelines 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. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N_2O emissions from nitrogen leaching and runoff considered the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines and the uncertainty in the estimate of total N.

The estimate of N_2O emissions of 2.7 Mt CO_2 eq from nitrogen leaching and runoff in 2022 lies within an uncertainty range of -80% to +100%, or 0.54 Mt CO_2 eq to 5.4 Mt CO_2 eq 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%).

The same methodology and emission factors are used for the entire time series (1990–2022).

5.4.2.2.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.2.2.5. Recalculations

Recalculations occurred mainly due to updates to IPCC AR5 GWP values, and to a minor extent due to activity data updates and error correction throughout the time series. These changes revised emissions downward by 0.20 Mt CO_2 eq in 1990, 0.25 Mt CO_2 eq in 2005, and 0.33 Mt CO_2 eq in 2021 (Table 5–10). The short-term and long-term trends were unchanged.

5.4.2.2.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

5.5. CH_4 and N_2O Emissions from Field Burning of Agricultural Residues (CRF Category 3.F)

5.5.1. Source Category Description

Crop residues are sometimes burned in Canada, as a matter of convenience and for the purpose of 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 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[2] 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. Uncertainties and Time-Series Consistency

The uncertainties associated with CH_4 and N_2O emissions from field burning of agricultural residues were 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. On the basis of 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 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 were estimated to be ±64% and ±69%, respectively.

5.5.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data and methodologies are documented and archived in both paper and electronic form.

5.5.5. Recalculations

Recalculations for the whole time series were due to the implementation of the IPCC AR5 GWP values, revising CH_4 emissions upward by 12% and N_2O emissions downward by 11.1%. The net impact was a downward revision in emissions of 15 kt CO_2 eq in 1990, 2.8 kt CO_2 eq in 2005, and 2.3 kt CO_2 eq in 2021. These recalculations did not impact the short-term or long-term trends.

5.5.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

2 https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5044

5.6. CO_2 Emissions from Liming (CRF Category 3.G)

5.6.1. Source 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.

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. Uncertainties and Time-Series Consistency

The 95% confidence limits for data on annual lime consumption in each province were estimated to be ±30%. This uncertainty was 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 was considered to be -50% based on the 2006 IPCC Guidelines (IPCC, 2006). The overall mean and uncertainties were estimated to be 0.17 ± 0.14 Mt CO_2 eq for the level uncertainty.

The same methodology is used for the entire time series of emission estimates (1990–2022).

5.6.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.6.5. Recalculations

There were no recalculations to this category in this submission, and no changes to the short-term or long-term trends.

5.6.6. Planned Improvements

We are planning to implement Expert Review Team (ERT) recommendation on including the impurity of limestone in our estimates in the next inventory submission.

5.7. CO_2 Emissions from Urea Application (CRF Category 3.H)

5.7.1. Source Category Description

When urea [$CO(NH_2)_2$] or urea-based nitrogen fertilizers are applied to soil to augment crop production, CO_2 is released when the urea undergoes hydrolysis. According to the 2006 IPCC Guidelines, the quantity of CO_2 released to 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 that is released as CO_2 after hydrolysis. Methods and data sources are outlined in Annex 3.4.

5.7.3. Uncertainties and Time-Series Consistency

The 95% confidence limits for data on the annual urea or urea-based fertilizer consumption were estimated to be ±15%. The uncertainty estimate associated with the emissions was based on simple error propagation using survey uncertainty and an uncertainty of -50% associated with the emission factor specified in the 2006 IPCC Guidelines. The overall mean and uncertainties were estimated to be 2.4 ± 1.2 Mt CO_2 eq for the level 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 2022 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. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. 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 the years 1990, 2005, or 2021.

The long-term and short-term trends remain unchanged at +266% and +138%.

5.7.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

CHAPTER 6

LAND USE, LAND-USE CHANGE AND FORESTRY (CRF SECTOR 4)

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; additional emissions of CO_2, methane (CH_4), nitrous oxide (N_2O) and carbon monoxide (CO)[1] due to controlled biomass burning; CO_2, CH_4 and N_2O emissions from drained organic forest soils and wetland drainage and rewetting for peat extraction purposes; 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] and non-CO_2 emissions and CO_2 removals, amounted to net emissions of 49 Mt in 1990, 66 Mt in 2005 and 51 Mt in 2022.[3] When applied to the national totals, the net flux estimates result in an increase of 8.1% in 1990, 8.7% in 2005 and 7.3% in 2022 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 format (CRF) 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 years of the time series[4]. Carbon emissions increased from 1990 to 2005 by 17 Mt and subsequently declined due to the downward trend in net removals 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 emissions or disposal of HWP extracted from Canadian forests that have either reached their end of useful life or have been combusted for bioenergy. Forest management resulted in a decrease in net removals from 88 Mt to 63 Mt during the 1990–2005

1 Emissions of CO are reported as CO in CRF Table 4, but are not included in the sectoral totals, and are instead reported as indirect CO_2 in CRF 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 according to the protocol described in Annex 8, 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/.

period in the Forest Land category. This decline in removals reflects the influence of 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 removals by forest land have then returned to, and surpassed, earlier levels, reaching a maximum value of 110 Mt in 2022, mainly due to reduced harvest levels relative to rates observed in the early 2000s.

Emissions and disposals from the Harvested Wood Products category[5], which is closely linked to the Forest Land category, have ranged between 130 Mt and 150 Mt during the reported 1990–2022 period. Between 2004 and 2009, harvest rates fell sharply and emissions decreased to a minimum observed in 2009, and again reaching a low of 130 Mt in 2022 (Table 6–1). Emissions are influenced primarily by the trend in forest harvest rates during the reporting period and also the long-term impact of harvesting levels before 1990, as some of the C in HWP harvested prior to 1990 is emitted during the reporting period (Table 6–1). Emissions are influenced primarily by the trend in forest harvest rates during the reporting period and also the long-term impact of harvesting levels before 1990, as some of the C in HWP harvested prior to 1990 is emitted during the reporting period.

The combined net flux from the Forest Land and Harvested Wood Products categories—the latter excluding HWP from forest conversion activities and firewood harvest from non-forest lands since 1990—amounted to net emissions of 38 Mt in 1990 and 20 Mt in 2022, peaking at 80 Mt in 2005. These estimates represent the combined total of net removals from forest land and net emissions and disposal of HWP from forests.

Emissions and removals from stands recovering from natural disturbances beyond the control of human intervention are tracked separately from those stands that are tracked in the anthropogenic component. 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 (see section 6.3.1.2 for more details) on forest carbon. Since 1990, the net flux from lands impacted by natural disturbances has ranged from removals of 130 Mt in 1992 to peak emissions of 300 Mt in 2021 (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

Table 6–1 **Net Greenhouse Gas Flux Estimates in the Land Use, Land-Use Change and Forestry Sector, in Selected Years**

Sectoral Category		Net GHG Flux (kt CO_2 eq)[b]							
		1990	2005	2017	2018	2019	2020	2021	2022
LAND USE, LAND-USE CHANGE AND FORESTRY TOTAL[a]		**49 000**	**66 000**	**19 000**	**23 000**	**14 000**	**26 000**	**14 000**	**51 000**
a.	**Forest Land**	**-89 000**	**-64 000**	**-99 000**	**-99 000**	**-100 000**	**-100 000**	**-100 000**	**-110 000**
	Forest Land Remaining Forest Land	-88 000	-63 000	-99 000	-99 000	-100 000	-100 000	-100 000	-110 000
	Land Converted to Forest Land	-1 100	-950	-390	-330	-300	-240	-180	-130
b.	**Cropland**	**310**	**-23 000**	**-24 000**	**-23 000**	**-19 000**	**-16 000**	**-19 000**	**22 000**
	Cropland Remaining Cropland	-9 400	-27 000	-27 000	-26 000	-22 000	-19 000	-22 000	18 000
	Land Converted to Cropland	9 700	4 100	3 400	3 600	3 500	3 500	3 600	3 600
c.	**Grassland**	**0.7**	**0.9**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**
	Grassland Remaining Grassland	0.7	0.9	1.3	1.3	1.3	1.3	1.3	1.3
	Land Converted to Grassland	NO	NO	NO	NO	NO	NO	NO	NO
d.	**Wetlands**	**5 400**	**3 100**	**3 100**	**2 800**	**3 100**	**3 500**	**3 200**	**3 300**
	Wetlands Remaining Wetlands	1 500	2 600	2 700	2 500	2 700	2 900	2 700	3 100
	Land Converted to Wetlands	3 900	510	420	250	410	560	440	290
e.	**Settlements**	**1 800**	**1 800**	**2 400**	**2 300**	**2 200**	**2 300**	**2 200**	**2 200**
	Settlements Remaining Settlements	-4 200	-4 400	-4 400	-4 400	-4 400	-4 400	-4 400	-4 400
	Land Converted to Settlements	6 100	6 100	6 800	6 700	6 600	6 800	6 600	6 700
f.	**Other Land**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**
g.	**Harvested Wood Products**	**130 000**	**150 000**	**140 000**	**140 000**	**130 000**	**140 000**	**130 000**	**130 000**
	Forest conversion[c]	*21 000*	*16 000*	*17 000*	*17 000*	*16 000*	*17 000*	*17 000*	*16 000*
	Indirect CO_2[d]	*640*	*780*	*670*	*640*	*530*	*480*	*500*	*480*
	Natural disturbances[e]	*-120 000*	*17 000*	*220 000*	*250 000*	*160 000*	*4 200*	*300 000*	*93 000*

Notes:
NE = Not estimated
NO = Not occurring

a. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.
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, Land Converted to Settlements and Harvested Wood Products subcategories.
d. Indirect emissions of CO_2 from the atmospheric oxidation of CO that results from controlled biomass burning, reported in CRF 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.

of wildfires and insect disturbances. Since 2017, on average, emissions from lands impacted by natural disturbances, both wildfire and insect disturbance are estimated to be 190 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.

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—in turn, increasing C input to soils—have resulted in an increase in net removals of CO_2 in the Cropland category during the 1990–2006 period. This trend was further augmented 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 somewhat attenuated by higher annual crop yields. 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 2002 (4.6 Mt), 2003 (8.3 Mt) and 2022 (22 Mt) associated with the drought in Western Canada and the peak removals in 2009 (36 Mt) and 2014 (45 Mt) associated with high crop yields. As a result, short-term trends must be interpreted with care.

Over the 1990–2022 period, net emissions in the Wetlands category (peat extraction and flooded lands) ranged from a peak of 5.5 Mt (1993) to a low of 2.8 Mt (2018). Trends in this category are mainly driven by the creation of large reservoirs before 1990, resulting in higher residual emissions over the 1990–1993 period. Emissions from flooded lands accounted for 32% of all emissions in the Wetlands category in 2022, compared to 83% in 1990. Emissions in the Land Converted to Wetlands category decreased from 3.9 Mt to 0.3 Mt over the reporting period.

Net emissions reported in the Settlements category fluctuated between 1.3 Mt (1997) and 2.6 Mt (2016), driven mainly by rates of conversion of forested land, which accounted for 6.7 Mt of emissions in 2022. Relatively steady removals of around 4.4 Mt per year from the growth of urban trees offset these emissions on average by 71% 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 and is a fraction of the Harvested Wood Products category. Considering these categories together, the emissions due to forest conversion decreased from 21 Mt in 1990 to 16 Mt in 2022, including the emissions from HWP resulting from forest conversion activities since 1990. This decline in emissions consists of decreases of 4.3 Mt and 1.8 Mt in immediate and residual emissions from the conversion of forest to cropland and to wetlands, respectively; an increase of 0.6 Mt in these emissions from the conversion of forest to settlements; and an increase of 0.8 Mt in emissions from the resulting HWP use and disposal since 1990.

In order to avoid double counting, the estimates of C stock changes in CRF 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 CRF 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 from wetland drainage and rewetting for peat extraction purposes are reported in CRF Table 4(II) along with emissions of N_2O. Carbon emissions in the form of CO are reported as such in CRF Table 4, but are not included in the sectoral totals, and are instead reported as indirect CO_2 in CRF Table 6. Emissions and removals of CO_2 and emissions of CH_4, N_2O and CO are automatically tallied in CRF Table 4.

This year's submission includes significant recalculations in the reported estimates for Forest Land and the most recent years of Harvested Wood Products, as well as minor revisions to Cropland, Wetlands and categories touched by Forest Conversion. Finally, the implementation of 100-year GWPs from AR 5 had minor impacts on the final result (46, 51, and 31 kt in years 1990, 2005 and 2021 respectively). The most notable recalculations were a result of the changes to historical harvest data that determine the area of the anthropogenic Forest Land component (Kurz et al. submitted). The data revisions reduced the estimated historical harvested forest area by 34 million hectares across five provinces (BC, AB, SK, ON, QC). As a result, Forest Land emissions and removals were revised upwards by 110 Mt, 72 Mt and 28 Mt in 1990, 2005 and 2021 respectively (more information provided in section 6.3.1.5). These recalculations also include minor revisions (< 1 Mt) resulting from corrections to the CBM code and addition of some additional reforestation areas. Updates to Harvested Wood Products activity data lead to significant recalculations in 2020 (+7.9 Mt) and 2021 (+4.0 Mt), and minor recalculations throughout the remainder of the time series due refinements to model parameters.

Minor revisions to Cropland activity data using a high resolution land-use change information resulted in recalculations throughout the time series. Other smaller recalculations occurred in the Forest Land and Wetlands categories due to updated mapping values for deforestation rates, addition of forest-cleared and flooded areas associated to a hydro-related large event in Ontario, and updated 2021 activity data for peat extraction.

Finally, minor recalculations resulted from the implementation of GWP values from IPCC AR 5.

The combined impact of recalculations in the LULUCF sector (Table 6–2) were upward recalculations of 110 Mt in 1990, 72 Mt in 2005 and 31 Mt in 2021, shifting the entire time series from net removals reported in the 2023 inventory report to a net source of emissions in this inventory report.

Table 6–2 **Summary of Recalculations in Reported Estimates for the Land Use, Land-Use Change and Forestry Sector**

Sectoral Category			1990	2005	2017	2018	2019	2020	2021
LAND USE, LAND-USE CHANGE AND FORESTRY TOTAL[a]		**kt**	**110 000**	**72 000**	**35 000**	**34 000**	**32 000**	**39 000**	**31 000**
		%	**180%**	**1300%**	**220%**	**300%**	**170%**	**290%**	**180%**
a.	**Forest Land**	**kt**	**110 000**	**72 000**	**36 000**	**34 000**	**33 000**	**30 000**	**28 000**
		%	**56%**	**53%**	**27%**	**26%**	**24%**	**23%**	**21%**
	Forest Land Remaining Forest Land	kt	110 000	72 000	36 000	34 000	33 000	30 000	28 000
		%	56%	53%	27%	26%	24%	23%	21%
	Land Converted to Forest Land	kt	0.0	0.0	0.0	0.7	0.6	0.6	-3.3
		%	0.0%	0.0%	0.0%	0.2%	0.2%	0.2%	-1.9%
b.	**Cropland**	**kt**	**-700**	**- 700**	**-1 400**	**- 440**	**- 980**	**560**	**-1 300**
		%	-69%	-3.2%	-6.0%	-2.0%	-6%	3%	-7%
	Cropland Remaining Cropland	kt	-840	- 880	-1 400	- 740	-1 100	560	-1 400
		%	-9.8%	-3.4%	-5.4%	-2.9%	-5%	3%	-7%
	Land Converted to Cropland	kt	140	180	30	300	150	0	130
		%	1.5%	4.7%	0.9%	9.1%	4.4%	0.0%	3.7%
c.	**Grassland**	**kt**	**0.0**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0**
		%	**6.6%**	**6.6%**	**6.6%**	**6.6%**	**6.6%**	**6.6%**	**6.6%**
	Grassland Remaining Grassland	kt	0.0	0.1	0.1	0.1	0.1	0.1	0
		%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%
d.	**Wetlands**	**kt**	**8.4**	**6**	**4**	**5.5**	**- 4.7**	**12**	**- 130**
		%	0.2%	0.2%	0.1%	0.2%	-0.2%	0.3%	-3.8%
	Wetlands Remaining Wetlands	kt	7.1	2.3	2.5	3.9	3.6	3.6	- 130
		%	0.5%	0.1%	0.1%	0.2%	0.1%	0.1%	-4.6%
	Land Converted to Wetlands	kt	1.2	3.6	1.5	1.6	- 8.3	8	7
		%	0.0%	0.7%	0.4%	0.7%	-2.0%	1.4%	1.5%
e.	**Settlements**	**kt**	**-47**	**260**	**230**	**210**	**260**	**290**	**140**
		%	**-2.5%**	**17%**	**11%**	**10%**	**13%**	**14%**	**6.8%**
	Settlements Remaining Settlements	kt	0.0	-	-	-	0.0	-	0.0
		%	0.0%	-	-	-	0.0%	-	0.0%
	Land Converted to Settlements	kt	-47	260	230	210	260	290	140
		%	-0.8%	4.4%	3.5%	3.3%	4.1%	4.5%	2.1%
g.	**Harvested Wood Products**	**kt**	**60**	**140**	**27**	**72**	**65**	**7 900**	**4 000**
		%	0.05%	0.1%	0.0%	0.1%	0.1%	6.2%	3.1%
	Forest conversion[b]	*kt*	*60*	*140*	*27*	*72*	*65*	*7 900*	*4 000*
		%	*0.0%*	*0.1%*	*0.0%*	*0.1%*	*0.1%*	*6.2%*	*3.1%*
	Implementation of AR 5 GWPs	*kt*	*46*	*51*	*47*	*40*	*32*	*30*	*31*

Notes:
A hyphen (-) indicates no recalculations
a. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.
b. Not a reporting category.

6

See sections 6.3 to 6.9, Table 6–3 and Table 8–4 for more details on the changes implemented.

Estimates for all forest-related categories are developed using the same modelling framework. Therefore, changes to the forest model and to the distribution of disturbances in the landscape can result in changes to the forest stands available for modelling subsequent events (such as forest conversion), resulting in indirect recalculations in land conversion categories as well as in C transfers to HWP.

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.

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		
Updated pre-1990 disturbance history, also referred to as "last pass disturbance"	Continuous improvement	Complete time series
Minor correction to CBM-CF3 code related to tracking of post-natural disturbance history rules	Continuous improvement	Complete time series
Implementation of the IPCC AR5 global warming potentials for methane and nitrous oxide	Continuous improvement	Complete time series
Reforestation activity update	Activity data updates	2021
Afforestation activity updates	Activity data updates	2018; 2021–2022
Cropland		
Updated LU coverage layers for all years using high resolution data	Activity data updates	2018–2020
Integration of SLC census source data	Activity data updates	2021
Updated crop yields based on EVI data	Continuous improvement	Complete time series
Updated annual crop production and livestock data	Activity data updates	2022
Improve time series activity data on forest land to cropland conversions	Continuous improvement	2011–2021
Grassland		
Implementation of the IPCC AR5 global warming potentials for methane and nitrous oxide	Continuous improvement	Complete time series
Wetlands		
Updates of 2021 activity data on peat extraction from NRCan	Activity data updates	2021–2021
Addition of flooded areas associated to a hydro-related large event in Ontario	Activity data updates	2013–2021
Adjustments to deforestation rates with newly mapped values	Continuous improvement	1990–2021
Implementation of the IPCC AR5 global warming potentials for methane and nitrous oxide		
Settlements		
Addition of forest-cleared areas associated to a hydro-related large event in Ontario	Activity data updates	2013–2021
Improve time series activity data on forest land to settlement land conversions	Continuous improvement	Complete time series
Harvested Wood Products		
Updated HWP model parameters based on latest Food and Agriculture Organization (FAO) statistics on forest products	Activity data updates	2019–2021
Updated HWP commodity conversion parameters	Continuous improvement	Complete time series
Updated waste Incineration activity data	Activity data updates	Complete time series

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 Annex 6.5.

6

6.2. Land Category Definitions and Representation of Managed Lands

In order 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 purpose of the GHG inventory, managed forests are those managed for timber and non-timber resources (including parks) or subject to fire protection. Annex 3.5.2 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 that is 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 are not already included 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 and land flooded for hydroelectric 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.

As a consequence 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, its creation 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 Flooded Land (reservoirs), when a 10-year transition period is used (IPCC, 2006), and 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. However, the use of the default 20-year transition period is simply procedural, since higher tier estimation methods are employed for 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 2022. 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 CRF 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 (section 6.8.2.2). Each column total equals the total land area reported in the CRF 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 CRF 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 CRF 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 Annex 3.5.1.

The land areas reported in the CRF 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 a fraction of total reservoir areas (those flooded for 10 years or less), not the total area of reservoirs in Canada.

Similarly, the areas of land conversion reported in the relevant CRF sectoral background tables refer to the cumulative total land area converted over the last 20 years (10 years for reservoirs and one year for peat extraction) and should not be confused with annual rates of land-use change. The trends observed in the CRF 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 (10 years for reservoirs and one year for peat extraction) to the “land remaining land” categories (e.g. Forest Land Remaining Forest Land and Cropland Remaining Cropland).

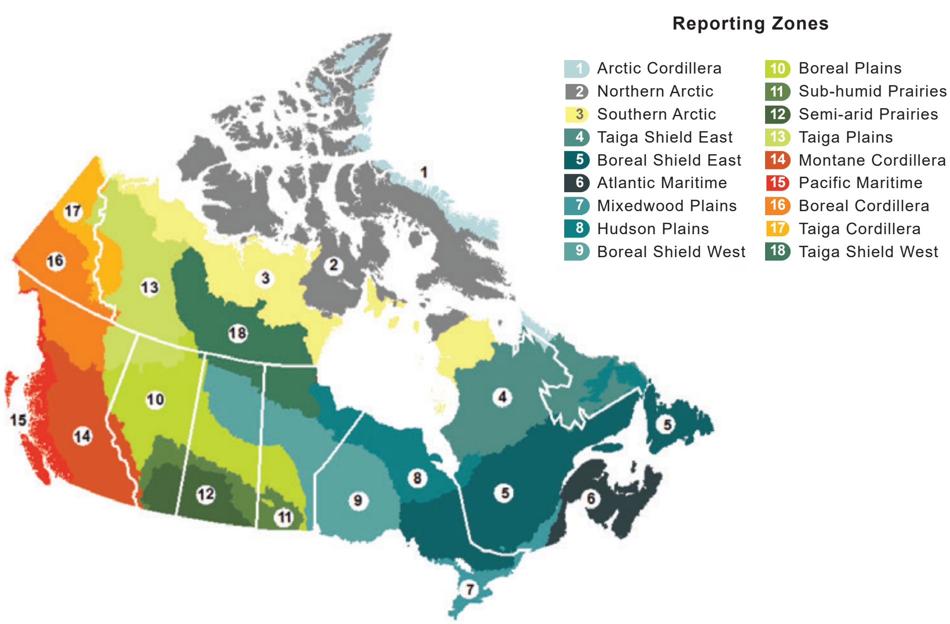
Annual estimates of managed and unmanaged forest areas are reported separately in CRF Table 4.1 for the first time in this submission and the remaining unmanaged land area reported in this CRF Table 4.1 includes both unmanaged and managed non-forest land for which there are no estimates of emissions 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 Annex 3.5.1 for more details).

Table 6–4 **Land Use and Land-Use Change Matrix for the 2022 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]	166 284	59 165	22	NO	0.0	27	NO
Anthropogenic component	*163 477*	*2 391*	*22*	*NO*	*0.0*	*27*	*NO*
Natural disturbance component	*2 807*	*56 774*	*NO*	*NO*	*NO*	*NO*	*NO*
Cropland	0.4	NO	45 791	NO	NE	11	NO
Grassland	NO	NO	0.1	7 067	NE	0.9	NO
Wetlands[c]	NO	NO	NE	NO	494	NE	NO
Settlements[c]	NO	NO	NE	NO	NO	992	NO
Other	NO	NO	NO	NO	0.5	NO	NE

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 CRF 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 CRF.

