NATIONAL INVENTORY REPORT 1990–2021: GREENHOUSE GAS SOURCES AND SINKS IN CANADA

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

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Rapport d'inventaire national 1990–2021 : Sources et puits de gaz à effet de serre au Canada

FOREWORD

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC or Convention) on December 4, 1992. Under Decisions 3/CP.1, 9/CP.2 and 24/CP.19 of the UNFCCC, national inventories of sources and sinks of greenhouse gases (GHGs) must be submitted to the UNFCCC by April 15 of each year. This report is part of Canada's annual inventory submission under the Convention.

Canada's 2023 national GHG inventory complies with the requirements of the revised UNFCCC reporting guidelines for national GHG inventories (see Decision 24/CP.19). The reporting guidelines require Annex I 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 2022. Ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce their uncertainties as far as practicable.

April 2023

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Executive Summary

Tatyana Abou-Chaker, Sean Angel, Alice Au, Warren Baker, Nicholas Bishop, Dominique Blain, 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, Anne-Marie St-Laurent Thibault, Kristine Tracey, Brittany Sullivan, Brett Taylor, Arumugam Thiagarajan, and Melanie Vanderpol.

Chapter 1: Introduction

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Chapter 2: Greenhouse Gas Emission Trends

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Chapter 4: Industrial Processes and Product Use (CRF Sector 2)

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Chapter 6: Land Use, Land-Use Change and Forestry (CRF Sector 4)

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Chapter 7: Waste (CRF Sector 5)

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Chapter 8: Recalculations and Improvements

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Annexes

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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 was led by Catherine Robert. Compilation of uncertainty estimates as well as key category analyses were led by Samuel Belliveau. 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 Sara Gagnon-Calestagne. Special thanks to Samuel Belliveau, Alessia Czerwinski, and Monique Murphy for the development of webpages related to this publication. The compilation and coordination of the CRF tables (companion to this document in Canada's United Nations Framework Convention on Climate Change submission) was managed by Catherine Robert.

We would like to acknowledge the contributions of our colleagues in the Oil, Gas and Alternative Energy Division (OGAED) and the Regulatory Analysis and Valuation Division at ECCC who contributed in analyzing oil and gas data and developing emission factors and parameters used to estimate fugitive emissions from the oil and gas sector. Special thanks are also given to Richard Holt and Navin Sundar of the Cross Sectoral Energy Division of ECCC for implementing the Marine Emissions Inventory Tool. We also thank Marianne Racine of the Chemicals Production Division of ECCC for providing bulk hydrofluorocarbon (HFC) import and export data, as well as providing inputs on data corrections and inquiries.

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Readers' Comments

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LIST OF COMMON ABBREVIATIONS AND UNITS

Abbreviations

CAC	criteria air contaminant
CANSIM	Statistics Canada's key socioeconomic database
CEPA 1999	*Canadian Environmental Protection Act, 1999*
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
DOC	dissolved organic carbon
ECCC	Environment and Climate Change Canada
EF	emission factor
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
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
LTO	landing and takeoff
LULUCF	Land Use, Land-Use Change and Forestry
MSW	municipal solid waste
N/A	not available
NDC	nationally determined contribution
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
PFC	perfluorocarbon
POP	persistent organic pollutant
QA	quality assurance
QC	quality control

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

TAN .... total ammoniacal nitrogen

UOG .... upstream oil and gas

VKT .... vehicle kilometres traveled

UNECE.............................. United Nations Economic Commission for Europe