Figure 6–1 **Reporting Zones for Land Use, Land-Use Change and Forestry Sector Estimates**



6

6.3. Forest Land (CRF Category 4.A)

Forests and other wooded lands cover 410 million hectares (Mha) of Canadian territory; forest lands alone occupy 360 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 2022, the net GHG balance reported for the anthropogenic component of the managed Forest Land (see section 6.3.1.2) amounted to removals of 110 Mt (Table 6–1 and CRF Table 4), while emissions from wood products originating from Canada's managed forests amounted to 130 Mt.

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 from drained organic forest soils. For the purposes of UNFCCC reporting, the Forest Land category is divided into Forest Land Remaining Forest Land (anthropogenic component) (170 Mha, net removals of 110 Mt in 2022) and Land Converted to Forest Land (0.02 Mha, net removals of 0.1 Mt in 2022) subcategories.

6.3.1. Forest Land Remaining Forest Land (CRF Category 4.A.1)

6.3.1.1. Sink 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 CO_2 emissions in the Harvested Wood Products category associated to forest products represents the net flux of carbon between managed forests and the atmosphere (Figure 6–2).

Estimated net removals 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. The impact of non-anthropogenic disturbances (i.e. natural disturbances such as wildfires, insect infestations and windthrow) in the managed forest are also presented (Table 6–5).[7] Net removals in the Forest Land category decreased from 88 Mt in 1990 to 63 Mt in 2005 and have gradually returned to, and then surpassed, earlier levels, reaching a maximum value of 110 Mt of removals in 2022. Harvest rates increased nationally during the period of 1990 to 2004 resulting in decreasing removals. The shift in trend from decreasing removals to increasing removals coincides with a sharp decline in harvest rates between 2004 and 2009 (Figure 6–2), which was largely due to changes in export markets. Harvest levels never returned to levels observed in 2004 and 2005. As such the trend of increasing removals, from a minimum of 63 Mt in 2005 to a maximum of 110 Mt in 2022 was maintained for the rest of the reporting period as areas that were harvested prior to peak harvest rates in 2004 shift from a net source of emissions to a net removal with the regrowth of the harvested stand (Figure 6–2).

The decrease in removals 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, 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 C accumulation 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 zone, increased harvest rates also resulted in a shift in the average age of forests in that reporting zone, but insect infestations and fire also caused a reduction in the area of commercially mature forest stands and, consequently, a reduction in the 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,

6 Canada's statistical data – forest inventory. Natural Resources Canada. [Accessed 2023 Jan 25]. Available online at: https://cfs.nrcan.gc.ca/statsprofile.

7 Impacts of natural disturbances with greater than 20% tree mortality.

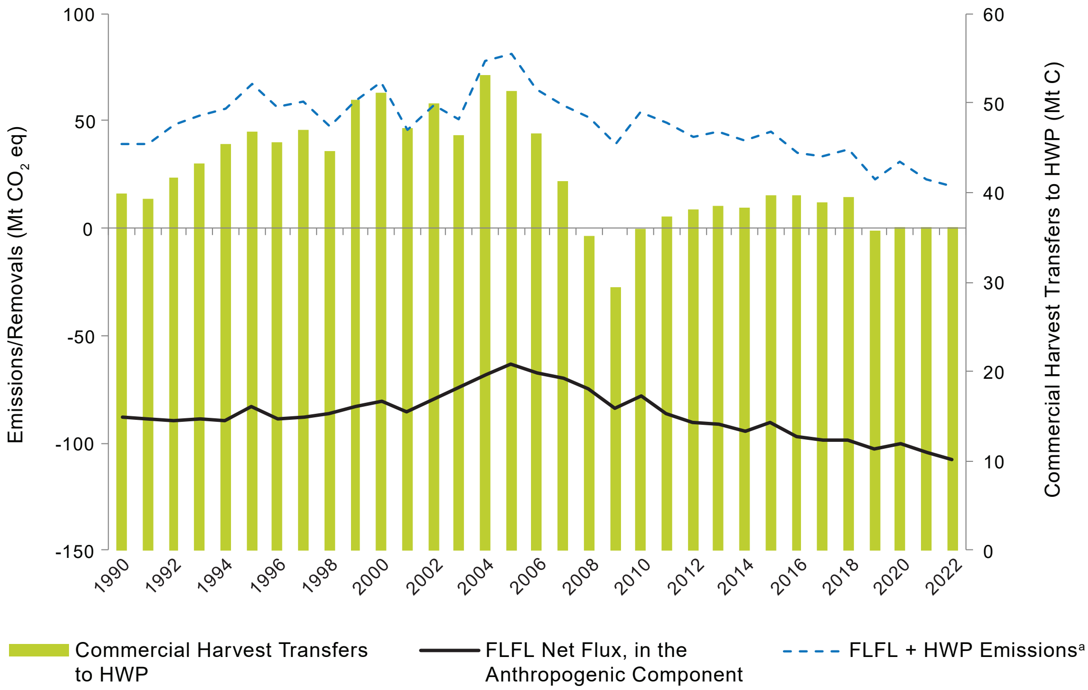
8 Average age of the forest in this context refers to the age-class structure of the forest and carbon uptake refers to net primary production.

low-mortality insect infestations have impacted large areas of the Boreal Shield East and Atlantic Maritime reporting zones and, since 2010, have had an effect on reported emissions and removals in these regions that may continue over the next few decades.

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 210 Mt in 1990, 46 Mt in 2005 and 15 Mt in 2022. 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.

Emissions and removals reported from the forest sector, excluding the impacts of severe natural disturbances, but including disposals and emissions from HWP extracted from Canadian forests, which are reported in the Harvested Wood Products category, demonstrate that the Canadian Forest sector acts as a net source of carbon transferred to the atmosphere and to waste disposal in countries that have imported Canadian HWP as a result of short- and long-term impacts of human management (Figure 6–2).

Figure 6–2 **Emissions and Removals Related to Forest Land**



Notes:
a. Includes emissions from HWP originating from harvesting and salvage logging after natural disturbances
FLFL = Forest Land Remaining Forest Land
HWP = Harvested Wood Products

Table 6–5 **Area of, and Greenhouse Gas Fluxes and Carbon Transfers from, Forest Land Remaining Forest Land, Selected Years**

Subcategories	GHG	1990	2005	2017	2018	2019	2020	2021	2022
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	170 000	160 000	170 000	170 000	170 000	170 000
Areas with natural disturbance impacts		88 000	72 000	61 000	61 000	60 000	59 000	60 000	59 000
NET FLUX – REPORTED AND NOT REPORTED (kt CO_2 eq)[a, b]		**-210 000**	**-46 000**	**120 000**	**150 000**	**53 000**	**-96 000**	**200 000**	**-15 000**
Reported estimates[c]		**-88 000**	**-63 000**	**-99 000**	**-99 000**	**-100 000**	**-100 000**	**-100 000**	**-110 000**
Anthropogenic Component, Past Forest Management Activities		83 000	96 000	42 000	40 000	34 000	31 000	26 000	22 000
	CO_2	82 000	95 000	41 000	40 000	34 000	30 000	26 000	21 000
	CH_4	300	620	550	490	370	290	330	300
	N_2O	110	280	240	230	180	150	170	160
	CO[d]	210	520	420	400	300	230	260	240
Anthropogenic Component, Mature Stands of Natural Disturbance Origin	CO_2	-170 000	-160 000	-140 000	-140 000	-140 000	-130 000	-130 000	-130 000
Emissions/removals from lands impacted by natural disturbances		**-120 000**	**17 000**	**220 000**	**250 000**	**160 000**	**4 200**	**300 000**	**93 000**
Wildfires – direct immediate emissions[e]		30 000	61 000	210 000	240 000	150 000	14 000	270 000	87 000
	CO_2	26 000	52 000	180 000	210 000	130 000	12 000	240 000	75 000
	CH_4	3 000	5 900	21 000	23 000	15 000	1 400	27 000	8 500
	N_2O	1 200	2 400	8 200	9 300	5 800	550	11 000	3 400
Wildfires – indirect immediate CO_2 emissions[e]	CO	2 600	5 200	18 000	21 000	13 000	1 200	24 000	7 500
Post-wildfire CO_2 emissions and removals[e]	CO_2	-150 000	-92 000	-37 000	-29 000	-26 000	-30 000	-15 000	-18 000
Insects – emissions and removals[f]	CO_2	240	43 000	23 000	22 000	20 000	19 000	17 000	16 000
Other natural disturbances – emissions and removals[g]	CO_2	NO	26	5.5	2.3	2.1	2.0	1.8	1.7
CARBON TRANSFERRED TO HWP (kt C)[h]		**44 000**	**54 000**	**43 000**	**43 000**	**39 000**	**39 000**	**39 000**	**39 000**

Notes:
Totals may not add up due to rounding. Annex 8 describes the rounding protocol.
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. 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 CRF table 6.
e. 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.
f. Includes emissions due to insect infestations, mainly residual, and removals associated with subsequent natural stand regeneration.
g. Includes the remnant impact in emissions of Hurricane Juan on Nova Scotia forests in 2003 and removals from subsequent natural stand regeneration.
h. This transfer from land categories to the harvested wood products (HWP) C pool is presented here for information purposes. Includes salvage logging after natural disturbances. The current design of the CRF tables for the Land Use, Land-Use Change and Forestry Sector does not enable representation of carbon transfer to the HWP in-use pool.

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 in order 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 Annex 3.5.2.1.

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

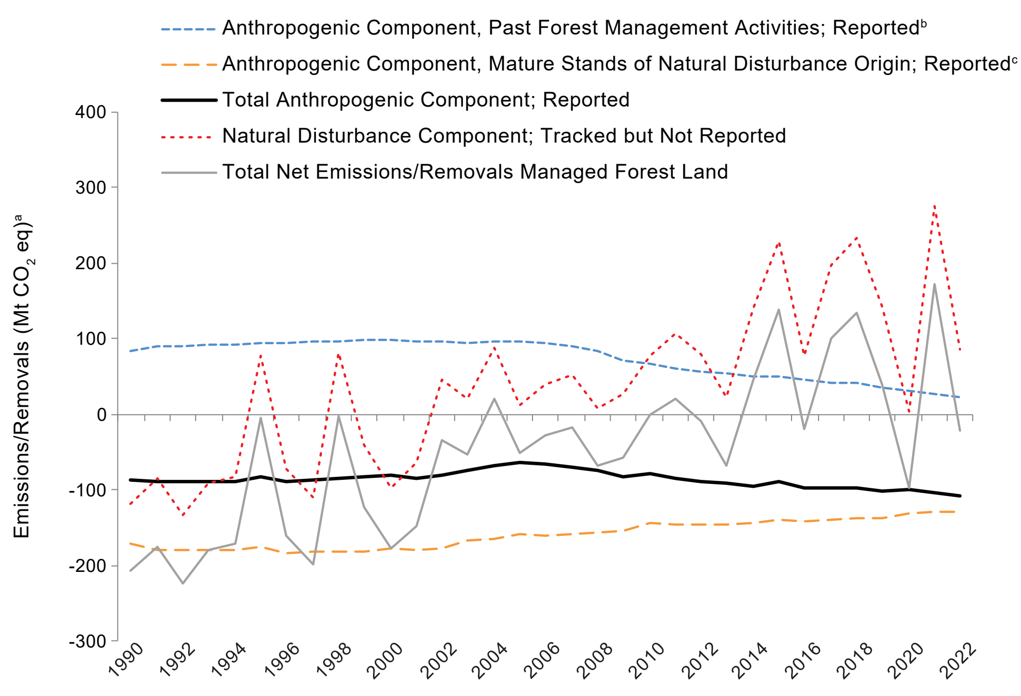
9 Canada's forest carbon reporting system: https://www.nrcan.gc.ca/climate-change-adapting-impacts-and-reducing-emissions/climate-change-impacts-forests/carbon-accounting/13087.

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, 2022). Additional information on the estimation approach is provided in Annex 3.5.2.6 and in Kurz et al. (2018).

Carbon stock changes in the anthropogenic component of managed forests are reported, by reporting zone in CRF 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 CRF 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 tracked in the HWP pool and reported in the Harvested

Figure 6–3 **Emissions from and Removals by Forest Land Remaining Forest Land, by Stand Component**



Notes:

a. Not including indirect CO_2 or emissions from HWP.

b. Clear-cut and partial harvests, commercial and pre-commercial thinning, and salvage logging.

c. Stands that have reached minimum operable age (either commercial maturity or pre-disturbance biomass threshold) and are eligible to be scheduled for harvest.

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Wood Products category, while the emissions from the C that decomposes on-site are reported in the Forest Land category. Owing to limitations in the current design of the CRF tables, the C transferred from the forest C pool to the HWP pool is not reported in CRF Table 4.A, since this would result in the automatic calculation of CO_2 emissions in the "net CO_2 emissions/removals" column of that table, which would amount to using the instant oxidation approach for HWP. Instead, and for transparency purposes, this C transfer is reported as C input in the HWP in-use pool in CRF Table 4.G, without removing it from the emissions reported in the "Net emissions/removals from HWP in use" column of CRF Table 4.G. For this reason, it is important to refrain from interpreting the net C stock change in the forest living biomass and DOM pools as shown in the current design of CRF Table 4.A as the actual C stock change value, since the losses of C from these pools are not completely represented in this table. More information on Canada's approach to HWP modelling is available in Annex 3.5.3.

Emissions of CO_2, CH_4 and N_2O from drained organic forest soils are reported in CRF Table 4(II). They are calculated using activity data obtained from a combination of historical documents, consultations and provincial statistics, and 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 Annex 3.5.2.4).

On the basis of 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 varied from 55 kt in 1990 to 0 kt in recent years, which is significantly lower than the threshold of 0.05% of national total GHG emissions excluding LULUCF, and do not exceed 500 kt.

6.3.1.3. Uncertainties and Time-Series Consistency

Uncertainty Estimates

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 output is subsequently assembled. For each project, 100 Monte Carlo runs are conducted using the base input data for the GHG estimates in this 2024 submission (covering the entire 1990-2022 time series). 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. Given the substantial changes in this submission, a comprehensive uncertainty analysis using Monte Carlo simulation was performed.

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 58 Mt in 1990, 78 Mt in 2005 and 77 Mt in 2022 (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 are 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 Annex 3.5.2.9, 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, for 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	-89	-150	69	-92	3.7
	2005	-65	-119	84	-41	-37
	2022	-108	-166	53	-89	-18
CH_4	1990	0.3	0.2	-31	0.5	82
	2005	0.6	0.4	-26	1.1	78
	2022	0.3	0.2	-31	0.5	74
N_2O	1990	0.1	0.1	-30	0.2	124
	2005	0.2	0.2	-20	0.5	117
	2022	0.1	0.1	-25	0.2	114

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 Annex 2.3 are taken from the error associated with the proportional error for 2022.

Time-Series Consistency

All estimates have been developed in a consistent manner. However, the forest inventory data incorporated in the analyses were not all collected in the same year across the country. Annex 3.5.2.5 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. Quality Assurance / Quality Control 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 CRF 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 errors in the above-ground biomass, deadwood, litter and mineral soil C pools were 7.5%, 30.8%, 9.9% and 8.4%, respectively. The contribution of the above-ground biomass and deadwood pools to the error in the ecosystem subtotal pools was small, but the contribution from soils was large. 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.

As part of quality assurance 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 occurred in Forest Land, the most significant of which, is due to corrections made to the pre-1990 Forest Land disturbance history data, i.e., wildfire or clearcut, which determine the stand origin at the initiation of CBM-CFS3 simulations in 1990 (for more details, see Annex 3.5.2.5). Specifically, a review of the entire harvested land base, initiated in 2018, was completed. As a result, new and updated data on historical harvest areas in Canada (1890 to 1989) were finalized for implementation in the 2024 submission after completion and submission of a peer-reviewed manuscript (Kurz et al. submitted).

The historical harvest area is a key factor in determining the area of land that is reported as a part of the anthropogenic component under Canada's reporting approach. Consequently, the emissions and removals are reported in the Forest Land subsector. These revisions to historical harvest areas were compiled for five provinces (British Columbia, Alberta, Saskatchewan, Ontario and Quebec). The implementation of this change reduced the area of the managed forest that is included in the anthropogenic component by 34 Mha (Figure 6–4) at the initiation of the time series. These reductions in the area of the historically harvested land translated into a corresponding shift of the removals that occur in the anthropogenic component of the managed forest to the natural disturbance component. Further, a greater proportion of stands initiated by wildfire led to greater initial amounts of DOM.

These reductions in the area of the historically harvested land and increases in DOM translate into a reduction in the forest sink associated to the anthropogenic component (Figure 6–5). The revised estimates of the anthropogenic carbon sink in Canada's managed forest are net removals of approximately 88 Mt in 1990, decreasing to 63 Mt in 2005, followed by an increase to 110 Mt in 2022. These proposed revisions result in a downward recalculation in Forest Land estimates in this submission of 110, 72 and 28 Mt in 1990, 2005 and 2021 respectively from the net removals reported in the 2023 submission.

Figure 6–4 **Revisions to historic harvest area, resulting from a review of the harvested landbase in Canada**

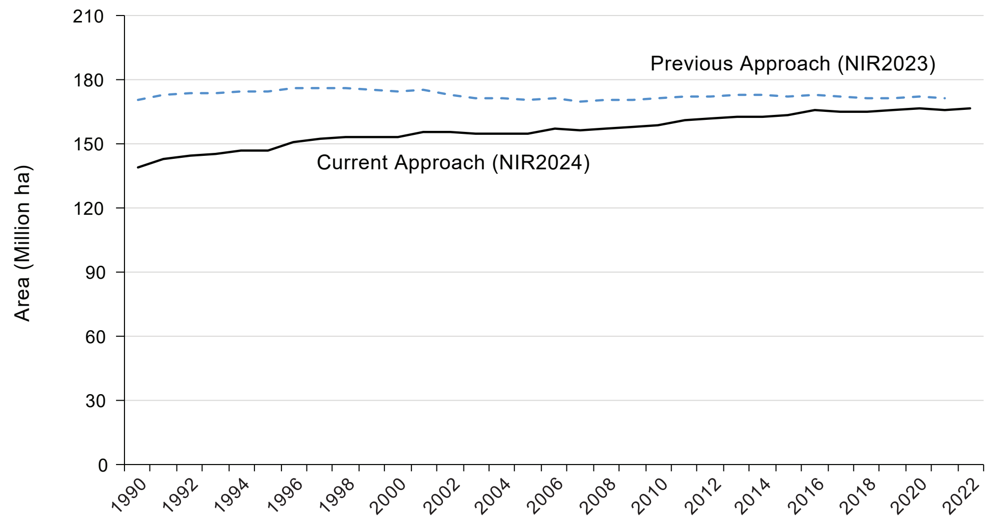
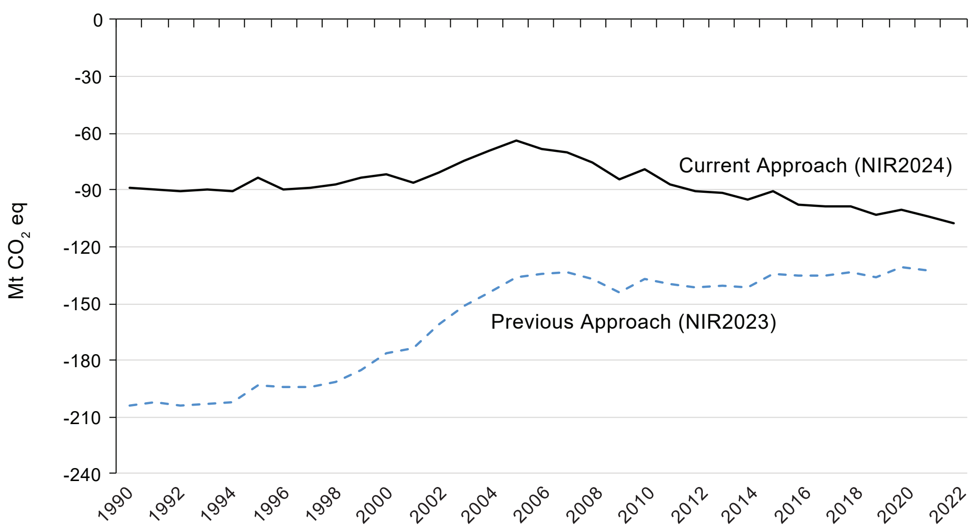


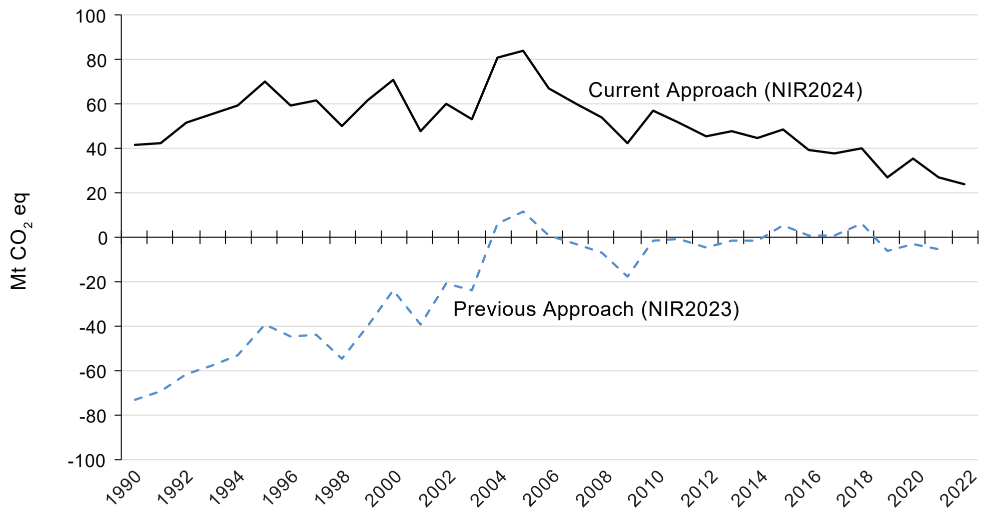
Figure 6–5 **Revisions to CO_2 removals reported under Forest Land resulting from revisions to historic harvest areas**



The Forest Land and Harvested Wood Products categories combined include both GHG fluxes between the atmosphere and Canada's managed forests, and track emissions and the global disposal of harvested wood products (HWP) originating from domestic harvest. The update reduced the reported carbon sink in Canada's managed forest and as a result when the emissions from HWP are added, the reported anthropogenic net balance is a net source in all years of the time-series going from 40 Mt in 1990 to 85 Mt in 2005 and decreasing to 25 Mt in 2022.

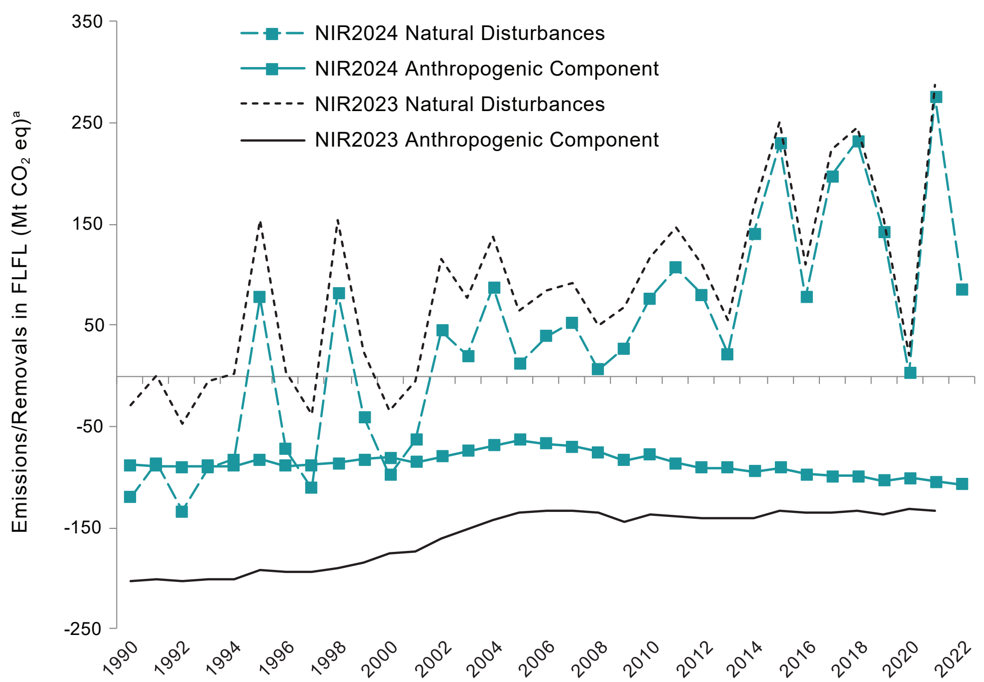
Other less significant recalculations occurred in the forest sector due to a minor code correction of CBM-CFS3 and updates to afforestation activity data in recent years.

Figure 6–6 **Revisions to CO_2 emissions and removals from the forest sector, combining Forest Land removals and emissions and disposals of Harvested Wood Products**



Emissions and removals were shifted from the anthropogenic component to the natural component, and by increasing areas of land as originating from wildfire origin, the emissions and removals from naturally disturbed stands were revised upward as an inverse of the anthropogenic component revision (lower removals, or greater emissions) (Figure 6–7). The transfer in emissions between reported and unreported categories was not the only impact of the increase in the area of stands of wildfire origin. On average, estimated stocks of DOM in the whole of the managed forest increased and as a result increased emissions from decomposition. As a consequence, total emissions and removals were revised upwards by on average of 22 Mt, but ranged between peak recalculations of 37 Mt in 1999 and a low of 5 Mt in 2016.

Figure 6–7 **Recalculations in the Natural Disturbance Component and Anthropogenic Component of Forest Land Remaining Forest Land**



Note:
a. Not including indirect CO_2.

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6.3.1.6. Planned Improvements

In general, planned improvements include (i) updates to baseline inputs (data, processes and parameters) such as activity data on fires, stand origin characterization as well as continuous refinements to certain parameters in the CBM-CFS3 modelling framework; and (ii) science improvements such as refinements to wildfire emissions estimates through variable burn intensity and new calibrated soil and dead organic matter C modelling parameters. 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.

Several improvements are planned for the Forest Land category in the next 2025 inventory submission. Briefly, improvements include improved representation of the impacts of wildfires, refinements to deforestation activity in the Prairie Ecozone, refinements to slash-burning in British Columbia and improved transparency related to direct impacts of forest harvest on carbon stocks and improved consistency of wood waste and bioenergy among inventory sectors.

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 (CRF 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 23 kha in 2022. Given that activity data after 2008 are only for Ontario and for 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 1.1 Mt in 1990 to 0.1 Mt in 2022. Net C accumulation largely occurred in living biomass (32 Gg C in 2022, CRF Table 4.A). 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 as a whole 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 in 1970–1989 and 2003–2008 were estimated based on activity rates observed in the FAACS data, supplemented by data from the Forest 2020 Plantation Demonstration Assessment (NRCan, 2005b). In addition, since the 2022 submission the estimates reported in this category includes the effect of afforestation activity data for Ontario for 2007–2018 obtained through a data sharing agreement with Forests Ontario providing access to its database of tree planting activities.

For the year 2022, estimates associated with recent afforestation activities in Canada were prepared, as was the case in 2021, using a methodology specifically developed that incorporates site-specific pre-planting C stocks into the estimation of the initial and then subsequent C content for the new afforestation sites (see Annex A3.5.2.7 and Hafer et al., 2022).

GHG emissions and removals on land newly converted to forest land were estimated using the CBM-CFS3, as described in Annex 3.5.2.1. Changes in soil C stocks are highly uncertain because of difficulties in locating data prior to plantation. 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 https://data-donnees.az.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/E-LULUCF/?lang=en

6.3.2.3. Uncertainties 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. Quality Assurance / Quality Control 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 CRF Reporter software.

6.3.2.5. Recalculations

Very small recalculations occurred in this reporting category due to the addition of 902 hectares afforested by Forests Ontario in 2018 that have now passed their 5-year survival survey assessment, and activity data updates for areas afforested under new afforestation programs. This change caused a downward recalculation in net removals of 3 kt (-1.5%) in 2021.

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 in the future.

6.4. Harvested Wood Products (CRF Category 4.G)

6.4.1. Source Category Description

Emissions in the Harvested Wood Products category are reported using a variation of the Simple Decay Approach described in the annex to Volume 4, Chapter 12, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (hereafter referred to as the 2006 IPCC Guidelines) (IPCC, 2006). This approach is similar to the Production Approach, but differs in that the HWP pool is treated as a C transfer related to wood harvest and hence does not assume the instant oxidation of wood in the year of harvest (more details provided in Annex 3.5.3).

Emissions and disposals associated with this category result from the use and disposal of HWP manufactured from wood obtained from forest harvesting, from residential firewood harvesting in forests and other wooded lands, and from 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.

Emissions from this source are influenced by current rates of harvesting and production of short-lived products and wood waste as well as the past rates of production of longer-lived wood products. Emissions have fluctuated between a low of 130 Mt in 2009 (lowest harvest year) and a peak of 150 Mt in 1995. In 2022, the HWP category contributed emissions and disposals of 130 Mt, 0.8 Mt greater than the 1990 value and 16 Mt below the 2005 value (Table 6–7).

For the entire reporting period, with the exception of 2009, emissions and disposals resulting from the inclusion of the HWP pool (stacked areas in Figure 6–8) are lower than the transfers of carbon in biomass to the HWP pool (dotted line in Figure 6–8), which was the value reported for submissions prior to the implementation of the HWP model in 2015. The differences in these values, (bars in Figure 6–8) range between -61 Mt in 2004 (highest harvest year) and 0.6 Mt in 2009 (lowest harvest year). These differences represent the annual net change of C storage in the HWP pool. Net stocks in the HWP pool have increased each year, with the exception of 2009. In 1990, emissions and disposals of short-lived wood products made up 85% of annual emissions and disposals, which decreased to 77% in 2005 and further to 67% in 2022 (Table 6–7).

Harvested Wood Products emission and disposals 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 in managed forests (Figure 6–2).

Table 6–7 **Carbon Stocks in the Harvested Wood Products Pool and Emissions Resulting from Their Use and Disposal**									
Source Subcategories / Commodities	Land Category	1990	2005	2017	2018	2019	2020	2021	2022
CARBON STOCKS (kt C)[a]									
Inputs		**46 000**	**56 000**	**44 000**	**45 000**	**40 000**	**40 000**	**40 000**	**40 000**
Conventional harvest[b]	Forest Land	40 000	51 000	39 000	40 000	36 000	36 000	36 000	36 000
Forest conversion[b]	Cropland	1 200	470	500	530	520	510	530	530
	Wetlands	1.8	5.8	18	0	3.7	3.1	3.5	0
	Settlements	620	710	750	660	680	750	740	720
Residential firewood[c]	Forest Land	4 200	3 100	3 700	3 500	3 200	2 900	2 800	2 900
	Cropland	230	130	210	190	150	140	140	140
	Settlements	82	83	84	84	84	84	84	84
Exports		19 000	31 000	22 000	21 000	20 000	18 000	19 000	19 000
Net stocks[d]		330 000	520 000	600 000	600 000	610 000	610 000	620 000	620 000
EMISSIONS (kt CO_2)[a]		**130 000**	**150 000**	**140 000**	**140 000**	**130 000**	**140 000**	**130 000**	**130 000**
Domestic harvest		**88 000**	**75 000**	**72 000**	**76 000**	**68 000**	**74 000**	**71 000**	**71 000**
Solid wood – sawnwood		5 500	7 800	9 600	9 800	9 900	10 000	10 000	10 000
Solid wood – wood panels		2 700	3 300	4 100	4 200	4 300	4 400	4 400	4 500
Other solid wood products		920	1 900	2 200	2 200	2 200	2 200	2 200	2 300
Pulp and paper market		8 300	740	3 400	3 300	3 000	2 800	2 600	2 500
Residential firewood and industrial fuelwood		52 000	59 000	50 000	54 000	47 000	50 000	48 000	49 000
Mill residue[e]		19 000	1 700	2 600	1 800	1 200	5 200	2 900	2 900
Worldwide from Canadian harvest		**42 000**	**73 000**	**64 000**	**64 000**	**63 000**	**62 000**	**61 000**	**60 000**
Solid wood – sawnwood		9 900	16 000	19 000	19 000	19 000	20 000	20 000	20 000
Solid wood – wood panels		780	4 300	5 800	6 000	6 100	6 200	6 200	6 300
Other solid wood products		52	51	62	64	65	66	67	69
Pulp and paper market		31 000	51 000	37 000	36 000	35 000	34 000	33 000	32 000
Mill residue[e]		460	2 100	2 400	2 100	1 900	2 100	2 000	2 000

Notes:
NO = Not occurring
a. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.
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 CRF 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 CRF 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.

6.4.2. Methodological Issues

A country-specific model, 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 off-site from the point of forest harvest, forest conversion or firewood collection. 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).

In more concrete terms, the HWP model takes the C output from wood harvest, exports a portion as roundwood, converts all harvested wood into commodities, exports some of the commodities produced, and keeps track of the additions to and removals from in-use HWP and from bioenergy.

Inputs to the model (Table 6–7) include (i) the annual mass of C from conventional contemporary[12] 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 2.9% 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). The C input from historical harvests is derived from historical commodity production data from Statistics Canada at a national level of spatial resolution, covering the 1900–1989 period.

11 Canada's forest carbon reporting system: https://www.nrcan.gc.ca/climate-change-adapting-impacts-and-reducing-emissions/climate-change-impacts-forests/carbon-accounting/13087

12 Contemporary harvesting refers to harvest activities that occurred since 1990.

Data on annual volumes of residential firewood and industrial fuelwood are provided by the Energy sector. 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, 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 NFD,[13] 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 Annex 3.1 (data sources) and Annex 3.5.3.

The trend in emissions from HWP disposal was derived from historical commodity production data combined with information on the duration of the life cycle of various commodities (Table 6–7). The impact of any significant changes in harvesting levels or in the mix of products is therefore redistributed over several subsequent years and decades as commodities are gradually retired from use.

Activity data, annual estimates of C inputs, stock changes in the HWP pool and the resulting net emissions for each commodity are reported in CRF Table 4.G. In accordance with the Simple Decay Approach, the following assumptions were made in reporting HWP-related data in this table:

- column B (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 losses in CRF tables 4.A–4.F if using a reporting approach other than the Simple Decay Approach and are included in this table for completeness and transparency purposes
- column C (Losses): corresponds to C losses from the combustion of firewood and from the oxidation of milling waste, using decay equation 12.1 in Volume 4, Chapter 12, of the 2006 IPCC Guidelines, for HWP with longer half-lives
- column E (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 F (Net emissions/removals from HWP in use, CO_2): values reported in this column correspond to the CO_2 emissions associated with the C losses reported in column C; C gains reported in column B are not considered in the calculation of this column to avoid the double counting of removals, since emissions from the instant oxidation of harvested wood are not reported in CRF tables 4.A through 4.F

6.4.3. Uncertainties and Time-Series Consistency

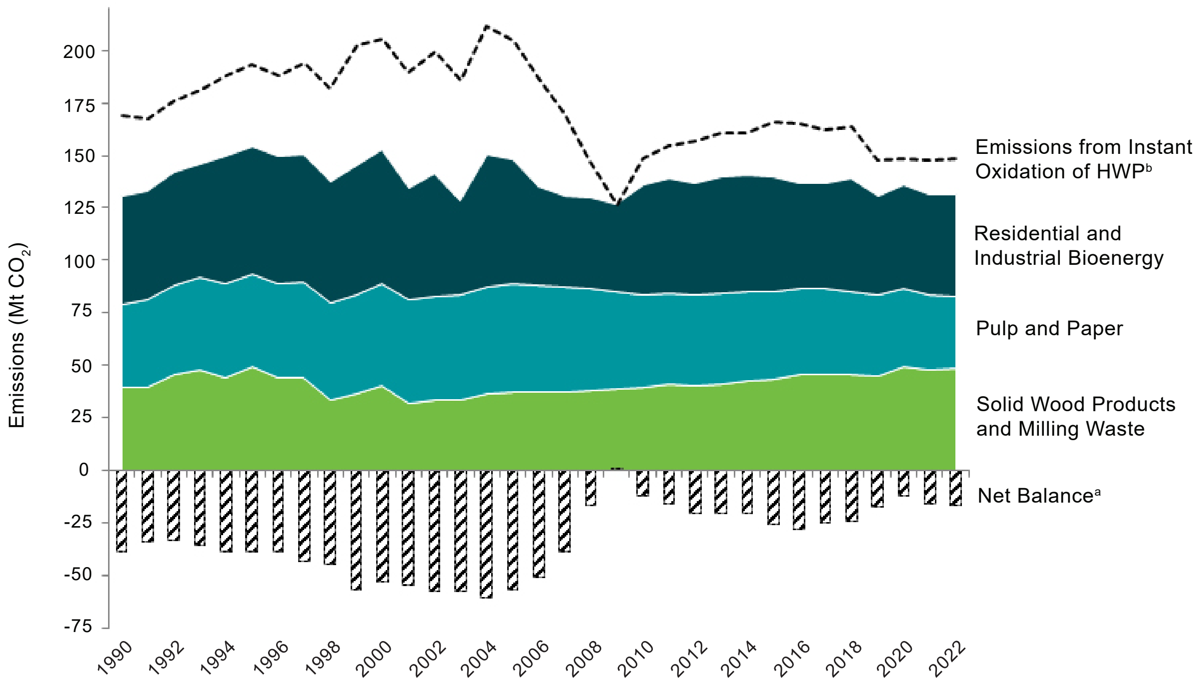
In the assessment of the uncertainty associated with the Harvested Wood Products category, model parameters are varied during Monte Carlo simulations. In addition, 100 HWP inputs are derived from the CBM-CFS3 (ecosystem) uncertainty analyses. These simulations are used to estimate the combined uncertainty 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. As no substantial changes were made to the HWP model Monte Carlo simulations were not performed (the most recent one was for the 2021 submission and covered the entire 1990–2019 time series). Instead, in the current submission, confidence intervals were extrapolated for each category. More details are provided in Annex 3.5.3.

6.4.4. Quality Assurance / Quality Control 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 CRF Reporter software.

13 National Forestry Database, available online at http://nfdp.ccfm.org/en/data/harvest.php.

Figure 6–8 **Emissions from the Harvested Wood Products Pool Using the Simple Decay Approach**



Notes:

a. The net balance is the difference between the C transferred to the HWP pool and emissions from the HWP, a value that cannot be reported in the CRF tables as they are currently structured.

b. This data series represents the carbon transferred annually from the forest and other land into the HWP C pool in units of CO_2, i.e., the emissions that would result from using an instant oxidation approach, and is presented for reference purposes only. It includes salvage logging after natural disturbances in forests.

Table 6–8 **Estimates of CO_2 Emissions from Harvested Wood Products, with 2.5th and 97.5th Percentiles, in Selected Years**

Inventory Year	Source of C inputs	Emissions (Mt CO_2)	2.5th Percentile (Mt)	% Uncertainty (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
1990	Forest conversion – since 1990	2.7	1.8	-34	3.2	20
	Residential firewood collection	16	16	-3.4	17	3.6
	Conventional harvest – since 1990	59	42	-28	70	19
	Historical harvest – before 1990	53	41	-24	67	25
2005	Forest conversion – since 1990	2.9	2.1	-29	3.4	15
	Residential firewood collection	12	11	-3.8	12	4.2
	Conventional harvest – since 1990	118	101	-14	129	9.8
	Historical harvest – before 1990	15	12	-24	20	33
2022	Forest conversion – since 1990	3.5	2.6	-26	3.8	8.3
	Residential firewood collection	11	11	-5.2	12	5.0
	Conventional harvest – since 1990	106	99	-6.9	111	4.8
	Historical harvest – before 1990	10	7.9	-23	12	12

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;[14] (ii) Updated HWP commodity conversion parameters; (iii) updated waste incineration activity data; and (iv) improved and updated deforestation data (see section 6.9.5).

The combined effect of these changes resulted in small downward recalculations in total emissions in this category of 0.01 Mt in 1990 and 0.1 Mt in 2005, and an upward recalculation of 4.0 Mt (+3.1%) in 2021.

6.4.6. Planned Improvements

Research is underway to develop more accurate residential biomass burning emission factors, and to improve our knowledge of industrial bioenergy and improve the characterization of the biomass feedstock used as fuel in the industry sector. Further research is in progress to improve the regional differentiation of HWP production and trade, so that the provincial/territorial summaries more accurately reflect regional conditions.

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 (CRF Category 4.B)

Cropland covers approximately 46 Mha of Canada's territory. In 2022, the net GHG balance in the Cropland category amounted to net emissions of 22 Mt (Table 6–1). For UNFCCC reporting purposes, the Cropland category is divided into Cropland Remaining Cropland (net emissions of 18 Mt in 2022) and Land (i.e. either forest or grassland) Converted to Cropland (net emissions of 3.6 Mt and 0.01Mt, respectively, in 2022). 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 (CRF Category 4.B.1)

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. 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).

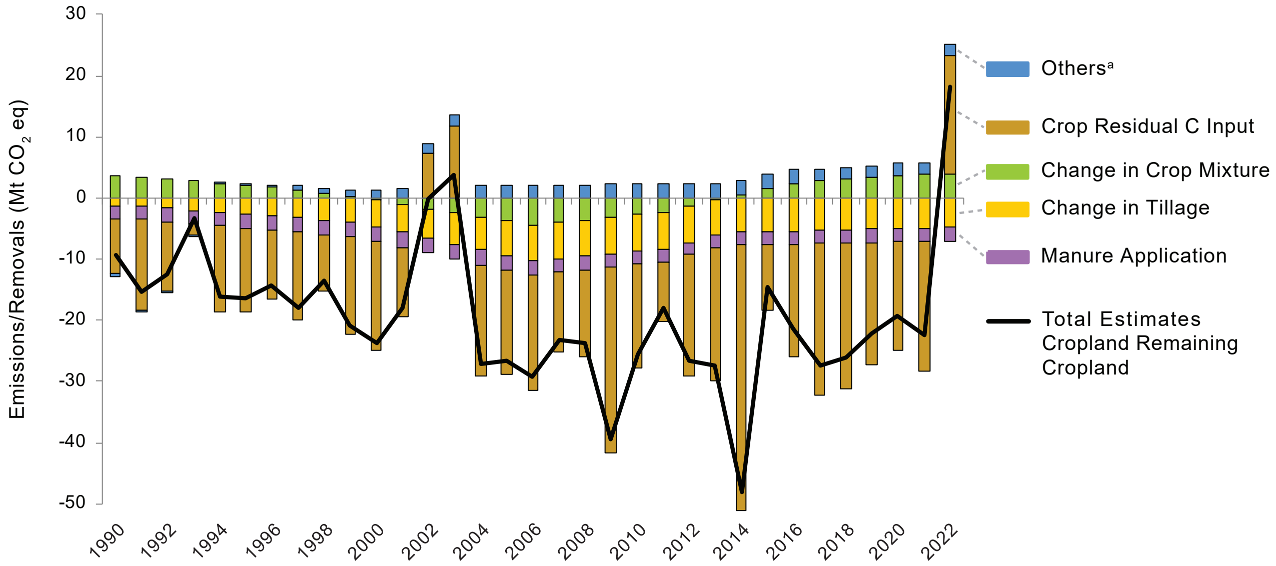
6.5.1.1. CO_2 Emissions from, and Removals by, Mineral Soils

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 9.4 Mt (Table 6–9). CO_2 removals by soil increased to 27 Mt in 2005. In 2022, Cropland soils exceptionally switched to emissions of 18 Mt due to a significant drought event in 2021. Since 1990, on average, the yields of major field crops increased by 25% for barley, 68% for canola, 53% for corn, 19% for soybean and 78% for spring wheat. However, crop yields fluctuated by year, impacting C inputs to soils from

14 FAOSTAT Forestry Production and Trade, available online at http://www.fao.org/faostat/en/#data/FO and FAOSTAT Forestry Trade Flows, available online at http://www.fao.org/faostat/en/#data/FT.

Figure 6–9 **Emissions and Removals Related to Cropland Remaining Cropland**



Note:

a. "Others" include emissions/removals associated with perennial woody crops and cultivation of histosols, and residual emissions from land conversion.

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)[a]							
		1990	2005	2017	2018	2019	2020	2021	2022
TOTAL CROPLAND REMAINING CROPLAND		**-9 400**	**-27 000**	**-27 000**	**-26 000**	**-22 000**	**-19 000**	**-22 000**	**18 000**
Cultivation of histosols		**300**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Perennial woody crops		**-1000**	**42**	**-190**	**-130**	**- 9**	**20**	**16**	**16**
Total mineral soils		**-8 700**	**-27 000**	**-28 000**	**-26 000**	**-22 000**	**-19 000**	**-23 000**	**18 000**
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	14 000	14 000	15 000	15 000	15 000	16 000
Tillage changes	Conventional to reduced	- 870	-1 000	-700	-680	-650	-630	-600	-590
	Conventional to no-till	-420	-3 700	-3 600	-3 600	-3 500	-3 500	-3 500	-3 400
	Other[b]	-0.5	-860	- 970	- 940	- 920	-900	-870	-850
Crop residue C input		-9 000	-17 000	-25 000	-24 000	-20 000	-18 000	-21 000	19 000
Manure application		-2 100	-2 500	-2 200	-2 200	-2 200	-2 200	-2 200	-2 100
Land conversion – residual emissions[c]		200	1 800	1 800	1 800	1 800	1 800	1 700	1 700

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.

crop residues, resulting in fluctuations in net removals of CO_2 by soils of 9 Mt in 1990, 17 Mt in 2005, and a net emission of 19 Mt in 2022. Interannual variability tends to be high throughout the time series, reflecting weather-related impacts to crop production (Figure 6–9).

Conservation tillage increased significantly, from 11 Mha in 1990 to 28 Mha in 2022, 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 4.9 Mt in 2022 (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 4.0 Mt in 2022.

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 2.0 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 decreased by roughly 8.6 Mt, 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.

Methodological Issues

According to the 2006 IPCC Guidelines, 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. A number of 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 in order to estimate nitrous oxide emissions from crop residues (Thiagarajan et al., 2018), as can data on carbon 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 carbon inputs multiplied by the estimated area of crop production. Soil C removals resulting from manure application were estimated using manure-induced carbon retention factors, using manure production rates consistent with the data developed for estimating emissions of nitrous oxide in Chapter 5. Calculations were performed at the scale of Soil Landscapes of Canada (SLC) polygons (see Annex 3.5.1). 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 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) is 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 both 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. Applications of manure on perennial cropping systems was considered to have no net impact on soil C due to a lack of empirical data for estimating a retention factor.

A more detailed description of the methodologies used for determining C factors and other key parameters can be found in Annex 3.5.4.1.

Uncertainties 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 in relation to 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 process and situational uncertainties can be found in Annex 3.5.4.1. 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.

Quality Assurance / Quality Control and Verification

Tier 1 QC checks implemented by AAFC specifically address estimate development in the Cropland Remaining Cropland subcategory. ECCC, 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 into the CRF Reporter software. In addition, activity data, methodologies and changes have been documented and archived in both 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 quality assurance assessment of its methods. Some limitations in the current system were found with respect to 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 as influenced by tillage 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 carbon retention represents the average fraction of C input from various manures that is retained in the soil. A country-specific method using manure-induced carbon 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 are capable of using 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 Annex 1 Parties, the IPCC Tier 2 Steady State approach 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 quality assurance 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 (summer of 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.

Recalculations

In this submission, recalculations occurred due to the reallocation of annual-perennial activity data based on improved spatial resolution of the 2021 Census of Agriculture, land-use coverage updates and revised crop yields. This change caused recalculations for the years 1990–2021.

Other less significant recalculations were due to other activity data updates on tillage practices, manure application, woody biomass and residual emissions.