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

C_6H_6 .... benzene

CO .... carbon monoxide

CO_2 .... carbon dioxide

CO_2 eq .... carbon dioxide equivalent

H_2 .... hydrogen

H_2O .... water

H_2S .... hydrogen sulphide

HNO_3 .... nitric acid

Mg .... magnesium

$MgCO_3$ .... magnesite; magnesium carbonate

MgO .... magnesia; dolomitic lime

N .... nitrogen

N_2 .... nitrogen gas

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

SO_2 .... sulphur dioxide

SO_x .... sulphur oxides

Notation Keys

IE .... included elsewhere

NA .... not applicable

NE .... not estimated

NO .... not occurring

Units

g .... gram

Gg .... gigagram

Gt .... gigatonne

ha .... hectare

kg .... kilogram

kha .... kilohectare

km .... kilometre

kt .... kilotonne

kWh .... kilowatt-hour

m .... metre

Mg .... megagram

Mha .... million hectares

mm .... millimetre

ML .... megalitre

Mt .... megatonne

MW .... megawatt

PJ .... petajoule

TJ .... terajoule

t .... tonne

TWh .... terawatt-hour

EXECUTIVE SUMMARY

ES.1. Key Points

- In 2021, Canada's greenhouse gas (GHG) emissions were 670 megatonnes of carbon dioxide equivalent (Mt CO_2 eq), decreasing by 62 Mt (8.4%) from 2005 and increasing by 12 Mt (1.8%) from 2020, but remaining 53 Mt (7.4%) below pre-pandemic (2019) emission levels.
- Transport and Oil and Gas Extraction combustion emissions increased by 9.0 Mt (5.0%) and 4.0 Mt (4.0%), respectively, between 2020 and 2021, while emissions from Residential Stationary Combustion Sources and Agricultural Soils respectively decreased by 1.5 Mt (4.0%) and 1.4 Mt (7.0%), respectively.
- The emissions intensity for the entire Canadian economy (GHG per gross domestic product [GDP]) has declined by 42% since 1990 and by 29% since 2005.
- While the COVID-19 pandemic undoubtedly impacted recent year emissions, the sustained decline in emission intensities over time can be attributed to fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.
- Significant methodological improvements were implemented in the estimation of waste landfills and transport emissions, among others, along with the inclusion of a new source, post-meter fugitive emissions; overall this edition of the inventory incorporates downward revisions of 9.0 Mt in 2005 and 14 Mt in 2020. 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.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 achieve its objective and implement its provisions, the UNFCCC sets out several guiding principles and commitments. Specifically, Articles 4 and 12 commit 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 all GHGs not controlled by the Montreal Protocol, with the exception of hydrofluorocarbons (HFCs).[1]

Canada's National Greenhouse Gas Inventory is prepared and submitted annually to the UNFCCC by April 15 of each year 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. The annual inventory submission consists of the NIR and the Common Reporting Format (CRF) tables.

The GHG inventory includes emissions and removals of carbon dioxide (CO_2), and emissions of methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), 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 Intergovernmental Panel on Climate Change's (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 Methodological Improvements box below).

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 below).

In keeping with the UNFCCC Reporting Guidelines, the GHG inventory reports annual emissions from 1990 up to and including two years prior to its submission (e.g. 2021 for the 2023 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 UNFCCC Reporting Guidelines.

Section ES.3 of this Executive Summary provides 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 2005–2021 period.

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 and a timetable for implementation of measures. Building from this Plan, Canada's Methane Strategy (2022) outlines measures to further reduce domestic methane emissions by more than 35% by 2030, compared to 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 behaviors. 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.

1 The Montreal Protocol on Substances that Deplete the Ozone Layer is an international environmental agreement designed to reduce the global production and consumption of ozone-depleting substances. The United Nations Environment Programme (UNEP) is assisting the Parties in the achievement of the Montreal Protocol objectives. (UNEP, n.d.)

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. Finally, section ES.7 provides some detail on the components of this submission and outlines key elements of its preparation.

ES.3. Overview, National GHG Emissions

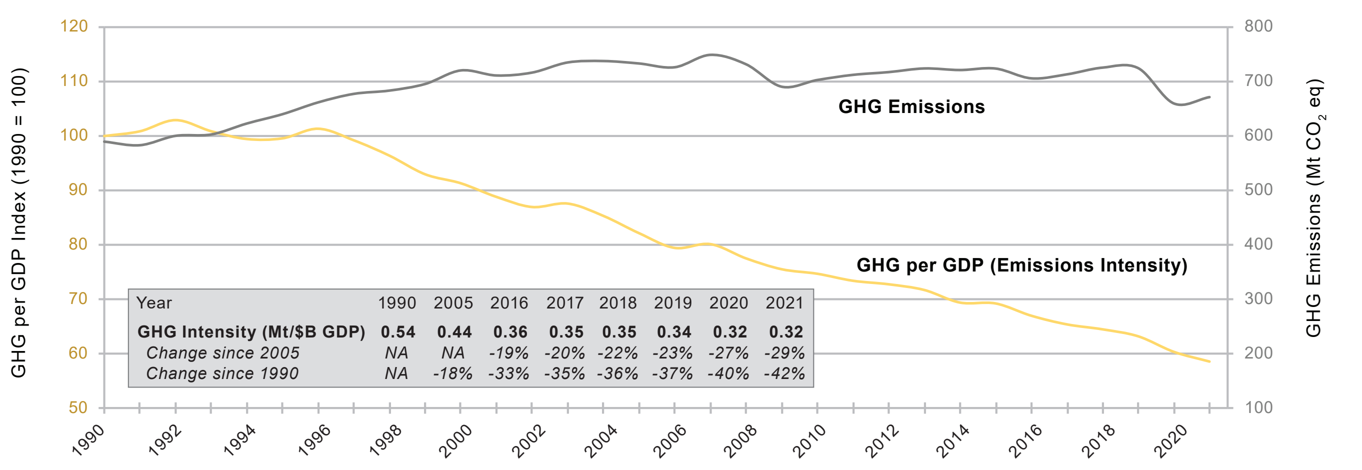
Canada accounts for approximately 1.6% of global GHG emissions (Climate Watch, 2023 for the year 2019), making it the 10th largest emitter. While Canada is one of the highest per capita emitters, per capita emissions have declined since 2005 from 22.7 t CO_2 eq/capita to 17.5 t CO_2 eq/capita in 2021 (StatCan, n.d.[a]).

Changes in Total Emissions

After fluctuations in recent years, Canada's GHG emissions were 670 Mt CO_2 eq[3] in 2021, a net decrease of 62 Mt or 8.4% from 2005 emissions.[4] In general, year-to-year fluctuations are superimposed over actual trends observed over a longer time 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 declined by 42% since 1990 and by 29% since 2005 (Figure ES–1). The decline in emissions intensity can be attributed to fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.

Recent emission fluctuations are described here, while the remainder of this Executive Summary and Chapter 2 focuses on trends and their drivers. The COVID-19 pandemic contributed to an abrupt decrease of 64 Mt (9.0%) 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 (-24 Mt or -7.4%) and Fugitive Sources (-9.0 Mt or -14%).

Figure ES–1 **Canadian GHG Emissions and Indexed Trend Emissions Intensity (excluding Land Use, Land-Use Change and Forestry)**



Year	1990	2005	2016	2017	2018	2019	2020	2021
GHG Intensity (Mt/$B GDP)	**0.54**	**0.44**	**0.36**	**0.35**	**0.35**	**0.34**	**0.32**	**0.32**
Change since 2005	*NA*	*NA*	*-19%*	*-20%*	*-22%*	*-23%*	*-27%*	*-29%*
Change since 1990	*NA*	*-18%*	*-33%*	*-35%*	*-36%*	*-37%*	*-40%*	*-42%*

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

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

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

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

Between 2020 and 2021, the major contributors to the overall increase were the Transport subsector and Oil and Gas Extraction category with increases of 9.0 Mt (5.0%) and 4.0 Mt (4.0%), respectively. During that same time period, emissions from the Residential Stationary Combustion Sources category and Agricultural Soils subsector decreased respectively by 1.5 Mt (4.0%) and 1.4 Mt (7.0%).

Between 2019 and 2020, the decrease in Transport 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 2021, Road Transportation was responsible for the majority of the emissions increase in Transport (5.2 Mt or 4.7%).