The combined effect of these changes resulted in an downward adjustment in reductions of 0.8 Mt in 1990 and emissions of 0.02 Mt in 2005 and a significant downward recalculation of -1.4 Mt in net CO_2 removals in 2021.

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.

6.5.1.2. CO_2 Emissions from the Cultivation of Organic Soils

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).

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 5 Mg C ha^{-1} yr^{-1} (IPCC, 2006).

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 1990–2021) was 16 kha, or 0.03% of the cropland area. Nearly 90% of cultivated histosols are located in the Boreal Shield East, Mixedwood Plains and Boreal Plains reporting zones.

Uncertainties 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, 2006). The overall mean and uncertainties associated with this source of emissions were estimated to be 0.3 ± 0.09 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.

Quality Assurance / Quality Control and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies have been documented and archived in both paper and electronic form.

Recalculations

There were no recalculations in this source category.

Planned Improvements

No immediate plan is in place to improve emission estimates for this source.

6.5.1.3. CO_2 Emissions from and Removals by Woody Biomass

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 not reported as a biomass loss in the Cropland Remaining Cropland category in order to avoid the double counting of emissions with those from the combustion as firewood, which are reported under the Harvested Wood Products category. For more details, see section 6.4 and Annex 3.5.4.1.

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 taken into account 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 amounted to net removals of 1.0 Mt in 1990, and net emissions of 0.04 Mt in 2005 and 0.01 Mt in 2022. The emissions associated with woody biomass transferred to the HWP pool and used for residential bioenergy accounted for 0.8 Mt, 0.5 Mt and 0.5 Mt of the total firewood emissions reported under the Harvested Wood Products category in 1990, 2005 and 2022, respectively.

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 Annex 3.5.4.1.

Woody biomass in the Cropland category also includes perennial trees and shrubs in farmyards, shelterbelts and hedgerows. The method employed tracks the woody volume lost as a result of clearing and gained as a result of planting and annual growth through the use of earth observation-based monitoring and ecozone-specific growth parameters. More information on the assumptions and parameters involved can be found in Annex 3.5.4.1.

Uncertainties 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 was used for vineyards, fruit orchards and Christmas trees.

If a loss in the area of fruit trees, vineyards or Christmas trees occurs and this area is believed to have been converted to annual crops, a perennial to annual crop land conversion is also deemed to occur, with an associated uncertainty that contributes to the uncertainty surrounding the C change. For a gain in the area of fruit trees, vineyards or Christmas trees, the uncertainty associated with the annual C change was also assumed to be the default uncertainty 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. (2015b) 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. (2015b).

The same methodology was used for the entire time series of emission estimates.

Quality Assurance / Quality Control and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies have been documented and archived in both paper and electronic form.

Recalculations

Recalculations were due to improved spatial resolution of the 2021 Census of Agriculture and land use coverage updates resulting in changes to woody biomass from 1992 to 2021. The impacts on Cropland Remaining Cropland were minor and resulted in an upward recalculation of net emissions in 2005 by 4 kt and a reductions in 2021 by -65 kt.

Planned Improvements

Work has begun to explore new methodologies for improving 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 (CRF 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 9.7 Mt in 1990 to 3.6 Mt in 2022. Emissions in the Grassland Converted to Cropland subcategory are relatively small.

6.5.2.1. Forest Land Converted to Cropland (CRF Category 4.B.2.1)

The clearing of forest land for use as agricultural land is still an ongoing practice in Canada, accounting for 45% of forest area conversion in 2021. The cumulative area reported under the Forest Land Converted to Cropland subcategory in CRF Table 4.B amounted to 1300 kha during the 20 years prior to 1990 and 402 kha during the 20 years prior to 2022. 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 2022, immediate emissions from the conversion of forest to cropland totalled 1.5 Mt, while residual emissions from events that occurred in the last 20 years totalled 1.7 Mt.

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 the estimation of 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 Annex 3.5.4.3.

Methodological Issues – 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 Annex 3.5.4.3). 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 Annex 3.5.4.3). 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 Annex 3.5.4.3.

As in the case of direct N_2O emissions from agricultural soils (see Agriculture sector, Chapter 5), an IPCC Tier 2 method 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 is occurring, 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 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.

Uncertainties 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.

Using this estimation approach, uncertainty estimates were derived independently for the biomass and DOM pools and for soil organic matter. The uncertainty associated with the activity data (see section 6.9.3 for more details) was incorporated in all analyses.

Table 6–10 **Uncertainty Associated with the Components of CO_2 and Non-CO_2 Emissions from Forest Land Converted to Cropland for the 2022 Inventory Year**

Emission Components	Emissions (kt CO_2 eq)	Uncertainty (kt CO_2 eq)
Immediate CO_2 emissions	1 263	±393
Residual CO_2 emissions from the DOM pool[a]	1 798	±444
Residual CO_2 emissions from the soil pool	257	±159
CH_4 emissions	145	±73
N_2O emissions	64	±21

Note:
a. DOM = dead organic matter

The fate of biomass and DOM when forest conversion occurs and the ensuing emissions are modelled using the same framework as that used in the Forest Land category. Consequently, the corresponding uncertainty estimates were also developed under this framework, using the same Monte Carlo runs utilized 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 Annex 3.5.4.3.

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 Annex 3.5.4.3.

Quality Assurance / Quality Control and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines. 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 both paper and electronic form.

Recalculations

Recalculations that occurred in this subcategory are mainly the result of the refinement of activity data due to improved spatial resolution of the 2021 Census of Agriculture and land use coverage updates. Minor impacts occurred due to IPCC AR5 GWP values for N_2O and CH_4. Overall, this update resulted in upward adjustments to the emission estimates of 0.02 Mt in 1990 and 0.02 Mt in 2005, and 0.02 Mt in 2021.

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 (CRF Category 4.B.2.2)

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. According to the research by Bailey and Liang (2013) on the burning of managed grassland in Canada, C losses from above- or below-ground biomass or DOM upon conversion are insignificant. The authors reported that the average above-ground biomass was 1100 kg ha^{-1} in Brown Chernozem soils, and 1700 kg ha^{-1} in Dark Brown Chernozem soils. The above-ground biomass of the managed grassland would be lower than its respective yield under crop production (Liang et al., 2005). Total emissions from soils in 2022 amounted to 51 kt, down from 283 kt in 1990, including C losses and N_2O emissions from the conversion.

Methodological Issues

A number of 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 Annex 3.5.4.2).

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 from 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 Annex 3.5.4.2.

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 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 Annex 3.4.3).

Uncertainty 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 to be 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 40 ± 19 kt for the level uncertainty and -100 ± 45 kt for the trend uncertainty.

The same methodology and emission factors were used for the entire time series of emission estimates.

Quality Assurance / Quality Control and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies have been documented and archived in both paper and electronic form.

Recalculations

Recalculations that occurred in this subcategory were mainly the result of refinements to annual/perennial crop activity data to the 2021 Census of Agriculture and land use coverage updates. To a lesser extent there were recalculations due to IPCC AR5 GWP values.

These modifications resulted in an downward recalculation of removals by 16 kt in 1990 and 10 kt in 2005, and upward recalculation of 23 kt in 2021.

Planned Improvements

Canada plans to validate the modelled soil C change factors with measured and published soil C change factors for grassland conversion as these become available. More details are provided in Chapter 8, Table 8–5.

6.6. Grassland (CRF 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, based on the assumption 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 (CRF 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 CRF 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, taking into account 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. Uncertainties 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 the amount of 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. Quality Assurance / Quality Control and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines. The activity data and methodologies have been documented and archived in both paper and electronic form.

6.6.1.5. Recalculations

There were no recalculations in the emission estimates for this source category. Very small recalculations occurred, however, in the totals areas reported for some years as an indirect impact of the updates applied to Cropland areas and estimates (see section 6.5.1).

6.6.1.6. Planned Improvements

No immediate plan is in place to improve the emission estimates for this source.

6.7. Wetlands (CRF Category 4.D)

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. As such, wetlands cover about 14% of Canada's land mass (ECCC, 2016). The Canadian Wetland Classification System divides wetlands into five broad categories: bogs, fens, marshes, swamps and shallow water (National Wetlands Working Group, 1997).

However, for the purposes of this report and in accordance with the land categories defined in the 2006 IPCC Guidelines (2006), the Wetlands category is restricted here to wetlands that are not already in the Forest Land, Cropland or Grassland categories. There is no corresponding estimate of the area of these wetlands in Canada.

In accordance with the 2006 IPCC Guidelines (IPCC, 2006), two types of managed wetlands are considered in this inventory. These wetlands are defined as those in which human intervention has directly altered the level of the water table and consequently the dynamics of GHG emissions/removals: (i) peatlands drained for peat extraction and (ii) flooded land (i.e. for the creation of hydroelectric reservoirs). As the GHG dynamics and the general approaches used to estimate emissions and removals are naturally very different, these two types of managed wetlands are considered separately.

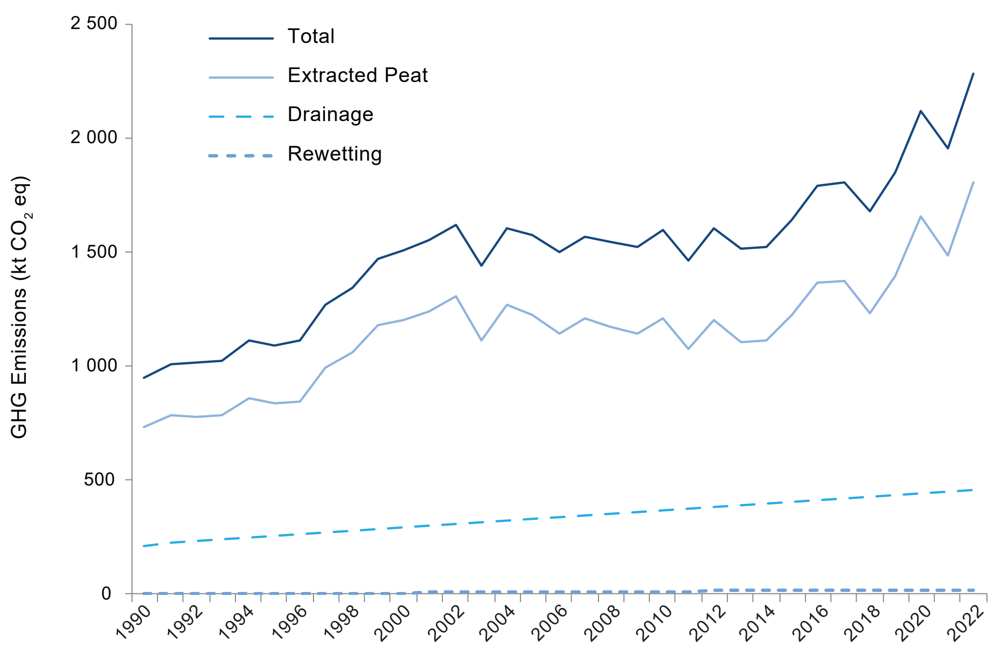
6.7.1. Peat Extraction (CRF Categories 4.D.1.1 and 4.D.2.1)

6.7.1.1. Source Category Description

Approximately 38 kha of the estimated 114 Mha of peatlands in Canada (NRCan, 2011) have been drained for peat extraction. Roughly 18 kha of these are currently being actively managed, while the other 20 kha are no longer under production. In the Canadian context, generally only bogs with a peat thickness of 2 m or more and an area of 50 ha or greater have commercial value for peat extraction (Keys, 1992). Peat production is concentrated in the provinces of New Brunswick, Quebec, Alberta and Manitoba. Canada produces peat for non-energy applications such as horticulture.

Emissions from peat extraction increased from 0.9 Mt in 1990 to 2.2 Mt in 2022 (Figure 6–10). The largest sources of emissions are peatland drainage and the decay of extracted peat. Trends in extracted peat are driven by both an expansion in the active peat production area from 13 kha in 1990 to 18 kha in 2013 and interannual variations in weather conditions, which impact peat drying and thus harvesting. Emissions from peatland drainage continue to grow as more peatland areas are drained and subsequently decommissioned, with an increasing proportion of these sites undergoing rehabilitation, rewetting and restoration.

Figure 6–10 **Emissions from Peatlands Converted and Managed for Peat Extraction**



6.7.1.2. Methodological Issues

Estimates were developed using a Tier 2 methodology, in accordance with the 2006 IPCC Guidelines (IPCC, 2006) and the 2013 IPCC Wetlands Supplement (IPCC, 2014). This approach is based on Canadian research on, and land management practices specific to, peat extraction in Canada. Emission estimates for drained and rewetted sites include on-site CO_2, CH_4 and N_2O emissions and off-site CO_2 emissions from water-borne C losses and from the decay of extracted peat. Domestic emission factors were derived from flux measurements reported in multiple research studies (see Annex 3.5.6.1). An earth-observation-based mapping approach was used to determine the extent of peatland areas converted for peat extraction in the 1990, 2007 and 2013 time periods and to identify the proportion of land-use types converted (forest land and other land). Converted areas were assigned to four land management subcategories based on image interpretation and industry information: actively mined, abandoned, rehabilitated and restored areas. National peat production statistics were used to estimate the annual amount of peat extracted (NRCan, 2020b). The extent of peat extraction areas is reported in CRF Table 4.D in the Land Converted to Peat Extraction subcategory for the first year after conversion and under the Peat Extraction Remaining Peat Extraction subcategory thereafter. The associated peat extraction emissions are reported in CRF Table 4(II) under the Peat Extraction Lands category. More information on the estimation methodology can be found in Annex 3.5.6.1.

6.7.1.3. Uncertainty and Time-Series Consistency

A formal uncertainty assessment has not yet been carried out for this category. The most important sources of uncertainty are the extent of converted areas estimated from mapping, emission factors for the various categories of decommissioned sites (e.g. rehabilitated and restored) and variations in the moisture content of extracted peat.

6.7.1.4. Quality Assurance / Quality Control 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. Industry and academic experts associated with the Canadian Sphagnum Peat Moss Association and Peatland Ecology Research Group carried out QC, validated the mapping estimates and reviewed the country-specific emission factors.

6.7.1.5. Recalculations

Recalculations in this category were due to updated peat production statistics in 2021, resulting in a downward recalculation of emissions of 0.1 Mt for that year.

6.7.1.6. Planned Improvements

Planned improvements include the addition of a new mapping sampling point for 2020 for high-resolution satellite imagery and remote sensing classification to update the area of peat extraction sites undergoing exploitation, restoration and abandonment.

Refinements to the approach for estimating emissions and removals from non-decommissioned peat extraction sites are being considered. However, this will depend on the availability of monitoring data to determine the status of naturally regenerating sites and the success rate of rehabilitation, rewetting and restoration activities. Advances in Canadian research combined with the increased post-extraction monitoring of sites will inform further improvements.

An uncertainty assessment is planned for future submissions.

More details are provided in Chapter 8, Table 8–5.

6.7.2. Flooded Land (CRF Categories 4.D.1.2 and 4.D.2.2)

6.7.2.1. Source Category Description

This category includes, in theory, all lands that have been flooded regardless of purpose. Owing to methodological limitations, only large hydroelectric reservoirs created by land flooding were included. Existing water bodies dammed for water control or energy generation were not considered if flooding was minimal (e.g. Manitoba's Lake Winnipeg, the Great Lakes).

Since 1970, this type of conversion has occurred mainly in reporting zones 4, 5, 8, and 14 (i.e. Taiga Shield East, Boreal Shield East, Hudson Plains and Montane Cordillera). The total land area flooded for 10 years or less fluctuated throughout the time series, from 960 kha in 1993 to 37 kha in 2005. In 2022, 46% of the 44 kha of reservoirs flooded for 10 years or less consisted of previously forested land (mostly unmanaged forests). Total emissions from reservoirs declined from 4.5 Mt in 1990 to 1.1 Mt in 2022.

6.7.2.2. Methodological Issues

Two concurrent methodologies were used to estimate GHG fluxes from flooded lands—one for forest clearing and the other for flooding. When there was evidence of forest biomass removal prior to flooding, the corresponding C stock changes in all non-flooded C pools were estimated in the same way as for all forest conversion events, using the CBM-CFS3 model (see section 6.9 and Annex 3.5.2.10). Emissions from the burning of non-flooded DOM are reported in CRF Table 4(V) in the Land Converted to Wetlands subcategory. Emissions from the decay of the remaining on-site residues are reported in CRF Table 4.D in the Land Converted to Flooded Land subcategory, for the first 10 years after land clearing, and in the Flooded Land Remaining Flooded Land subcategory beyond this period. The construction of large reservoirs in northern Quebec—the Toulnustouc, Eastmain 1 and Peribonka reservoirs, which were flooded in 2005, 2006 and 2008, respectively— involved this type of forest clearing prior to flooding. Note that emissions from forest clearing in the general area surrounding future reservoirs (e.g. for infrastructure development) are reported in the Forest Land Converted to Settlements subcategory.

The second methodology is used to estimate CO_2 emissions from the surface of reservoirs where flooding has been completed. The default approach for estimating emissions from land flooding assumes that all biomass C is emitted immediately (IPCC, 2006). In the Canadian context, this approach would overestimate emissions from reservoir creation, since most submerged

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vegetation, when present, does not decay for an extended period. A country-specific approach was developed and used to estimate emissions from reservoirs based on measurements of CO_2 fluxes above reservoir surfaces from multiple research studies (see Annex 3.5.6.2), consistent with the descriptions of the IPCC Tier 2 methodology (IPCC, 2006) and following the guidance in Appendix 2 of the 2006 IPCC Guidelines (IPCC, 2006). Annex 3.5.6.2 of this NIR contains more detail on this estimation methodology. The assessment includes CO_2 emissions only. Emissions from the surface of flooded lands are reported in CRF Table 4.D in the Land Converted to Flooded Land subcategory for a period of 10 years after flooding, in an attempt to minimize the potential double counting of dissolved organic carbon (DOC) lost from the watershed and subsequently emitted from reservoirs. Therefore, only CO_2 emissions are calculated for hydroelectric reservoirs that were completely flooded between 1981 and 2021.

For each reservoir, the proportion of pre-flooding area that was forest is used to apportion the resulting emissions to the Forest Land Converted to Flooded Land and Other Land Converted to Flooded Land subcategories.

It is important to note that fluctuations in the area of Land Converted to Flooded Land category reported in the CRF tables are not indicative of changes in current conversion rates, but rather reflect the difference between land areas recently flooded (less than 10 years before the inventory year) and older reservoirs (10 years or more before the inventory year), whose areas are transferred out of the inventory. The reporting system does not take account of all reservoir areas in Canada.

6.7.2.3. Uncertainties and Time-Series Consistency

For the Forest Land Converted to Flooded Land subcategory, see section 6.9, Forest Conversion. Annex 3.5.6.2 discusses the uncertainty associated with the Tier 2 estimation methodology.

Owing to current limitations in the LULUCF estimation methodologies, it is not possible to fully monitor the fate of DOC and ensure that it is accounted for under the appropriate land category. However, potential double counting in the Wetlands category is limited to watersheds containing managed lands, which would exclude several large reservoirs in the Taiga Shield East and Boreal Shield East reporting zones. Much of the DOC in these zones originates from unmanaged lands and is not subject to reporting.

6.7.2.4. Quality Assurance / Quality Control 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. For the Forest Land Converted to Flooded Land subcategory, also refer to the corresponding subheading in section 6.9, Forest Conversion.

Canada's approach to estimating emissions from forest flooding better reflects the land flooding processes over time than the default approach (IPCC, 2006), which assumes that all biomass C in flooded forests is immediately emitted. Canada's method is more refined in that it distinguishes forest clearing from flooding—emissions from the former are estimated in the same way as for all forest clearing activities associated with land-use changes. In addition, in Canada's approach, emissions from the surface of reservoirs are derived from measurements, rather than from an assumption (the immediate decay of all submerged biomass), which has not been verified.

6.7.2.5. Recalculations

Recalculations occurred due to the addition of the White River project in Ontario and updates to deforestation rates with new mapping (see sections 6.3.1.5 and 6.9.5 for more details). The combined impact of these changes caused an upward adjustment of emissions of 0.01 Mt in 2005 and of 0.1 Mt in 2021.

6.7.2.6. Planned Improvements

Further refinements to estimates CO_2 emissions from the surface of reservoirs will partly depend on the ability to quantify lateral transfers of DOC from watersheds to reservoir systems. The monitoring of DOC as it travels through the landscape to the point of emission or long-term storage is beyond current scientific capabilities and will require long-term investments in research. Efforts to ensure that activity data are updated and validated will continue on an ongoing basis.

Continuous improvements will focus on the development of knowledge, updated activity data, parameters and emission factors to estimate CH_4 emissions from flooded lands.

More details are provided in Chapter 8, Table 8–5.

6.8. Settlements (CRF Category 4.E)

The Settlements category is very 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 the extraction of resources other than timber (e.g. oil and gas, mining).

For the purpose of this inventory, the Settlements category is divided into the Settlements Remaining Settlements (urban trees) and Land Converted to Settlements subcategories. Estimates involve two types of land conversion: the conversion of forest land to settlements, which is reported in the Forest Land Converted to Settlements subcategory, and the conversion of non-forest land in the Canadian North, which is reported in the Grassland Converted to Settlements subcategory. In 2022, the 0.59 Mha of land in the Land Converted to Settlements subcategory accounted for emissions of 6.7 Mt.

6.8.1. Settlements Remaining Settlements (CRF Category 4.E.1)

6.8.1.1. Sink Category Description

This category includes estimates of C sequestration by urban trees in Canada. 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, amounting to around 4.4 Mt, on average. Estimates are reported for nine of the southernmost reporting zones, where major urban centres are situated. The largest removals in 2022 were in the Mixedwood Plains (1.6 Mt) and Pacific Maritime (1.5 Mt) reporting zones, which together accounted for 70% of total removals.

Emissions 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.

6.8.1.2. Methodological Issues

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 A6.5-8) 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 Annex 3.5.7.1.

6.8.1.3. Uncertainty and Time-Series Consistency

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. Annex 3.5.7.1 provides more information.

The same methodology and coefficients were used for the entire time series of emission estimates.

6.8.1.4. Quality Assurance / Quality Control 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.

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 (R^2) 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 on the basis of urban area, were within 2%.

6.8.1.5. Recalculations

There were no recalculations in this sink category.

6.8.1.6. Planned Improvements

Work will continue on updating the methodology, activity data estimates, and the coefficients used to estimate gross and net removals. Updates are planned for the 2005, 2015 and 2020 activity data, involving the sampling of digital aerial photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas around these years.

More details are provided in Chapter 8, Table 8–5.

6.8.2. Land Converted to Settlements (CRF Category 4.E.2)

In 2022, emissions in the Land Converted to Settlements subcategory totalled 6.7 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 were invested in quantifying the areas converted from forest to settlements, as this has been the leading forest conversion type since 2000. On average, during the 1990–2022 period, a total of 26 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 100% of emissions reported in this category. A consistent methodology was developed for all forest conversion and is outlined in section 6.9 and Annex A3.5.2.10.

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 as well as land conversion in the agricultural regions of Canada reported under the Cropland Converted to Settlements subcategory.

6.8.2.1. Cropland Converted to Settlements (CRF Category 4.E.2.2)

6.8.2.1.1. Source 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, during the 1990–2000 and 2000–2010 periods, 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. (2015a) using the methods described in Annex 3.5.7.2. 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. Uncertainties 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. (2015a) on the accuracy of each individual land-use map.

6.8.2.1.4. Quality Assurance / Quality Control 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.[15] 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.

15 Landsat Time Enabled Imagery – Canada: https://hub.arcgis.com/maps/9a239fbe2952436a80d3cff95cab34bc/about

6.8.2.1.5. Recalculations

No recalculations occurred in this source category.

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 (CRF Category 4.E.2.3)

6.8.2.2.1. Source Category Description

Resource development is the dominant driver of land-use change in Canada's Arctic and sub-Arctic regions. In 2022, the conversion of grassland to settlements in the Canadian North accounted for emissions of 19 kt, down from 48 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 and 2010, as described in Annex 3.5.7.2.

Biomass factors were based on field sampling and cross-checked with values in the literature for the Canadian North (Annex 3.5.7.2).

Emission estimates are limited to C stock changes in pre-conversion above-ground biomass. In spite of extensive fieldwork and comparison with the existing relevant literature, the estimation of actual or average biomass density over such a large area is challenging and remains fraught with uncertainty.

6.8.2.2.3. Uncertainties and Time-Series Consistency

An error propagation approach described in Annex 3.5.7.3 was used to estimate uncertainty for this category. The uncertainty estimate for this category ranges between 78% and 87% for the different reporting zones due to the difficulty in collecting ground data to estimate above-ground biomass and the variability of vegetation and climate conditions over this vast area.

6.8.2.2.4. Quality Assurance / Quality Control 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.

6.8.2.2.5. Recalculations

There were no recalculations in this source category.

6.8.2.2.6. Planned Improvements

Future efforts to improve estimates in this category will focus on gathering activity data for 2020 and compiling Canadian science to estimate emissions from the soil pool as well as improving estimates of pre-conversion above-ground biomass by adjusting the biomass factors used for each reporting zone with image-based vegetation indices and more ground data.

More details are provided in Chapter 8, Table 8–5.

6.9. Forest Conversion

6.9.1. Source 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 2022, the conversion of forest land to cropland, wetlands (peat extraction, and flooded lands [namely reservoirs]) and settlements resulted in total immediate and residual emissions of 13 Mt, down from 18 Mt in 1990. This decline includes a 4.3-Mt decrease in immediate and residual emissions from forest conversion to cropland and a 1.8-Mt decrease in emissions from forest conversion to wetlands (reservoirs). There was also an increase of 0.6 Mt in immediate and residual emissions from forest conversion to settlements. Note that the above values include residual emissions more than 20 years after conversion (10 years for reservoirs and one year for peat extraction) that are reported under the "land remaining" categories (e.g. Cropland Remaining Cropland and Wetlands Remaining Wetlands categories). Additional emissions associated with this source include those resulting from the use and disposal of HWP manufactured from wood from forest conversion activities since 1990, which are included in the estimates of CO_2 reported in CRF Table 4.G and which amounted to 3.3 Mt in 2022, up from 2.6 Mt in 1990 (see section 6.4 for more details).

Care should be taken in distinguishing annual forest conversion rates (64 kha in 1990 and 49 kha in 2022) from the total area of forest land converted to other land uses as reported in the CRF tables for each inventory year. The values in the CRF tables encompass all forest land conversion for 20 years, including the current inventory year (10 years for reservoirs and one year for peat extraction), 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 only a fraction of the total emissions produced from current and previous forest conversion activities reported in any inventory year. In 2022, immediate emissions (2.8 Mt) represented only 22% of the total reported land emissions due to forest conversion events; the balance is accounted for by residual emissions due to current and prior events. Decay rates for DOM are such that residual emissions continue beyond 20 years (10 years for reservoirs and one year for peat extraction), after which they are reported as part of the C stock changes in the Cropland Remaining Cropland and Wetlands Remaining Wetlands categories.

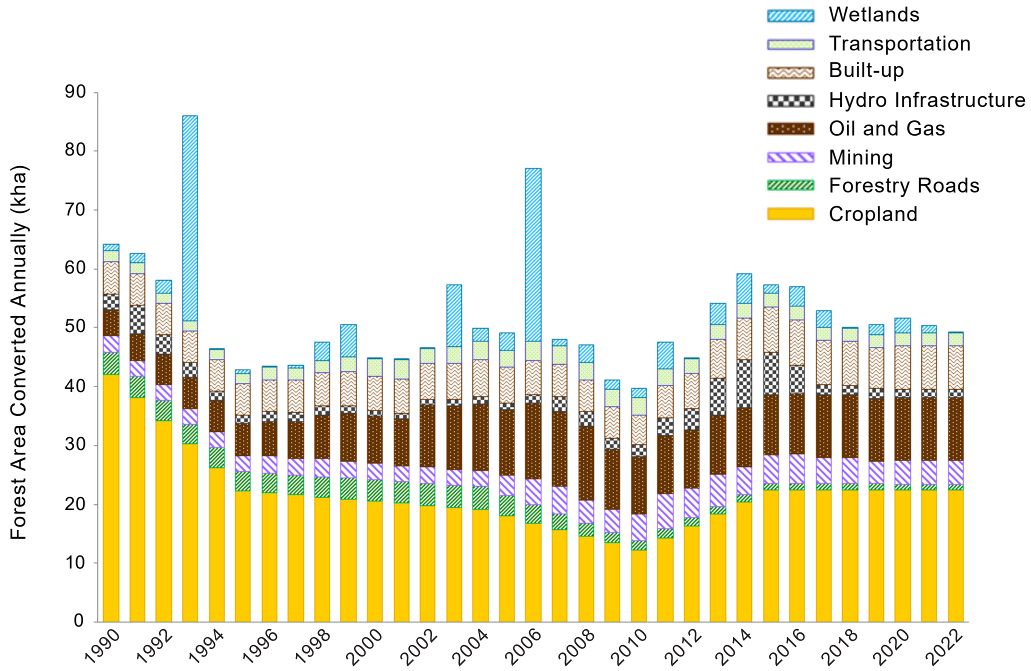
The primary drivers of forest conversion are agricultural expansion and resource extraction, accounting for 42% and 29%, respectively, of the cumulative area of forest conversion since 1990. Annual rates of forest conversion to cropland show a steady decrease over the 1990–2010 period. Since 2010, however, annual rates have increased to around 22 kha—reaching the levels observed in mid-1990s—due to a recent agricultural expansion, mostly in the Boreal Plains, Sub-humid Prairies and Mixedwood Plains zones (Figure 6–11). While this trend has been maintained constant since 2016, completion of the next mapping period will identify if this trend is continuing.

In contrast, annual rates of conversion of forest land to settlements for a range of end uses, including forestry roads, mining, oil and gas, hydro infrastructure, transportation and built-up lands, increased from 21 kha in 1990 to peaks of 31 kha in 2007 and 34 kha in 2014 and then dropped to 27 kha in 2022 (Figure 6–11). Since 2000, the conversion of land to settlements has become the main driver of forest conversion, accounting on average for 58% of the total area converted annually, except for the years 2003, 2006, and 2014 when large areas of forest were cleared for major hydroelectric development projects (Figure 6–11). This trend reflects 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 27% of the total forest area lost nationally in 2022.

The occasional impoundment of large reservoirs (e.g. La Forge 1 in 1993 and Eastmain 1 in 2006) may also convert extensive forest areas to wetlands (Figure 6–11). However, because much of the pre-conversion C stocks are flooded, 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 6–11 **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 in order 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 and 2018, defining time periods as 1975–1990, 1990–2000, 2000–2008, 2008–2013 and 2013–2018. 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 Annex 3.5.2.10.

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 Annex 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. Annex 3.5.2.1 summarizes the estimation procedures.

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6.9.3. Uncertainties 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 34 kha and 64 kha in 2021. Care should be taken not to apply the 30% range to the cumulative area reported in the CRF tables for forest land converted to another land category over the last 20 years (10 years for reservoirs). Annex 3.5.2.10 describes the main sources of uncertainty associated with the area estimates derived from remote sensing.

6.9.4. Quality Assurance / Quality Control and Verification

General QA/QC procedures are implemented in this category as outlined in section 1.3 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 Annex 3.5.2.10.

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 CRF Reporter software.

6.9.5. Recalculations

Updates to mapping caused minor changes in deforestation rates. Other changes were applied due to the addition of forest-cleared and flooded area for the major hydro-related event White River, in Ontario. These changes resulted in recalculations to forest conversion estimates of 0.2 Mt (+0.8%) and 0.6 Mt (+3.7%) in 1990 and 2005 respectively, and an upward adjustment of 0.5 Mt (+3.4%) in 2021, for immediate and residual emissions.

These changes had an indirect impact on the associated HWP pool emissions causing a downward adjustment of 0.1 Mt (4.8%) in 2005, and 0.2 Mt (+7.1%) in 2021.

More details can be found in section 6.3.1.5.

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.

CHAPTER 7

WASTE (CRF SECTOR 5)

7.1. Overview

The Waste sector in Canada includes emissions from the treatment and disposal of wastes, including Solid Waste Disposal (Landfills), Composting and Biological Treatment of Solid Waste, Incineration and Open Burning of Waste, and Wastewater Treatment and Discharge.

7.1.1. Emissions Summary

Sources and gases from the Waste sector include methane (CH_4) from Solid Waste Disposal (Landfills) and Industrial Wood Waste 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 2022, greenhouse gas (GHG) emissions from the Waste sector accounted for 23.4 Mt of total national emissions, compared with 21.3 Mt for 1990—an increase of 2.0 Mt or 10% (Table 7–1). The emissions from this sector represented 3.5% and 3.3% of total Canadian GHG emissions in 1990 and 2022, respectively.

The chief contributor to the Waste sector emissions was Solid Waste Disposal (Landfills) which, in 2022, accounted for 19.5 Mt CO_2 eq or 83% of the Waste sector emissions (Table 7–1).

When the waste treated or disposed of is derived from biomass, CO_2 emissions attributable to such waste are reported in the inventory as a memo item. CO_2 emissions of biogenic origin are not reported if they are reported elsewhere in the inventory or if the corresponding CO_2 uptake is not reported in the inventory (e.g., annual crops). In this latter case, emissions are not included in the inventory emission totals, since the absorption of CO_2 by the harvested vegetation is not estimated and thus the inclusion of these emissions in the Waste sector would result in an imbalance. Also, CO_2 emissions from wood and wood products are reported in the Land Use, Land-use Change and Forestry (LULUCF) sector. In contrast, CH_4 emissions from anaerobic decomposition of wastes are included in the inventory totals as part of the Waste sector.

Table 7–1 **Waste Sector GHG Emissions Summary, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)						
	1990	2005	2018	2019	2020	2021	2022
Waste	**21.3**	**24.2**	**23.4**	**23.5**	**23.0**	**23.1**	**23.4**
Solid Waste Disposal (Landfills)	18.1	20.4	19.5	19.6	19.1	19.2	19.5
Industrial Wood Waste Landfills	1.0	1.1	0.8	0.8	0.8	0.8	0.8
Biological Treatment of Solid Waste	0.1	0.2	0.4	0.4	0.4	0.5	0.5
Incineration and Open Burning of Waste	0.3	0.3	0.2	0.2	0.2	0.1	0.2
Wastewater Treatment and Discharge	1.9	2.2	2.6	2.5	2.5	2.5	2.5

Note: Totals may not add up due to rounding.

The majority of changes relative to previous inventory submissions are from recalculations and updates to activity data (Table 7–2). Detailed descriptions of the recalculations and activity data updates are provided in the recalculation section for each source in this chapter and in Chapter 8.

Table 7–2 **Summary of Recalculations in the Waste Sector for Selected Years (Mt CO_2 eq)**

Sector	1990	2000	2005	2010	2018	2019	2020	2021
Solid Waste Disposal (Landfills)								
2023 Submission (Previous Year)	16.14	17.92	18.21	16.52	17.27	17.16	17.14	17.24
2024 Submission (Current Year)	18.07	20.07	20.36	18.44	19.49	19.61	19.11	19.18
Recalculation								
GWP Recalculation	1.94	2.15	2.18	1.98	2.09	2.10	2.05	2.06
Activity Data and Method Change Recalculations	0.00	0.00	-0.03	-0.05	0.13	0.35	-0.08	-0.11
Total Recalculation	1.94	2.15	2.16	1.92	2.22	2.45	1.96	1.94
Industrial Wood Waste Landfills								
2023 Submission (Previous Year)	0.89	1.00	0.97	0.89	0.75	0.73	0.71	0.70
2024 Submission (Current Year)	1.00	1.11	1.08	1.00	0.84	0.82	0.80	0.78
Recalculation								
GWP Recalculation	0.11	0.12	0.12	0.11	0.09	0.09	0.09	0.08
Activity Data and Method Change Recalculations	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Recalculation	0.11	0.12	0.12	0.11	0.09	0.09	0.09	0.08
Biological Treatment of Solid Waste								
2023 Submission (Previous Year)	0.07	0.20	0.24	0.27	0.36	0.36	0.36	0.36
2024 Submission (Current Year)	0.08	0.21	0.24	0.27	0.38	0.38	0.39	0.48
Recalculation								
GWP Recalculation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Activity Data and Method Change Recalculations	0.01	0.01	0.00	0.01	0.02	0.02	0.03	0.12
Total Recalculation	0.01	0.01	0.00	0.01	0.02	0.02	0.03	0.12
Incineration and Open Burning of Waste								
2023 Submission (Previous Year)	0.26	0.33	0.35	0.31	0.18	0.18	0.16	0.15
2024 Submission (Current Year)	0.26	0.35	0.34	0.30	0.17	0.17	0.15	0.14
Recalculation								
GWP Recalculation	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Activity Data and Method Change Recalculations	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.00
Total Recalculation	0.00	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Wastewater Treatment and Discharge								
2023 Submission (Previous Year)	1.57	1.87	1.91	2.08	2.77	2.68	2.67	2.61
2024 Submission (Current Year)	1.90	2.15	2.22	2.33	2.58	2.54	2.52	2.52
Recalculation								
GWP Recalculation	0.03	0.01	0.01	0.01	-0.02	-0.03	-0.04	-0.04
Activity Data and Method Change Recalculations	0.30	0.28	0.29	0.24	-0.17	-0.11	-0.11	-0.05
Total Recalculation	0.34	0.29	0.30	0.25	-0.19	-0.14	-0.15	-0.09

Note: Totals may not add up due to rounding.

7.2. Solid Waste Disposal (Landfills) (CRF Category 5.A)

7.2.1. Source Category Description

The Solid Waste Disposal (Landfills) category provides a quantification of CH_4 emissions resulting from the decay of waste deposited in municipal landfills. Municipal solid waste (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 sewage sludge.

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, they are reported as a separate category (section 7.3).

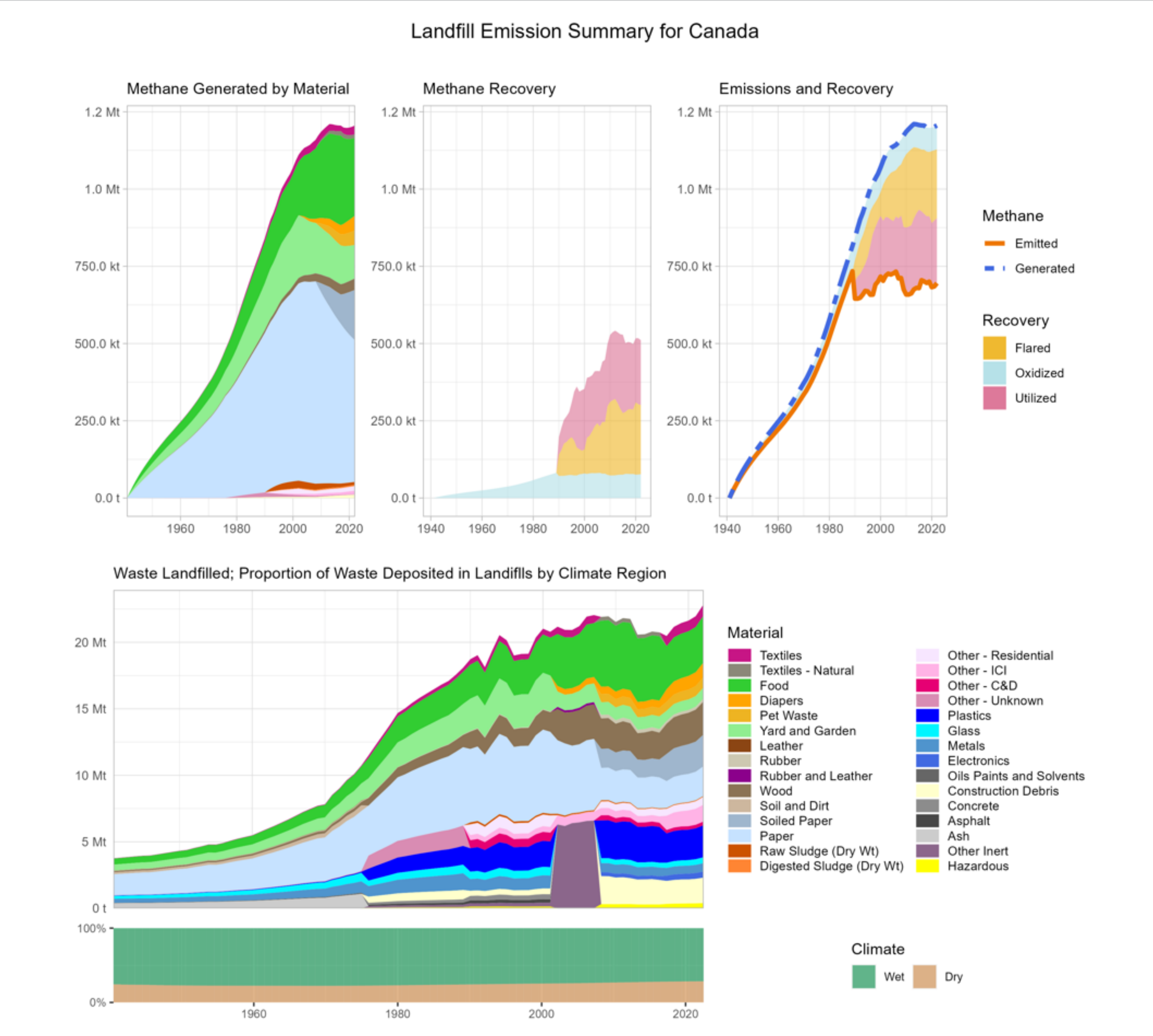
In Canada, most waste disposal occurs in managed municipal landfills. Few, if any, unmanaged waste disposal sites exist in Canada. The disposal of MSW is regulated by provinces and territories but is typically managed by municipal or regional authorities. While regulations vary across the country, common regulatory requirements include landfill gas capture and landfill covers. 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.

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 this sector. Emissions of N_2O are considered negligible.

MSW disposal is the dominant contributor of emissions from the Waste sector. This category accounts for approximately 83% of the Waste sector emissions (Table 7–1).

The primary factors influencing emissions from MSW landfills over time 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, from less than 5 Mt of waste landfilled per year before 1960, increasing to approximately 20 Mt/year in 1990, and remaining relatively stable since the early 2000s at approximately 25 Mt/year. Methane recovery has increased since the early 1990s, with 125 kt CH_4 recovered (flared and utilized) in 1990, increasing to approximately 330 kt CH_4 recovered in 2005, and holding steady 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 (e.g., a decreased proportion of paper waste over time), influencing the overall methane generation potential and decay rates (Figure 7–1).

Figure 7–1 **Waste Landfilled, Methane Generated (by Source Material), Recovered and Emitted**



7.2.2. Methodological Issues

Waste disposal 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 Solid Waste Disposal and Industrial Wood Waste Landfills (discussed in section 7.3.2).

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 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. One of the most important factors is the composition of the waste entering the landfill. As consumer habits and waste management practices change over time, so do the types of waste disposed of in MSW landfills. Another important factor influencing the production of CH_4 emissions within a landfill is moisture content. Moisture is considered to be a limiting factor in CH_4 generation. It is assumed that it is the major factor affecting moisture content within the landfill, and it is captured by climate region (wet or dry). While there are several other factors affecting CH_4 generation in landfills, such as pH and nutrient availability, they are not represented in the model.

Not all CH_4 generated within a landfill will be released into the atmosphere. To determine the amount of CH_4 released, the amount captured through landfill gas capture technology and the proportion of CH_4 oxidized in landfill covers are accounted for. 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 is 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. Uncertainties and Time Series Consistency

The level of uncertainty associated with CH_4 emissions from Solid Waste Disposal was estimated to be ±76% for CH_4 based on defaults available in the IPCC 2006 Guidelines (IPCC, 2006).

7.2.4. QA/QC and Verification

The annual quality control process consisted in verifying that all activity data and methodological updates had 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 had been incorporated correctly. Inter-annual emissions were compared to identify any unexpected changes in emissions at the regional and national level. Standard quality assurance checks were run, 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

Refinements were made for waste disposal tonnages, export and incineration data, and methane recovery data. The updated disposal data (disposal from Statistics Canada (Statistics Canada, n.d. [c]), export and incineration compiled by ECCC) replaces previously extrapolated values. New landfill gas recovery data was acquired from a voluntary survey of landfill operators. The survey included a full-timeseries data-validation with landfill operators. These have led to some recalculations in landfill gas collection estimates.

7.2.6. Planned Improvements

Opportunities for more refined data on amounts and types of waste landfilled in provinces 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.

7.3. Industrial Wood Waste Landfills (Included in CRF Category 5.A.1)

7.3.1. Source Category Description

Industrial Wood Waste Landfills are privately owned and operated by forest industries, such as sawmills and pulp and paper mills. These industries use landfills 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., saw mills) and the pulp and paper industry (e.g., paper manufacturing). Some industries have shown increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes. In recent years, residual wood previously regarded as waste is now 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 are reported as unmanaged landfills in the CRF. Industrial wood waste disposal accounts for 4.7% (1.0 Mt CO_2 eq) of the emissions from waste in 1990, 4.5% (1.1 Mt) in 2005, and 3.4% (0.8 Mt) in 2022.

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. However, 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 LFG recovery (flaring or use for energy) occurs at wood waste landfills.

7.3.3. Recalculations

No recalculations occurred for this subcategory for the current year.

7.3.4. Uncertainties 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.

7.3.5. 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 (CRF Category 5.B)

7.4.1. Source Category Description

This source category includes emissions from composting and anaerobic digestion at biogas facilities. 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 to be of biogenic origin and accounted for under the Agriculture, Forestry and Other Land Use (AFOLU) sector (IPCC, 2006).

In 2022, the Biological Treatment of Solid Waste category contributed 475 kt of CO_2 eq or 2.2% of total emissions to the Waste sector and 0.07% to Canada's total. Emissions were 394 kt (476.5%) above the 1990 levels of 81 kt.

7

7.4.2. Methodological Issues

The estimation of CH_4 and N_2O emissions from the biological treatment of waste in Canada 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 Environment and Climate Change Canada. 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).

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 the data gaps throughout the time series, the earliest available data point was carried back to 1990 for facilities that were known to be operating at that time. Otherwise, the last available data point is carried forward to the next available data point through time. 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 also carried forward until the next available data point for the facility. For additional quality assurance, composting and anaerobic digestion activity data totals were compared against Statistics Canada's Waste Management Industry Survey: Business and Government Sectors (Statistics Canada, n.d.[b]). The Statistics Canada data set includes waste diverted as a single tonnage to both composting and anaerobic digestion. For the 2021 reporting period, new survey data were made available. To ensure that facilities identified as active were captured within the emissions estimates the previously collected survey data were carried forward for the case where the facility did not provide information as a part of the 2021 reporting period. Further work will be conducted for the next inventory to verify the operational status of these facilities.

7.4.3. Uncertainties 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 range is from a high of ±176% down to ±99% for CH_4 and ±136% down 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 through primary literature and compiled in an in-house literature review. Activity data uncertainty was not calculated, given that it is based on direct facility data.

7.4.4. QA/QC and Verification

The quality control process for the Biological Treatment of Solid Waste category consisted of verifying all aspects of the emission estimate calculations, including:

- downloaded and manually inputted activity data
- calculations to carry forward or backward activity data to bridge data gaps in the time series
- inputted emission factors
- unit conversions and emission calculations

The final activity data and emission trends were plotted to identify any outliers. The recalculated emission estimates were also compared with the previous inventory's estimates to ensure that the changes in emission levels made sense.

7.4.5. Recalculations

No recalculations occurred for this subcategory.

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 (CRF Category 5.C)

7.5.1. Source Category Description

This category includes emissions from the incineration of waste. There are 31 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 are assumed to be negligible, representing less than the reporting threshold of 500 kt CO_2 eq and 0.05% of national GHG total emissions.

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 Environment and Climate Change Canada (ECCC, 2020c), 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 is 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 159kt CO_2 eq (0.68%) of total emissions to the Waste sector or 0.02% of Canada's total emissions in 2022. Emissions from this category are 39% below the 1990 level of 260 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 Environment and Climate Change Canada on an annual basis through the Greenhouse Gas Reporting Program (GHGRP). These publicly available data represent a significant portion of emissions from this sector.

In-house 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. Please see Annex 3.6 for details. In-house estimates are also derived for 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 in-house 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 facilities specific incineration technology. IPCC default factors were used, except for hazardous waste, for which emission factors were derived from site-specific data provided by a facility, which were deemed 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, which recommends using MSW emission factors when specific clinical emission factors are not available.

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. See Annex 3.6 for details.

7.5.3. Uncertainties and Time Series Consistency

IPCC default values are used to quantify uncertainty for the incineration sector. The activity data uncertainty is ±5%, while the CO_2, CH_4 and N_2O emission factor uncertainties are ±35%, ±98%, and ±88%, 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 Greenhouse Gas Reporting Program (GHGRP) were used where available. For facilities not reporting under the GHGRP, data were carried forward from the survey conducted in 2022. Waste classifications were reviewed and facilities were assigned appropriately to their primary disposal categories.

7.5.6. Planned Improvements

No planned improvements are scheduled for the Incineration and Open Burning of Waste category.

7.6. Wastewater Treatment and Discharge (CRF Category 5.D)

7.6.1. Source Category Description

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. In some coastal areas, untreated wastewater is discharged directly to the sea. Most industrial facilities discharge their wastewater to municipal treatment systems where it is treated in common with domestic wastewater. Several large industrial facilities 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 a number of technologies, often classified by the method of organic matter and nutrient removal: whether the removal mechanism is primarily 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 treatment in Canada are centralized primary systems (settling of solids), secondary systems (conventional waste activated sludge), aerobic and facultative lagoons, and septic systems. Discharge of untreated sewage to sea has been declining but is still carried out in some coastal regions. Other secondary treatment technology used in Canada include wetland treatment systems, sequence batch reactors, rotating biological contactors, trickling filters, 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).

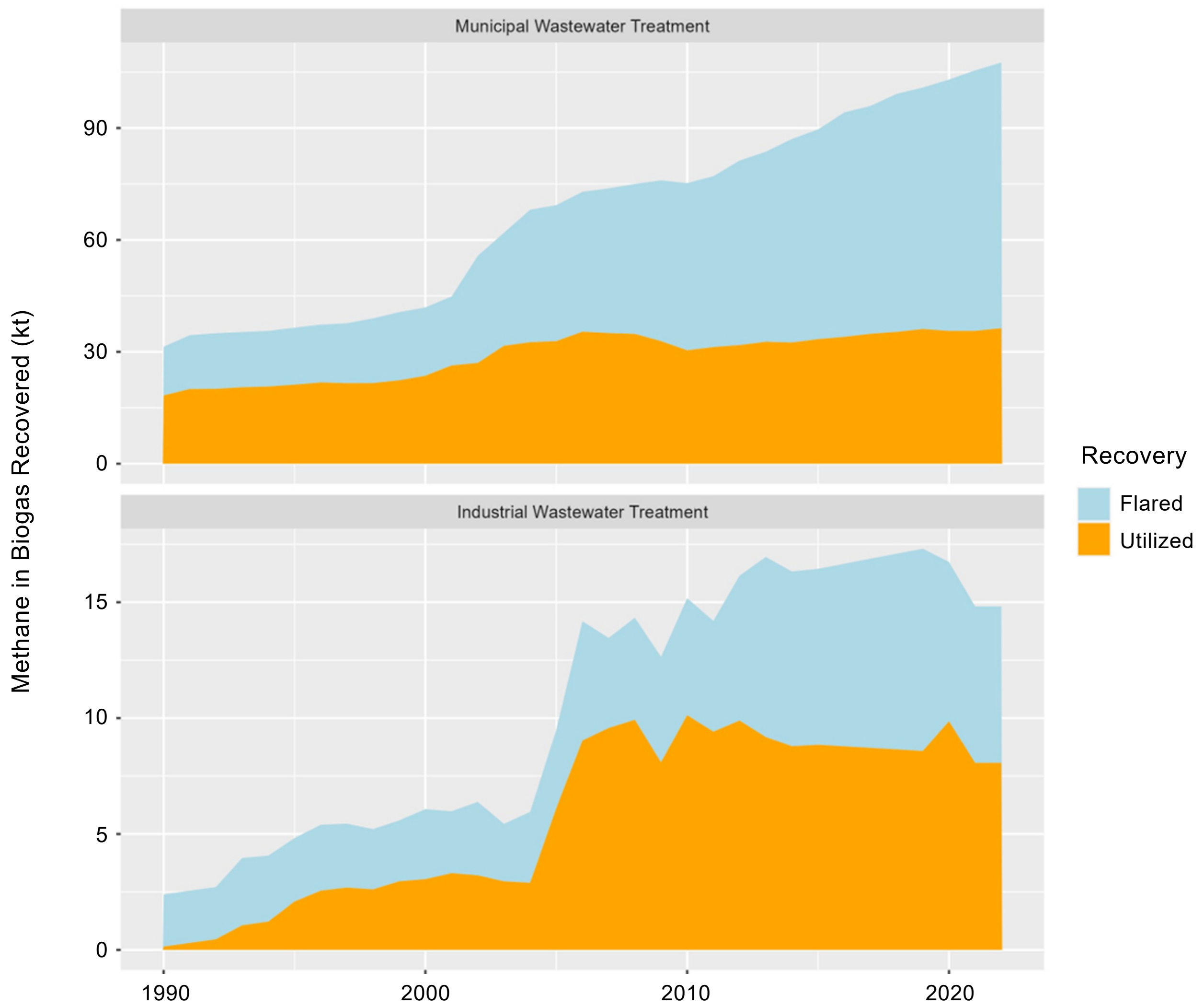
For Industrial Wastewater Treatment, 2.4 kt CH_4 was recovered in 1990, of which 2.3 kt CH_4 was flared and 0.1 kt CH_4 was utilized. In 2005, 3,3 kt CH_4 was flared and 6.1 kt Utilized. In 2022 the amount of CH_4 recovered increased by 517% (14.8 kt CH_4), of which 6.8 kt CH_4 was flared and 8.1 kt was utilized.

Recovered CH_4 for Municipal Wastewater Treatment in 1990 was 31.4 kt (13.1 kt flared, 18.3 kt utilized). In 2005, 36.5 kt CH_4 were flared and 32.9 kt CH_4 were utilized (total 69.3 kt CH_4 recovered). In 2022, 71.2 kt CH_4 were flared and 36.4 kt CH_4 were utilised (107.6 kt CH_4 total recovery). 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.

Figure 7–2 **Methane Recovered from Wastewater Treatment**



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The Wastewater Treatment and Discharge category accounted for 2560 kt CO_2 eq, or 12.6%, of the total emissions of the Waste sector in 2022. Wastewater Treatment and Discharge emissions in 2022 were 691 kt CO_2 eq (37.0%) above the 1990 level of 1869 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, whereas upgrades of several major wastewater systems from untreated discharge to sea to primary treatment in other provinces decreases emissions. Overall, the increasing trend in emissions is fairly steady, 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).

7.6.2. Methodological Issues

Annex 3.6 provides additional information on the methodologies used for various categories covered by this category.

The approach used to estimate CH_4 emissions from municipal wastewater treatment is based on the amount of organic matter generated per person in Canada and the conversion of organic matter to CH_4 in anaerobic treatment systems, according to IPCC 2006 Guidelines (IPCC, 2006; AECOM Canada, 2011).

Emission factors are treatment-type specific. 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. Calculation methods require the number of people serviced by each wastewater treatment system type (e.g., septic, lagoon, untreated). This was determined from an analysis of Statistics Canada's Households and the Environment Survey (Statistics Canada, n.d.[a]). The population served by each of the more than 3000 wastewater treatment or discharge systems in Canada was estimated on the basis of the relative regional volumes of wastewater treated by (or discharged through) that facility or system and the regional population, at the census metropolitan area level. A more complete description of the methodology is provided in Annex 3.6.

Emissions from on-site industrial wastewater treatment are based on reported GHG emissions to the Greenhouse Gas Reporting Program (GHGRP). In addition, to supplement this information, Environment and Climate Canada also conducts facility-level surveys to obtain CH_4 emissions, capture and use data from industrial facilities that treat their effluent anaerobically on-site. Facility data are updated (new data appended, existing data revised and corrected) with each successive survey. The latest survey was conducted in 2022. A complete description of the methodology is provided in Annex 3.6.

The N_2O emissions are estimated based on nitrogen in the wastewater in accordance with the IPCC 2006 Guidelines (IPCC, 2006). The amount of nitrogen introduced to wastewater is estimated based on per capita protein consumption, with factors applied to account for industrial and commercial co-discharge and additional nitrogen from household products; nitrogen lost during treatment is considered in the estimates. Emissions based on effluent nitrogen entering into a receiving water body are also included. A complete description of the methodology is provided in Annex 3.6.

7.6.3. Uncertainties and Time Series Consistency

The overall level of uncertainty associated with the Wastewater Treatment and Discharge category was estimated to be in the range of ±55% for CH_4 and ± 51% for N_2O based on IPCC 2006 default uncertainties.

The updated activity data for municipal wastewater treatment and discharge will necessitate an updated uncertainty assessment. This is in progress and planned for the following inventory.

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 manipulation error.

7.6.5. Recalculations

The 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). Error corrections for municipal wastewater treatment involved a modest number of unit conversions (methane recovery volumes were reported with relative pressures), updated inter-facility sludge transfers, and volumes treated for a few facilities (mostly in the early 1990s). Recalculations for industrial wastewater treatment involved a correction to double-counted emissions (mostly occurring from 2014 to 2016) and a correction to extrapolated emissions (mostly occurring in the 1990s and early 2000s).

7.6.6. Planned Improvements

Efforts are underway to characterize the types of receiving waterbodies for all wastewater treatment systems in Canada, to apply waterbody specific effluent emission factors.

CHAPTER 8

RECALCULATIONS AND IMPROVEMENTS

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 (chapters 3 to 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, or 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

The revisions of this submission include updated Global Warming Potentials (GWPs). The updated GWP values, as shown in Table 8–1, alter the relative contributions of each of the GHGs to Canada's national total (expressed in CO_2 eq.), although, the change in GWP alone does not affect the emission trends. The updated GWP values are being implemented in this year's GHG inventory, in accordance with UNFCCC Decision 5/CMA.3 paragraph 25, using the 100-year GWP values provided by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (IPCC AR5) (IPCC, 2014). The IPCC AR5 GWP values reflect the refined scientific understanding of the impact of each GHG on the atmospheric radiative balance, compared to CO_2. In Table 8–2 to Table 8–4 and in Figure 8–1, a distinction is made between the updated GWPs from the IPCC AR5 and those in the Fourth Assessment Report (IPCC AR4) that were used in last year's National Inventory Report (NIR), by referencing “AR4” and “AR5”. In those tables and figure, the impact of the recalculations is also distinct from the GWP update impact.

1 https://unfccc.int/sites/default/files/resource/cp24_auv_transparency.pdf

Figure 8–1 **Comparison of Emission Trends (2023 NIR vs 2024 NIR)**

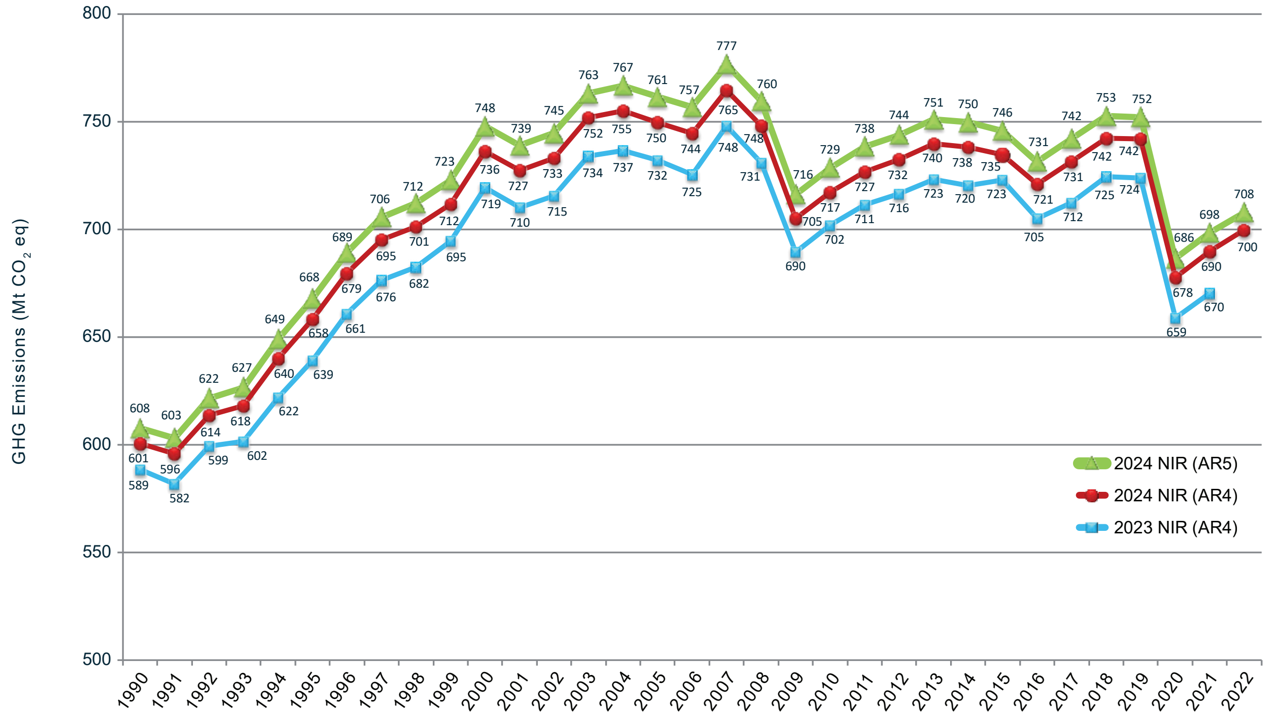

Table 8–1 **Examples of Global Warming Potentials (GWPs) Over a 100-Year Time Horizon**

Greenhouse Gas	Formula	GWP in the *Fourth Assessment Report* (AR4)	GWP in the *Fifth Assessment Report* (AR5)	% Change
Carbon dioxide	CO_2	1	1	-
Methane	CH_4	25	28	12.0%
Nitrous oxide	N_2O	298	265	-11.1%
Sulphur hexafluoride	SF_6	22 800	23 500	3.1%
Nitrogen trifluoride	NF_3	17 200	16 100	-6.4%

Note: Chapter 1 provides a complete list of GHG and GWPs used in this report.

Table 8–2 **Summary of Recalculations in the 2024 National Inventory (Excluding Land Use, Land-Use Change and Forestry)**

National Total	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2017	2018	2019	2020	2021	(1990–2021)	(2005–2021)
Previous Submission (2023 NIR)	588 603	719 464	732 219	712 232	724 615	723 679	658 788	670 428	13.9%	-8.4%
Current Submission (2024 NIR)	607 749	747 739	761 492	742 010	752 631	752 025	686 362	698 441	14.9%	-8.3%
Change in Emissions	12 198	16 840	17 374	19 243	17 700	18 423	18 978	19 304	-	-
	2.07%	2.34%	2.37%	2.70%	2.44%	2.55%	2.88%	2.88%	-	-
Change due to GWP Update	6 948	11 435	11 899	10 535	10 315	9 922	8 596	8 709	-	-
	1.16%	1.55%	1.59%	1.44%	1.39%	1.34%	1.27%	1.26%	-	-
Total Recalculations	19 146	28 275	29 273	29 778	28 016	28 345	27 574	28 013	-	-
	3.25%	3.93%	4.00%	4.18%	3.87%	3.92%	4.19%	4.18%	-	-

Note: " - " = Not applicable

In this year's GHG inventory, total emissions, including the GWP update, were revised upward for all years, as shown in Figure 8–1. In this figure, the blue line represents the emissions as they were reported in last year's GHG inventory (using IPCC AR4 GWPs); the red line represents the impact of recalculations only (2024 NIR, using IPCC AR4 GWPs); the green line represents the final emissions, including both recalculations and GWP updates.

Overall, as shown in Table 8–2, recalculations of previously reported 1990–2021 estimates have resulted in an increase in emissions between 3.1% and 4.5% for every year (between 19 Mt and 31 Mt) when both the recalculations impact and the GWP update impact are considered. When isolating the impact of the recalculations only, estimates have also resulted in an increase in emissions for all years, between 1.6% and 3% (between 11.6 Mt and 19 Mt). The trend between 1990 and 2021 is now reported as a 14.9% increase in total GHG emissions since 1990, compared with a 13.9% increase reported in last year's NIR. There is a net upward recalculation of 29 Mt for the base year 2005.

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 all IPCC sectors (Energy; Industrial Processes and Product Use [IPPU]; Agriculture; Land Use, Land-Use Change and Forestry [LULUCF]; and Waste) and Energy subsectors (Stationary Combustion, Transport and Fugitive Sources) and for all applicable years in the time series (1990–2021). These revisions are largely due to improved estimation methodologies as well as updated energy data.

As reflected in Table 8–3, for 2021, regardless of the GWP update, the revisions made resulted in the most significant changes in Fugitive Sources (+15.5 Mt) and Stationary Combustion (+3.0 Mt). These revisions are largely due to improved estimation methodologies as well as updated energy data. The sum of the revisions made for the Agriculture and Waste sectors is almost zero. The revisions due to updated GWP values are most significant for the Fugitive Sources (+6.4 Mt) and Waste sector (+2.1 Mt) due to the larger contribution of methane to overall emissions in those sectors. The change in the national total from 670 Mt in 2021 (as presented in the previous inventory) to 708 Mt in 2022 (as presented in the current inventory) is comprised of 9.3 Mt due to year-to-year differences, 19.3 Mt due to recalculations and 8.7 Mt due to the GWP update. Explanations of the recalculations for each source are presented below and emission values of those sources for selected years of the time series are presented in Table 8–4.

Energy (Stationary Combustion)

With respect to Stationary Combustion emissions, most of the recalculations for 2021 occurred in Oil and Gas Extraction (+4.6 Mt), Residential (+0.9), Petroleum Refining Industries (+0.6 Mt), Public Electricity and Heat Production (+0.3 Mt), Commercial/Institutional (-2.5 Mt), and Manufacturing Industries (-0.6 Mt). Recalculations also occurred throughout the time series, with the major source being updates to coal oxidation factors, natural gas and petroleum coke EFs, and fuel consumption data in the Report on Energy Supply and Demand (RESD). See section 3.1 for further recalculation details. The change to IPCC AR5 GWPs increased emissions over the entire time series ranging from 0.22 Mt in 1998 to a maximum of 0.36 Mt in 2008. The increase is mainly caused by non-marketable natural gas and residential firewood, due to their large methane (CH_4) EFs.

Table 8–3 **Change in Canada's GHG Emissions: from 670 Mt (for 2021, Previous Submission) to 708 Mt (for 2022, Current Submission)**

Sector	2021 to 2022 Change (Mt CO_2 eq)	2021 Change Due to Recalculations (Mt CO_2 eq)	2021 Change Due to GWP Update (Mt CO_2 eq)
Energy (Stationary Combustion)	2.5	3.0	0.3
Energy (Transport)	7.8	0.5	-0.2
Energy (Fugitive Sources)	-2.0	15.5	6.4
Industrial Processes and Product Use	-0.2	0.4	-0.8
Agriculture	0.9	-0.1	0.9
Waste	0.3	0.0	2.1
Total Change	**9.3**	**19.3**	**8.7**

Note: Totals may not add up due to rounding.

Recalculations to the Oil and Gas Extraction category occurred from 1990 to 2021. Revisions to producer-consumed natural gas CH_4 EFs in British Columbia, Alberta, and Saskatchewan caused upward revisions from 1990 to 2021 ranging from +0.01 Mt in 1993 to +0.8 Mt in 2008. Updates to natural gas volumes caused downward revisions from 2004 to 2010 and upward revisions from 2011 to 2021, ranging from -0.7 Mt in 2005 to +4.0 Mt in 2020.

Recalculations in the Residential category occurred between 1990 and 2021, with significant revisions from 2016 to 2021. These significant revisions were due to changes to natural gas volumes, causing recalculations ranging from -1.6 Mt to +0.8 Mt. Other recalculations were due to corrections to coal oxidation factors.

Recalculations to Petroleum Refining Industries were a result of updated natural gas and petroleum coke EFs and revisions to the RESD, specifically increased volumes for natural gas, petroleum coke, and still gas.

Recalculations in the Public Electricity and Heat Production category occurred for the entire time series. Recalculations from 1990 to 2021 were a result of revised natural gas and petroleum coke EFs, and revised coal oxidation factors, ranging from -0.6 Mt to +0.01 Mt. Revisions to coal, heavy fuel oil, light fuel oil, and natural gas volumes from 2005 to 2021 caused changes in emissions ranging from -4.8 Mt to +0.5 Mt.

Recalculations in the Commercial and Institutional category occurred for the entire time series, with significant revisions from 2016 to 2021. These significant revisions, ranging from -2.5 Mt to +2.3 Mt, were caused by revised volumes of natural gas. Prior to 2016, the recalculations were a result of revised quantities of landfill gas, sludge gas, municipal solid waste, and medical waste used for energy purposes.

Recalculations for Manufacturing Industries occurred for the entire time series, with significant revisions from 2007 to 2021. The significant changes were a result of revisions to the RESD, ranging from -0.7 Mt to -0.2 Mt. The revisions to the entire time series are due to updated coal oxidation factors, natural gas and petroleum coke EFs, and revised quantities of sludge gas, ranging from -0.06 Mt to +0.01 Mt.

Energy (Transport)

Insignificant recalculations for Transport occurred for the entire time series. From 1990–2020, these emissions were revised downwards, ranging from -0.15 Mt (-0.1%) in 2020 to -0.55 Mt (-0.4%) in 1994. For 2021, these emissions were revised upwards by +0.34 Mt (+0.2%). These revisions are primarily due to the adoption of IPCC AR5 GWP values and minor revisions to RESD fuel volumes for the 2021 reporting year.

The recalculations from adopting IPCC AR5 GWP values were insignificant for all Transport categories. However, both the magnitude and direction of those impacts varied by category due to the various types of engines associated with Transport. At the category level, the relative impact of adopting the updated GWP values was largest for Railways, resulting in those emissions being revised downwards for the entire time series, ranging from -67 kt (-1.1%) in 2002 to -87 kt (-1.1%) in 2008. In terms of absolute change, the adoption of the updated GWP values was largest for Road Transportation, resulting in downward revisions for the entire times series, ranging from -0.12 Mt (-0.1%) in 2021 to -0.63 Mt (-0.5%) in 2003. The only Transport category in which the adoption of the updated GWP values contributed to an upward revision of emissions was Off-Road Transportation, which occurred for the entire time series and ranged from +26 kt (+0.1%) in 2021 to +102 kt (+0.3%) in 2002.

The recalculations from revised RESD fuel volumes for the 2021 reporting year were insignificant for all Transport categories. These revisions were most impactful for diesel fuel oil volumes associated with Road Transportation and Off-Road Transportation, which when combined, contributed to an upward emissions revision of +0.49 Mt (+0.3%) for the 2021 reporting year.

Energy (Fugitives)

Significant recalculations occurred in the Oil and Natural Gas category of the Fugitives subsector for the entire time series. The change to IPCC AR5 GWP values resulted in upward revisions in each year, resulting in increases ranging from +5.5 Mt in 1990 to a maximum of +9.2 Mt in 2014. Additionally, updates to methodologies and activity data resulted in significant upward revisions, with overall increases ranging from +12.2 Mt (+27%) in 1990 to +19.1 Mt (+32%) in 1995. These revisions resulted from several recalculations with varying impacts:

1. **Atmospheric measurements of CH_4**: atmospheric measurements of CH_4 emissions from storage tanks, unlit flares, compressor buildings, engine sheds, and wellheads (Saskatchewan only) at Upstream Oil and Gas (UOG) facilities were integrated into inventory methodologies resulting in significant recalculations. For a full description of the methodology and how atmospheric measurements have been incorporated for UOG in British Columbia, Alberta, and Saskatchewan, see Annex 3.2 section A3.2.2.1.5. Overall, the integration of measurement-based CH_4 emissions for these sources resulted in upward revisions for all years, ranging from +11.9 Mt in 1990 to a maximum of +18.9 Mt in 2006. When incorporating the new data, double counting was minimized, by removing or adjusting estimates from fugitive equipment leaks, compressor seals, surface casing vent flow, and reported venting and flaring. For a full description of how the new methodology has been incorporated, see Annex 3.2 section A3.2.2.1.5.

2. **Surface casing vent flow (SCVF)**: Alberta estimates were recalculated following corrections to the estimated resolution dates of SCVFs in the model, which resulted in downward revisions for all years, ranging from -0.058 Mt in 1990 to -1.5 Mt in 2019. Updated provincial SCVF reports for British Columbia resulted in additional changes ranging from -3.2 kt in 2003 to +37 kt in 2021. See Annex 3.2, section A3.2.2.1.4 for more details on the SCVF methodology.
3. **Alberta pneumatics**: to reflect the trend in pneumatic device vent volumes reported to Alberta's OneStop system, pneumatic device reduction parameters were modified for 2021. These changes along with minor updates to facility counts resulted in an upward revision of +206 kt in 2021.
4. **Post-meter fugitives**: Post-meter estimates for CO_2 have been removed to avoid double-counting with combustion estimates, leading to recalculations ranging from -0.7 kt in 1990 to a maximum of -1.3 kt in 2011. For details on the methodology, see Annex 3.2, section A3.2.2.7.

Further recalculations to fugitive Oil and Natural Gas emissions occurred due to activity data updates, the most significant of which involved:

1. Natural gas transmission and storage, distribution: updated pipeline length data for 2021 resulted in recalculated emissions for that year, with an upward revision of +8.7 kt.
2. Petroleum refining: minor recalculations occurred from 2010 to 2021. Estimates were revised downward in 2020 by -2.9 kt, while the remaining years had upward revisions with a maximum increase of +25 kt in 2019.

Recalculations also occurred for fugitive emissions from Solid Fuels due to the GWP update and changes to activity data. The change to IPCC AR5 GWP values resulted in upward revisions for the entire time series, with increases ranging from +0.1 Mt in 2015 to +0.3 Mt in 1991. Updates to activity data for the Coal Mining and Handling sector resulted in minor upward revisions from 2001 to 2015, with a maximum increase of +1.5 kt in 2009.

Note that more detailed recalculation explanations for Fugitive Emissions from Fuels can be found in Chapter 3, section 3.3.

Industrial Processes and Product Use

There were recalculations for the IPPU sector for the whole time series (1990–2021), ranging from -2.07 Mt to -0.14 Mt. These recalculated values were overall results of both activity data updates and IPCC AR5 GWP updates, with GWP updates being the major contributor of the recalculations. Explanations on the two main recalculations that are due to activity data revisions are provided below.

1990 to 2021 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 Iron and Steel model that impacted the amount of petroleum coke assumed to be used as electrodes in Electric Arc Furnaces. The changes ranged from -0.04 Mt in 2001 to +0.16 Mt in 2021.

For the Iron and Steel Production category, the entire time series (1990–2021) were also recalculated because of updated Pig Iron production from 2017 to 2021, revisions to facility-reported data to the Greenhouse Gas Reporting Program (GHGRP) and a method change in the calculation of emissions from the use of limestone in Iron and Steel furnaces. The magnitude of recalculations ranged from +0.0006 Mt in 2007 to +0.62 Mt in 2017.

Agriculture

The majority of recalculations in the Agriculture sector were driven by the implementation of IPCC AR5 GWPs. The increase in the GWP for methane from 25 to 28 was offset by the decrease in the GWP for nitrous oxide from 298 to 265. The magnitude of the recalculations across the time series was influenced by offset between these gases GWP correction, as their relative contribution to the total emissions changes with time. Recalculations peaked in 2005 when methane and nitrous oxide contributed 66% and 33% of non-CO_2 emissions, respectively, based on the previous IPCC AR4 GWPs, but declined in 2021 when the relative contribution of the gases was 56% and 44% respectively.

Minor recalculations resulted from activity data updates associated with the implementation of a higher spatial resolution version of the 2021 census of agriculture, updated crop yields, and updated land use mapping.

As a result of these recalculations, agricultural emissions were revised upward by 1.3 Mt in 1990, 2.1 Mt in 2005, and 0.8 Mt in 2021.

Waste

Recalculations in the Waste sector resulted in changes to emission estimates of 2.4 Mt (13%), 2.6 Mt (12%) and 2.1 Mt (10%) in 1990, 2005 and 2021, respectively. These changes are primarily the result of the use of updated GWP values. The recalculations unrelated to GWP values included updated emissions model input data and revisions to facility-reported data, detailed as follows:

1. Recalculations for municipal solid waste landfills include updated waste disposal, export and incineration data, and updated methane recovery data. The updated disposal data replaces previously extrapolated values that were constant for the years 2019 to 2021. The updated methane recovery data replace previously extrapolated (held constant) values for 2021 and reflect a wider response coverage with the voluntary survey. Additional validation was completed for previously reported values of methane recovery, yielding revisions throughout the time series.
2. Recalculations in municipal wastewater treatment and discharge include minor corrections to facility-level data, such as volumes treated, treatment technology and methane recovered. Some specific corrections include better handling of cases when facilities report in mixed units: a correction to biogas volumes when reported pressures were in relative units (such as inches of H_2O or inches of mercury); and a correction to a query where five facilities were excluded. Finally, a correction was applied for remote regions where populations were under-assigned (resulting in a net ~1000–2000 persons underestimate for the country).
3. Industrial wastewater recalculations include corrections to calculation and compilation errors and updated data. A compilation query that was creating double counting in facilities that changed names or North American Industry Classification System (NAICS) codes was revised. A correction to the extrapolation of facility-reported emissions was made. The updated data include the latest GHGRP and National Pollutant Release Inventory (NPRI; releases to water) data.
4. Recalculations for biological treatment of waste include updates to activity data collected through a survey approach. For facilities not captured in the latest survey, it was assumed that the facility has remained active until confirmation of its closure (permanent or temporary) is obtained.

Land Use, Land-Use Change and Forestry

Recalculations occurred in Forest Land, Harvested Wood Products (HWP) and in Cropland. The most significant recalculation is due to corrections made to the pre-1990 Forest Land disturbance history data, i.e., wildfire or clearcut, which determine the stand origin at the initiation of CBM-CFS3 simulations in 1990 (for more details, see Annex 3.5.2.5). The historical harvest area is a key factor in determining the area of land that is reported as anthropogenic under Canada's reporting approach and, consequently, the emissions and removals that are reported in the Forest Land subsector. These revisions to historical harvest areas were compiled for five provinces (British Columbia, Alberta, Saskatchewan, Ontario and Quebec). The implementation of this change reduced the area of the managed forest that is included in the anthropogenic component by 34 Mha. These reductions in the area of the historically harvested land translated into a corresponding shift of the removals that occur in the anthropogenic component of the managed forest to the natural disturbance component. Further, a greater proportion of stands initiated by wildfire led to greater initial amounts of dead organic matter, which in turn increased the estimated emissions from decomposition in Forest Land.

Other less significant recalculations occurred in the forest sector due to a minor bug correction of CBM-CFS3 and updated parameters for the HWP model (for more details, see Annex 3.5.2.5). The combined effects of changes to reported anthropogenic Forest Land and HWP estimates, almost entirely driven by the correction to the pre-1990 disturbance history data, resulted in an upward correction in net emissions of 114 Mt in 1990, 72 Mt in 2005 and 32 Mt in 2021 in Forest Land and HWP.

Other less significant recalculations occurred in the Wetlands subsector due to the addition of forest-cleared and flooded areas associated with a hydro-related large event in Ontario, updated 2021 activity data for peat extraction.

Recalculations in Cropland were mainly driven by updates to activity data such as inclusion of updated crop yields and revisions to annual and perennial crop activity. Another less significant recalculation occurred in the conversion of Forest Land to Cropland. The impact of IPCC AR5 GWP changes were minimal. Altogether, 2021 saw increased net removals of 1.2 Mt.

The combined impact of all recalculations shifted the whole of the LULUCF sector from a net sink to a consistent net source for the entire time series, with net emissions increasing by 114 Mt in 1990, 72 Mt in 2005, and 31 Mt in 2021.

Refer to Table 8–5 and Chapter 6 for more details on implemented improvements.

Table 8–4 **Summary of Recalculations by Sector**										
	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2017	2018	2019	2020	2021	(1990–2021)	(2005–2021)
ENERGY (STATIONARY COMBUSTION)										
Previous Submission (2023 NIR)	277 940	344 828	339 171	317 990	321 141	321 626	297 756	300 321	8.1%	-11.5%
Current Submission (2024 NIR)	277 861	344 867	338 488	321 486	323 866	325 933	302 467	303 587	9.3%	-10.3%
Change in Emissions	**- 334**	**- 269**	**-1 000**	**3 210**	**2 426**	**4 013**	**4 427**	**2 993**	-	-
	-0.1%	**-0.1%**	**-0.3%**	**1.0%**	**0.8%**	**1.2%**	**1.5%**	**1.0%**	-	-
Change due to GWP Update	**255**	**308**	**318**	**286**	**299**	**294**	**284**	**274**	-	-
	0.1%	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	-	-
ENERGY (TRANSPORT)										
Previous Submission (2023 NIR)	145 493	178 199	190 657	202 486	208 680	210 047	178 731	187 695	29.0%	-1.6%
Current Submission (2024 NIR)	145 049	177 757	190 245	202 322	208 516	209 890	178 600	188 052	29.6%	-1.2%
Change in Emissions	**3**	**124**	**116**	**32**	**31**	**29**	**27**	**516**	-	-
	0.0%	**0.1%**	**0.1%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.3%**	-	-
Change due to GWP Update	**-447**	**-566**	**-528**	**-195**	**-195**	**-186**	**-158**	**-159**	-	-
	-0.3%	**-0.3%**	**-0.3%**	**-0.1%**	**-0.1%**	**-0.1%**	**-0.1%**	**-0.1%**	-	-
ENERGY (FUGITIVE SOURCES)										
Previous Submission (2023 NIR)	48 132	70 138	70 059	65 952	66 116	64 388	55 400	55 167	14.6%	-21.3%
Current Submission (2024 NIR)	66 148	95 386	96 880	89 382	89 138	86 063	76 630	77 139	16.6%	-20.4%
Change in Emissions	**12 204**	**16 768**	**18 117**	**15 432**	**15 124**	**14 155**	**14 772**	**15 549**	-	-
	25.4%	**23.9%**	**25.9%**	**23.4%**	**22.9%**	**22.0%**	**26.7%**	**28.2%**	-	-
Change due to GWP Update	**5 813**	**8 481**	**8 704**	**7 997**	**7 898**	**7 521**	**6 459**	**6 423**	-	-
	9.6%	**9.8%**	**9.9%**	**9.8%**	**9.7%**	**9.6%**	**9.2%**	**9.1%**	-	-
IPPU										
Previous Submission (2023 NIR)	56 966	54 022	56 509	52 442	53 868	52 882	50 360	51 943	-8.8%	-8.1%
Current Submission (2024 NIR)	54 891	53 153	55 396	52 300	53 503	52 318	49 681	51 499	-6.2%	-7.0%
Change in Emissions	**3**	**-35**	**-34**	**592**	**407**	**213**	**139**	**371**	-	-
	0.0%	**-0.1%**	**-0.1%**	**1.1%**	**0.8%**	**0.4%**	**0.3%**	**0.7%**	-	-
Change due to GWP Update	**-2 078**	**-835**	**-1 080**	**-735**	**-771**	**-778**	**-818**	**-815**	-	-
	-3.6%	**-1.5%**	**-1.9%**	**-1.4%**	**-1.4%**	**-1.5%**	**-1.6%**	**-1.6%**	-	-
AGRICULTURE										
Previous Submission (2023 NIR)	41 140	50 960	54 147	52 088	53 488	53 618	55 491	54 244	31.9%	0.2%
Current Submission (2024 NIR)	42 485	52 675	56 242	53 008	54 157	54 299	56 016	55 061	29.6%	-2.1%
Change in Emissions	**6**	**-71**	**-98**	**-92**	**-270**	**-243**	**-217**	**-80**	-	-
	0.0%	**-0.1%**	**-0.2%**	**-0.2%**	**-0.5%**	**-0.5%**	**-0.4%**	**-0.1%**	-	-
Change due to GWP Update	**1 339**	**1 785**	**2 193**	**1 013**	**939**	**924**	**742**	**897**	-	-
	3.3%	**3.5%**	**4.1%**	**1.9%**	**1.8%**	**1.7%**	**1.3%**	**1.7%**	-	-
WASTE										
Previous Submission (2023 NIR)	18 933	21 317	21 675	21 274	21 322	21 118	21 050	21 057	11.2%	-2.8%
Current Submission (2024 NIR)	21 314	23 900	24 241	23 511	23 450	23 521	22 968	23 103	8.4%	-4.7%
Change in Emissions	**316**	**323**	**273**	**68**	**-18**	**255**	**-170**	**-45**	-	-
	1.7%	**1.5%**	**1.3%**	**0.3%**	**-0.1%**	**1.2%**	**-0.8%**	**-0.2%**	-	-
Change due to GWP Update	**2 066**	**2 261**	**2 293**	**2 169**	**2 145**	**2 148**	**2 088**	**2 091**	-	-
	10.7%	**10.4%**	**10.4%**	**10.2%**	**10.1%**	**10.0%**	**10.0%**	**10.0%**	-	-
LULUCF										
Previous Submission (2023 NIR)	-64 507	-37 777	-5 542	-16 227	-11 294	-18 821	-13 388	-17 303	-73.2%	212.2%
Current Submission (2024 NIR)	49 184	57 116	65 994	19 100	22 987	13 631	25 642	13 537	-72.5%	-79.5%
Change in Emissions	**113 645**	**94 847**	**71 486**	**35 279**	**34 240**	**32 418**	**39 000**	**30 807**	-	-
	-176.2%	**-251.1%**	**-1 289.8%**	**-217.4%**	**-303.2%**	**-172.2%**	**-291.3%**	**-178.0%**	-	-
Change due to GWP Update	**46**	**46**	**51**	**47**	**41**	**34**	**30**	**32**	-	-
	0.1%	**0.1%**	**0.1%**	**0.2%**	**0.2%**	**0.2%**	**0.1%**	**0.2%**	-	-

Note:
" - " = Not applicable

8

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 must be 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.

This year, improvements to Canada's inventory resulted from recommendations from the Expert Review Teams (ERTs) reviews completed in previous years, continued implementation of the *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 8–5 provides additional information about the improvements implemented this year presented by IPCC sectors and Common Reporting Format (CRF) categories.

8.2.1. Expert Review Team Recommendations

Canada's inventory submission is typically reviewed annually by an ERT following agreed-upon UNFCCC review guidelines[2] as adopted in Decision 13/CP.20 at COP 20 in Lima in 2014. Reviews are coordinated by the UNFCCC Secretariat, and the ERT 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 UNFCCC Reporting Guidelines. At the end of the review, the ERT provides technical feedback on any methodological and procedural issues encountered. The ERT 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 an annual review report that is provided to the country under review and made public by the UNFCCC.

The recommendations from ERTs were taken into consideration when identifying potential improvements for this year. The latest review completed by the ERT can be found on the UNFCCC website.[3]

Methodological changes made this year that addressed the ERTs recommendations include the removal of post-meter fugitive CO_2 emissions from natural gas use to avoid double counting.

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:

- incorporation of upstream oil and gas CH_4 emissions derived from source-resolved atmospheric measurements in British Columbia, Alberta, and Saskatchewan
- incorporation of facility-reported data to Canada's Greenhouse Gas Reporting Program (GHGRP) to calculate emissions from limestone and dolomite used in pulp and paper mills and as flux in iron and steel production
- refinement of historical disturbance data in the Canadian forest sector
- continued refinement of waste models with waste-specific parameters for municipal solid waste (MSW) and industrial wood waste landfills

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.

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 https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports-2023

In addition, planned improvement activities (Table 8–6) 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 8–5 and Table 8–6 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.

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, 2023) 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 in order 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*. They have since repeated this exercise, taking stock of the progress made on the original blueprint and adapting objectives based on current science. 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 Carbon 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 projects developed in the improvement planning process reflect these dialogues.

The improvement plan consists of projects that (1) can be operationalized[4] 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 to the 2024 GHG inventory submission represents the fifth edition of the 3-year rolling (2024 to 2026) GHG emissions and removals from forests, land-use change events involving forests, and harvested wood products (HWP) that are reported in the NIR. The current three-year window includes improvements being implemented in this inventory submission, as noted in Table 8–5.

Several improvements are planned for the Forest Land category in the next 2025 inventory submission, some details on the most significant changes are provided in 6.3.1.6. In Table 8–6, a summary of improvement projects is provided, and the complete improvement plan is published annually on the Government of Canada's Open Data webpage.

4 "Operationalized" means being incorporated into the annual inventory production process.

Table 8–5 **Improvements to Canada's 2024 NIR**

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Energy (Fugitive Emissions)	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Incorporation of upstream oil and gas (UOG) CH_4 emissions derived from source-resolved atmospheric measurements.	This update improves the accuracy of CH_4 estimates from the Upstream Oil and Gas (UOG) industry. The new methodology incorporates recently published UOG CH_4 emissions derived by the Energy and Emissions Research Laboratory (EERL) at Carleton University for British Columbia (2021), Alberta (2021), and Saskatchewan (2020 and 2021). EERL's estimates utilize observed methane releases measured using Gas Mapping LiDAR (GML) during measurement campaigns over thousands of facilities spread across the major oil and gas production regions of British Columbia, Alberta, and Saskatchewan. Source-level estimates of CH_4 emissions from tanks, compressor buildings, engine sheds, and unlit flares are incorporated into UOG estimates by facility subtype. The new method avoids double-counting to the extent possible by removing emission estimates for these sources, with special care to account for combustion emissions from compressors and uncombusted flare volumes. Emissions are back-casted to 1990 at the source-level using facility counts and relevant activity data.	Continuous improvement	Annex 3.2.2.1
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Removal of post-meter fugitive CO_2 emissions from natural gas use to avoid double counting.	Following IPCC guidelines, an oxidation factor of 1 is used for natural gas combustion. Therefore, any post-meter fugitive CO_2 emissions are already included in CO_2 combustion. To eliminate double-counting, post-meter fugitive CO_2 emission estimates from natural gas appliances in the residential and commercial sector, natural gas vehicles, and industrial consumption of natural gas are no longer calculated.	UNFCCC ERT recommendation	Annex 3.2.2.7
IPPU	Other Limestone and Dolomite Use (CRF 2.A.4.d)	Implementation of an IPCC Tier 3 methodology.	The CO_2 emissions from limestone used in pulp and paper mills were previously estimated using a Tier 2 methodology for 1990–2021, using national-level activity data. A Tier 3 methodology has been implemented for the years 2018–2022, integrating plant-level activity data reported to Canada's GHGRP and replacing national-level activity data.	Continuous improvement	Chapter 4
	Other Limestone and Dolomite Use (CRF 2.A.4.d)	Correction of proxy activity data.	The proxy data used to estimate national activity data (2019–2021) and allocate provincial CO_2 emissions (1990–2021) from limestone used as flux in non-ferrous smelters was corrected to reflect gross output data from non-ferrous smelting and refining sector for 1990–2022. Previously, gross output proxy data from the non-ferrous metal foundries sector was used.	Continuous improvement	Chapter 4
	Iron and Steel Production (2.C.1)	Implementation of an IPCC Tier 3 methodology.	The CO_2 emissions from limestone and dolomite used as flux in iron and steel production were previously estimated using a Tier 2 methodology for 1990–2021. This method used national-level data, which contained discrepancies in the iron and steel sector for 2017–2018. A Tier 3 methodology has been implemented for the years 2017–2022, integrating plant-level activity data reported to Canada's GHGRP and replacing national-level activity data.	Continuous improvement	Chapter 4
	Iron and Steel Production (2.C.1)	Update to the disaggregation of activity data.	The national activity data for stone used as flux in iron and steel production was previously disaggregated between limestone and dolomite in a 70/30 split ratio for 1990–2021. For 2017–2022, facility-reported data to Canada's GHGRP has been integrated to represent quantities of limestone to dolomite flux stone used in these years. The average split ratio of limestone to dolomite from 2017–2022 (59/41) has been applied to disaggregate the national activity data for the years 1990–2016.	Continuous improvement	Chapter 4
	Iron and Steel Production (2.C.1)	Update of CO_2 EF.	The CO_2 emission factors (EFs) for limestone and dolomite used as flux in iron and steel production had previously been kept constant for 1990–2021. The emission factors have been updated for 2007–2016, averaging the 2006 EFs (from a 2006 study) with the average emission factors calculated from facility-reported data to Canada's GHGRP for 2017–2022.	Continuous improvement	Chapter 4
LULUCF	Forest Land Remaining Forest Land (CRF 4.A.1)	Refinement of historical disturbance data.	Completion of a multi-year analysis to review and refine the area of forest land that had been historically harvested in Canada. For the majority of jurisdictions in Canada, where both harvest and wildfire are significant disturbances, the most reliable pre-1990 sources of data are provincial forest inventory records. In the provinces with large forestry industries, historic harvest data were 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 disturbed by wildfire. The stand origin prior to 1990 determines if the stand will be placed in the natural or anthropogenic partition. As a result the area of the anthropogenic component of the managed forest was reduced by 34 million hectares. By reducing the historic harvest area, a smaller area of growing forest is actively removing CO_2 from the atmosphere, resulting in smaller anthropogenic sink. Some modifications were also made to the CBM-CFS3 code to correct inconsistencies to improve tracking post-natural disturbance recovery rules.	Continuous improvement	section 6.3.1 Annex 3.5.2
	Land Converted to Forest Land (CRF 4.A.2)	Refinements to recent afforestation land use conversion types.	Recent afforestation site data have been reviewed to determine their pre-conversion land use. The initial implementation of recent afforestation files assumed that afforestation occurred on cropland.	Continuous improvement	section 6.3.2 Annex 3.5.2.6
	Cropland Remaining Cropland (CRF 4.B.1)	Refinements to Census data based on improved spatial representation and improved alignment with updated earth observation products.	Updated earth observation based land use (LU) coverage layers from which included the integration of an additional LU coverage year for 2020 and updates to LU mapping for previous years. Updated inventory crop yield estimates. The yield table was updated to improve spatial distribution of yield data. Integration of Soil Landscapes of Canada (SLC) census source data for 2021 to improve the spatial distribution of Census information from the provincial and Census Division spatial scale to distribute at the soil polygon scale.	Continuous improvement	section 6.5 Annex 3.5.4
Waste	Solid Waste Disposal (CRF 5.A)	Activity data improvements.	Refinements were made for waste disposal tonnages, export and incineration data, and methane recovery data. The updated disposal data (disposal from Statistics Canada, export and incineration compiled by ECCC) replaces previously extrapolated values.	Continuous improvement	section 7.2.5
	Wastewater Treatment/ Discharge (CRF 5.D)	Compilation query improvements and activity data updates.	Corrections were made to address calculation and compilation errors and updated data activity data. A query for the compilation of (industrial) wastewater data was corrected to remove double counting that was occurring in some cases. Improvements were also made to the extrapolation of these data.	Continuous improvement	Annex 3.6.4

Table 8–6 **Summary of Canada's Inventory Improvement Plan**

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Energy	General	Conversion of volumes of natural gas to energy units.	An assessment of energy conversion factors across three federal departments to allow volumes of natural gas to be converted to energy units by the province in which they are consumed.	UNFCCC ERT recommendation	Data collection and analysis underway
	Fuel Combustion – Manufacturing Industries and Construction (CRF 1.A.2)	Update EFs for waste fuels.	Work is underway to separate emission factors from fossil and biomass sources to more accurately allocate emissions from waste fuels into the appropriate fuel category.	UNFCCC ERT recommendation	Data analysis underway
	Fuel Combustion - Other Sectors (CRF 1.A.4)	Analyze and incorporate digester gas into emission estimates.	Work is underway to incorporate emissions from digester gas used for energy purposes into the stationary combustion model.	Continuous improvement	Data collection and analysis underway
	Fuel Combustion – Other Sectors (CRF 1.A.4)	Analyze and incorporate updated EFs for residential biomass combustion.	Work is underway to incorporate updated emission factors from residential biomass combustion into the stationary combustion model.	Continuous improvement	Data analysis underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Analyze and incorporate raw gas composition data for the province of British Columbia into emission estimates.	The British Columbia Energy Regulator (BCER) collects measured raw gas composition data for oil and gas wells drilled in the province and makes the data available on their website. The data will be analyzed to improve fugitive emission estimates from oil and gas facilities and the CO_2 EFs used to estimate emissions from raw gas combustion at oil and gas facilities.	Continuous improvement	Data analysis underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Analyze and incorporate updated EFs for abandoned oil and gas wells in Alberta and Saskatchewan.	New CH_4 emission factors derived from recent province-specific measurement studies of abandoned (plugged) and inactive/suspended (unplugged) oil and gas wells will be evaluated for incorporation into emission estimates.	Continuous improvement	Data analysis underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Develop Canadian-specific EFs from measurement data to improve estimates for post-meter fugitive emissions.	Canada currently estimates post-meter fugitive CH_4 emissions from natural gas appliances in the residential and commercial sector, natural gas vehicles, and industrial consumption of natural gas using IPCC default EFs. Ongoing measurements of residential and commercial appliances in Canada will be evaluated and used to develop Canadian specific EFs.	Continuous improvement	Data collection and analysis underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Further refinements to the incorporation of upstream oil and gas (UOG) CH_4 emissions derived from source-resolved atmospheric measurements.	The incorporation of UOG CH_4 emissions derived from source-resolved atmospheric measurements will be further refined to include additional sources, include measurements from additional field campaigns, and improve backcast techniques where required.	Continuous improvement	Data collection and analysis underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Refine method used to estimate emissions from SCVFs.	Continuous improvements to SCVF emission estimates using provincial data and available measurements, where available.	Continuous improvement	Data analysis underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Improved natural gas transmission and distribution emissions.	Work is underway to incorporate emission estimates for natural gas transmission, distribution and storage received from the Canadian Energy Partnership for Environmental Innovation (CEPEI) for the years 2016–2022. Historical emission estimates will be revised as required to reflect the most up-to-date data. Historical emission estimates will be revised as required to reflect the most up-to-date data.	Continuous improvement	Data analysis underway
	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.	Continuous improvement	Data analysis underway
	Road Transportation (CRF 1.A.3.b)	Update on-road vehicle population estimates.	Work is underway to incorporate the latest annual road motor vehicle registration totals reported by Statistics Canada into the road transportation emissions methodology. The increased detail of these reported totals is expected to result in updated on-road vehicle population estimates for most of the time series.	Continuous improvement	Data analysis underway
	Off-Road Transportation (General)	Revamp of off-road emissions model inputs.	Work is underway to incorporate several updates to off-road model inputs. Model inputs subject to updates include geographical distributions assigned to off-road vehicles/equipment and the annual hours-of-use parameter for select off-road equipment types.	Continuous improvement	Data collection and analysis underway
Oil and Gas (economic sector)	Natural Gas Production and Processing Conventional Light Oil Production Conventional Heavy Oil Production Oil Sands (Mining, In-Situ, Upgrading)	Refine allocation of emissions to the various Oil and Gas sector segments, i.e., Conventional Light Oil Production, Conventional Heavy Oil Production, Natural Gas Production and Processing, Oil Sands (Mining, In-situ and Upgrading), etc.	Statistics Canada reports fuel consumption data in the aggregated category "Total Mining and Oil and Gas Extraction" which includes all mining sectors (i.e., coal, metal mining, non-metal mining and quarrying, oil sands mining) and oil and gas extraction. Work is underway to refine the model used to allocate fuel consumption and the subsequent emissions from the aggregated category to more discrete categories and subcategories.	Continuous improvement	No significant progress made

Table 8–6 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
IPPU	Cement Production (CRF 2.A.1)	Investigate 2018 activity data discrepancy.	An activity data outlier in 2018 was identified, impacting the Implied Emission Factor (IEF) for Cement Production for this year. Activity data for Cement Production is under review to determine if corrections are required to resolve this discrepancy.	UNFCCC ERT recommendation	Data analysis underway
	Lime Production (CRF 2.A.2)	Resolve 2019 and 2021 activity data discrepancies.	Activity data outliers were identified in 2019 and 2021, impacting the Implied Emission Factors (IEFs) for Lime Production for these years. Activity data for Lime Production is under review to determine whether corrections are required, or if a new data source is necessary.	UNFCCC ERT recommendation	Data analysis underway
	Other Limestone and Dolomite Use (CRF 2.A.4.d)	Investigate potential activity data discrepancies for 2010 and onwards.	Potential activity data discrepancies were identified for limestone and dolomite use activity data, particularly for 2010 and onwards. Activity data is under review to determine whether corrections are required.	UNFCCC ERT recommendation	Data analysis underway
	Methanol Production (CRF 2.B.8.a)	Validate the applicability of EFs used.	The EFs used to estimate emissions from methanol production came from the 2010 Cheminfo study. The improvement plan is to assess the applicability of such EFs for years post-2010.	UNFCCC ERT recommendation	Data collection and analysis underway
	Titanium Dioxide Production (CRF 2.B.6)	Collect activity data and report category in the inventory. Prevent double-counting by reconciling anthracite coal and petroleum coke emissions associated with production of titanium slag and titanium dioxide using the chloride process between the Energy sector's Non-Ferrous Metals category, and IPPU sector's Titanium Dioxide Production category.	This category was previously assessed to be insignificant based on a Tier 1 estimate conducted in 2010 that included titanium dioxide produced using the chloride method at one facility. It was discovered upon review that this assessment was incomplete, and that titanium slag production has also taken place in Canada throughout the time-series at one facility. Using titanium slag process input and output material quantities and carbon contents reported in provincial reports that were submitted to the federal GHGRP from 2017 to 2019, emissions from the category are estimated to be potentially significant (more than 500 kt CO_2 eq). The inventory team is exploring different data sources for estimating emissions. For example, the inventory team is attempting to coordinate a data sharing agreement with the Quebec provincial government and the two facilities to allow access to provincially collected time-series information on production levels and process input and output quantities that would permit the use of the IPCC 2006 Tier 2 method for estimating emissions. In addition, the majority of emissions from this category are currently reported as part of the Energy sector's CO_2 emissions associated with Non-Ferrous Metals and Chemicals. The inventory team is analyzing how to reconcile these emissions with the Titanium Dioxide Production category to ensure that double-counting does not occur.	Continuous improvement	Data collection and analysis underway
	Iron and Steel Production (CRF 2.C.1)	Allocate natural gas and coal emissions associated with manufacturing with iron and steel manufacturing to Iron and Steel Production instead of the Energy sector's Manufacturing, and the IPPU sector's Non-Energy Products from Fuels and Solvent Use, respectively.	CO_2 emissions associated with Iron and Steel Production originate from the use of reductants other than metallurgical coke, specifically natural gas and coal. Natural gas is used as a reductant in the blast furnace and direct reduced iron (DRI) processes of iron manufacturing and is currently reported as part of the Energy sector's CO_2 emissions associated with Iron and Steel Production. A fraction of coal, shown in the RESD's non-energy line, is used in iron and steel making and is currently reported under the Non-Energy Products from Fuels and Solvent Use subcategory. It is planned to allocate the aforementioned emissions to the Iron and Steel Production Category, as detailed information becomes available.	UNFCCC ERT recommendation	Data collection and analysis underway
	Non-Metallurgical Magnesia Production (CRF 2.A.4.c) Magnesium Production (CRF 2.C.4)	Reallocation of CO_2 emissions associated with magnesium production from Non-Metallurgical Magnesia Production to Magnesium Production.	A portion of CO_2 emissions from magnesium production facilities that use magnesite as a raw material are currently reported under Non-Metallurgical Magnesia Production. In this improvement, CO_2 emissions from magnesium production facilities reported in Non-Metallurgical Magnesia Production (2.A.4.c) will be recalculated using the 2006 IPCC Tier 1 methodology (volume 3, section 4.5) and reallocated to 2.C.4. The CO_2 emissions to be reported in 2.C.4 will further account for facilities that use dolomite as a raw material.	Continuous improvement	Data analysis underway
	Non-Energy Products from Fuels and Solvent Use (CRF 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.	UNFCCC ERT recommendation	Initiated data collection / study
	Product Uses as Substitutes for ODS (HFCs, CRF 2.F)	Develop means to annually update imports and exports of manufactured -items containing HFCs.	A data gap exists with the manufactured item data, for which the last completely surveyed year is 2010. 2010 quantities along with some incomplete 2011–2015 data are used to extrapolate manufactured item quantities for 2011–2022. To fill this gap, the inventory team is exploring various options, such as collaborating with the United States Environmental Protection Agency's GHGRP, which collects information on the export and import of manufactured items containing HFCs. Manufactured item use statistics (e.g., number of vehicles with A/C units, and their vintage), manufactured item import/export data, and a voluntary survey of domestic importers and exporters will be examined to determine a method to arrive at updated HFC quantities.	UNFCCC ERT recommendation	Initiated data collection / study

Table 8–6 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
IPPU (cont'd)	Electrical Equipment (CRF 2.G.1)	Reporting of CF_4 emissions.	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 CF_4 gas. Currently, Canada only reports SF_6 from this source category and it is planned to report CF_4 emissions as well.	Continuous improvement	Initiated data collection / study
	Hydrogen Production	Include CO_2 emissions resulting from stand-alone hydrogen production facilities in Canada.	Collection of hydrogen production activity data and estimation of CO_2 emissions from this source using methods presented in the 2019 Refinement to the 2006 IPCC Guidelines.	Continuous improvement	Data analysis underway
	Product Uses as Substitutes for ODS – HFCs (CRF 2.F)	Update end-of-life EFs for HFCs in refrigeration and air conditioning applications.	The end-of-life EFs for HFCs in refrigeration and air conditioning applications are currently selected from the low end of the range from the 2006 IPCC Guidelines based on information collected through a 2013 Cheminfo survey and an analysis of the regulatory environment in Canada. The end-of-life EF for closed-cell foam blowing agents is currently set to 100% (the IPCC default) in the absence of country-specific information. It has been noted by an UNFCCC ERT review team that the industry practices are changing, and it is likely that changes to the EFs will have occurred during the time-series, which is especially relevant for the end-of-life emission factor and recovery rates. An information collection on HFC recovery at the end-of-life for refrigeration, air conditioning, and foam blowing applications will be sent to the Refrigeration Management Canada (RMC) program operated by the Heating, Refrigeration and Air Conditioning Institute of Canada as well as reclamation and destruction facilities. The inventory team has established contact with RMC in the past and intends to continue the communication to explore options for sharing of data (if any). If data can be collected, they will be assessed to determine the feasibility of developing updated EFs or to verify the current EFs	UNFCCC ERT recommendation	Data collection underway
	Semiconductor Manufacturing – SF_6 (CRF 2.E.1)	Eliminate the use of discontinued SF_6 import data from the semiconductor methodology.	The current SF_6 emissions estimate for semiconductors uses SF_6 import data from Statistics Canada as input. This SF_6 import data was terminated after 2011, and estimates of SF_6 imports for 2012–2022 are calculated using gross economic output data for NAICS 334 – Computer and Electronic Product Manufacturing. Sales data collected from large distributors in recent years (2014–2020) deviates significantly from the estimated SF_6 import data extrapolated using proxy data from the 2011 Statistics Canada value. As such, it is believed that SF_6 emissions from semiconductor manufacturing may be overestimated. The inventory team is exploring other data options for revising the model to eliminate the use of the discontinued SF_6 import data.	Continuous improvement	Alternative methods being considered
	SF_6 and PFCs from other product use – SF_6 and PFCs (CRF 2.G.2)	Data collection and significance assessment.	The UNFCCC ERT has recommended that the inventory team investigate whether SF_6 and PFC uses mentioned in the 2006 IPCC Guidelines (vol. 3, chap. 8, section 8.3) occur in Canada, and to determine the significance of emissions (in accordance with paragraph 37(b) of the UNFCCC Annex 1 inventory reporting guidelines). Historical sales data collected from gas distributors through voluntary data surveys indicate some use of SF_6 and PFCs for applications mentioned in the 2006 IPCC Guidelines. The inventory team aims to collect top-down import/export or sales data to analyze the significance of the category. The inventory team is exploring collaboration with the United States Environmental Protection Agency's GHGRP to receive data on SF_6 and PFC exports from the United States to Canada. Alternatively, a historical survey will be sent to gas distributors to obtain a time-series estimate of SF_6 and PFCs sold within Canada for applications mentioned. Once data is collected, a Tier 1 emission estimation will be performed to assess the significance of emissions coming from this category. If the category is determined to be significant, efforts will be made to develop and publish emission estimates for the whole time series.	UNFCCC ERT recommendation	Data collection underway
	N_2O Emissions from Medical Applications (CRF 2.G.3.a) and Propellant Usage (CRF 2.G.3.b)	Update N_2O sales patterns by application.	The N_2O sales pattern by application is based on 2005 data and has been assumed to be the same since. Work is underway to update the sales pattern by application.	Continuous improvement	Data collection underway
	PFC Emissions from Other Contained Product Uses (CRF 2.G.4)	Reallocation of all activity data to other CRF categories, such as applications in CRF 2.E.1, 2.F, or 2.G.2.	Activity data contributing to CRF 2.G.4 are under review and legacy data sources are being investigated in order to reallocate activity data to the correct categories.	UNFCCC ERT recommendation	Data analysis underway

Table 8–6 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Agriculture	Enteric Fermentation/ Manure Management (CRF 3.A/3.B)/ Agricultural Soils (CRF 3.D)	Integrate new information on animal nutrition.	Continued improvements to animal nutrition time series are being carried out based on the review and compilation of multiple data sources. Although priority is on the beef sector, minor refinements to the dairy and swine sectors will be carried out as required. Data have been collected and analyzed, but model development is not complete. Approval and alignment with AAFC methodologies, specifically methodologies used in the estimation of ammonia volatilization, are required, to be followed by database implementation.	Continuous improvement	Developing new parameters
	Enteric Fermentation/ Manure Management (CRF 3.A/3.B)/ Agricultural Soils (CRF 3.D)	Update dairy nutrition parameters.	A dairy nutrition time series is currently used to track changes in animal feed and characteristics for dairy cattle. 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 database implementation.	Continuous improvement	Data analysis underway
	Manure Management (CRF 3.B)	Integrate new information on manure management systems.	Integrate information from multiple surveys to attempt 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 require approval and alignment with AAFC methodologies, specifically methodologies used in the estimation of ammonia volatilization, followed by database implementation.	Continuous improvement	Developing new parameters
	Manure Management (CRF 3.B)	Revise methane conversion factors (MCFs).	Methane conversion factors (MCFs) obtained from the 2006 IPCC Guidelines are currently used in the calculation of manure management methane emissions. For certain manure management systems, the default MCF is selected based on a relationship with the average annual temperature of the manure systems. An updated methodology has been provided in the 2019 Refinement to the 2006 Guidelines that uses monthly temperatures and retention time as predictors of methane loss, rather than an averaged annual temperature. Canada plans to implement the 2019 refinement approach as both a continuous improvement and to address an ERT recommendation to regarding the current averaged MCFs used.	UNFCCC ERT recommendation	Data collection underway
	Agricultural Soils (CRF 3.D)	Integrate estimates of N_2O emissions from land application of compost.	Canada currently does not report N_2O emissions from the application of compost to agricultural soils because of a lack of activity data. 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.	UNFCCC ERT recommendation	Data analysis underway
	Agricultural Soils (CRF 3.D)	Revision of methodologies for estimating soil nitrous oxide emissions from cultivation of histosols.	Revise estimates for Cropland on drainage of organic soils considering guidance from the IPCC Wetlands Supplement.	Continuous improvement	Data analysis underway
	Field Burning of Agricultural Residues (CRF 3.F)	Improve estimates of crop residue burning.	Data on crop residue burning are available from the Farm Environmental Management Survey (2011), but these data have not been updated for estimating emissions of GHGs. Survey data on field burning of agricultural residues will be extracted and incorporated into the database.	Continuous improvement	Data analysis underway
LULUCF	Cross-cutting	Address completeness of LULUCF subcategories with estimates reported as not estimated (NE).	Improve the completeness of reporting of pools in mandatory categories currently reported as NE.	UNFCCC ERT recommendation	Data collection underway
	Cross-cutting	Development of a plan and time frame for estimating and reporting uncertainties for all LULUCF subcategories.	Canada provides detailed uncertainty analysis for most LULUCF subcategories. However, uncertainty analysis for all subcategories has not been undertaken due to resource limitations. 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.	UNFCCC ERT recommendation	Alternative methods being considered
	General: Land Transition Matrix (CRF 4.1)	Revise and improve the consistency and completeness of the land transition matrix.	Include in the next NIR any update on the status of implementation of the project to revise and improve the consistency and completeness of the land transition matrix.	UNFCCC ERT recommendation	Data analysis underway
	Forest Conversion and other land-use change categories (it may impact Cropland, Wetlands, Settlements land categories and Harvested Wood Products, i.e., CRF 4.B.2, 4.D.2, 4.E.2 and 4.G respectively)	Land-use change improvements.	Improvements include: i) C loss from wetland soils during wetland to settlement conversion in the oil sands region; ii) refinements to estimates of northern land-use change; iii) capturing the impacts of expanding cities on land C stocks and fluxes; iv) update older time periods of deforestation activity data used by CBM-CFS3 and v) update deforestation impact assumptions.	Continuous improvement UNFCCC ERT recommendation	Developing new parameters Data analysis underway
	Forest Land (CRF 4.A) Harvested Wood Products (CRF 4.G)	Baseline data/processes/ parameters improvements.	Improvements include: i) improved spatial distribution of harvest and volume to C; ii) update climate normal data; iii) integrate activity data associated to recent afforestation; and iv) provincial inventory updates	Continuous improvement	Data analysis underway

Table 8–6 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
LULUCF (cont'd)	Forest Land (CRF 4.A) Biomass burning (CRF 4(V))	Science improvements.	Improvements include: i) refinements to wildfire emissions estimates through variable burn intensity; ii) refinements to British Columbia slashburning activity; iv) new calibrated soil and dead organic matter C modelling parameters, updated uncertainty analysis confidence intervals; and v) integrating nationwide estimates of controlled biomass burning in the NIR, Air Pollutant and Black Carbon Emissions Inventories.	Continuous improvement	Data analysis underway
	Cropland (CRF 4.B.1)	An integrated modeling of soil carbon storage through Bayesian methods.	Using 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 to improve model performances through Bayesian optimization (RothC, IPCC Tier 2 Steady State, DeNitrification DeComposition (DNDC) and Introductory Carbon Budget Model (ICBM)	Continuous improvement	Data collection and method development underway
	Cropland (CRF 4.B.1)	Woody Biomass improvements.	Improve estimation of areas under woody biomass and changes in C stocks in croplands since 1980 through use of earth observation data and deep learning methods.	Continuous improvement	Data analysis underway
	Wetland Remaining Wetland (CRF 4.D.1)	Update to Peat Extraction Model and Activity Data.	New Canadian science will be integrated into the peat extraction model emission factors and activity data quantifying wetland restoration and abandonment will be updated with a new sampling point for 2020 to estimate extent of peatland areas disturbed by peat extraction with high-resolution satellite imagery.	Continuous improvement	Data analysis underway and method development underway.
	Wetlands Converted to Cropland (CRF 4.B.2)	Address completeness of LULUCF subcategories with estimates reported as NE.	Improve the completeness of reporting of pools in mandatory categories currently reported as NE. Carbon loss resulting from agricultural drainage of inland mineral wetland in the Prairie Potholes Region.	UNFCCC ERT recommendation	Data collection underway
	Wetland Remaining Wetland (CRF 4.D.1.2) Land Converted to Wetland (Flooded Land) (CRF 4.D.2.2)	Development of activity data, parameters and EFs for CH_4 and CO_2 in flooded lands.	Improve knowledge of CH_4 and CO_2 emissions in flooded lands with updated activity data and EFs.	Continuous improvement	Data collection underway
	Settlements Remaining Settlements (CRF 4.E.1.1)	Development of a new time series for 2005, 2015, and 2020 for urban trees and urban area boundaries. Revise model and urban boundaries.	Updates for 2005, 2015 and 2020 activity data by sampling of digital air photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas. Updates to urban area boundaries that better represent settlements. Refine model to improve estimates of carbon stock change.	Continuous improvement	Data collection underway and method development underway
	Harvested Wood Products (CRF 4.G)	Harvested Wood Products improvements.	Improvements include: i) to add regional detail to HWP production and trade parameters used in the HWP model; ii) to enhance the uncertainty analysis of HWP estimates by considering the uncertainty inherent to the C inputs; iii) develop country-specific half-lives for a significant portion of Canada's HWP production that reflects much longer HWP residence times in housing than the IPCC default values; iv) improve the accuracy of residential biomass burning EFs; and v) improve knowledge and characterization of industrial fuelwood.	Continuous improvement	Developing new parameters
Waste	Solid Waste Disposal (CRF 5.A.2)	Inclusion of Tier 3, facility-reported emissions.	For the medium- to long-term, areas of focus are: incorporating facility reported GHG data, review and potential use of CH_4 direct measurement at landfills, and improving the characterization of harvested wood products in the waste stream.	Continuous improvement	N/A
	Wastewater Treatment and Discharge (CRF 5.D)	Update to receiving waterbody type (effluent emissions).	Efforts are underway to map effluent discharge to water body type (such as lake, river, estuary, etc.,) to apply specific receiving water body type emission factors.	Continuous improvement	Data analysis underway
	Wastewater Treatment and Discharge (CRF 5.D)	Update to population associated with treatment technology.	Assessing the possibility of further disaggregating the spatial distribution of septic-use rates to include small and medium sized cities. Current methods assess 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 influence estimates of population using centralized treatment systems.	Continuous improvement	Analysis underway

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PART 2 AND PART 3

The 2024 edition of Canada's National Inventory Report (NIR) has been published simultaneously in both official languages, English and French. The NIR Part 1 (Executive Summary and Chapters 1 to 8) has been submitted in PDF format to the United Nations Framework Convention on Climate Change (UNFCCC) in both official languages. All content from NIR Parts 2 and 3 (Annexes 1 to 13) is also available in both official languages, in various formats at open.canada.ca[1] as outlined below.

NIR	Annex	Content
Part 2	1	Key categories
	2	Uncertainty
	3	Methodologies
	3.1	Fossil fuel combustion
	3.2	Fossil fuel production, processing, transmission and distribution
	3.3	Industrial Processes and Product Use sector
	3.4	Agriculture sector
	3.5	Land Use, Land-Use Change and Forestry sector
	3.6	Waste sector
	4	Comparison of sectoral and reference approaches, and the national energy balance
	5	Assessment of completeness
	6	Emission factors
	7	Ozone and aerosol precursors
Part 3	8	IPCC sector rounding protocol
	9	Canada GHG emission tables by IPCC sector, 1990–2022
	10	Canada GHG emission tables by economic sector, 1990–2022
	11	Provincial and territorial GHG emission tables by IPCC sector, 1990–2022
	12	Provincial and territorial GHG emission tables by economic sector, 1990–2022
	13	Electricity in Canada: Summary and intensity tables

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