Between 2019 and 2020, decreases in Public Electricity and Heat Production (-8.1 Mt or -12%) were due to reduced coal consumption partially offset by an increase in natural gas consumption. Plant closures can partially explain decreases in Manufacturing Industries (-3.8 Mt or -8.7%). Between 2020 and 2021, combustion emissions from Oil and Gas Extraction increased by 4.0 Mt (4.0%), consistent with a rise in crude bitumen (13%), synthetic crude oil (6%) from oil sands and natural gas (4%). Emissions from Manufacturing industries also increased by 1.2 Mt (3%). In contrast, emissions in the Residential category decreased by 1.5 Mt (4.0%) between 2020 and 2021, largely driven by a continued decreasing consumption of light fuel oil. Public Electricity and Heat Production also decreased by 1.1 Mt (1.7%) between 2020 and 2021, due to further reductions in coal consumption.

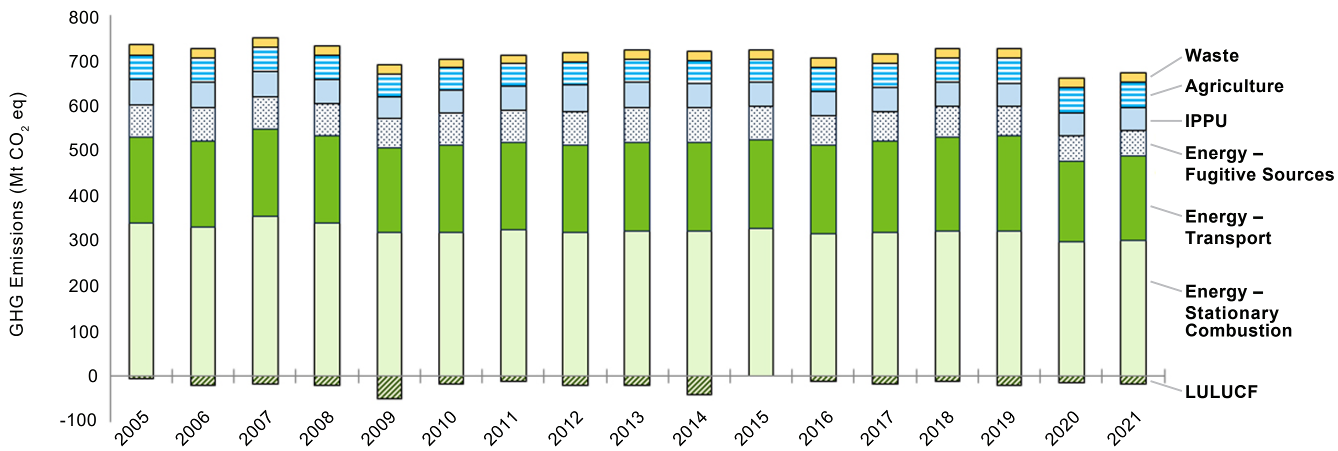
Temporary plant shutdowns during the first pandemic year can also partially explain the decrease between 2019 and 2020 in the Industrial Processes and Product Use (IPPU) sector (-2.5 Mt or -4.8%). Between 2020 and 2021, the IPPU sector emissions increased by 1.6 Mt (3.1%) mostly due to a return to pre-pandemic production levels in some sectors.

For Fugitive Sources, emission decreases between 2019 and 2020 included venting (-6.8 Mt or -21%), and leaks from oil (-1.3 Mt or -9.9%) and natural gas production and processing facilities (-1.1 Mt or -9.1%). Fugitive sources emissions remained stable between 2020 and 2021.

Within Agricultural Soils, between 2020 and 2021, emissions decreased by 1.4 Mt (7.0%), mainly due to a sharp decrease in crop production following drought conditions on the prairies.

Notwithstanding the 2019–2021 abrupt decrease, the general emission breakdown by IPCC sector has not substantially changed over time (Figure ES–2).

Figure ES–2 **Trends in Canadian GHG Emissions by Intergovernmental Panel on Climate Change Sector (2005–2021)**

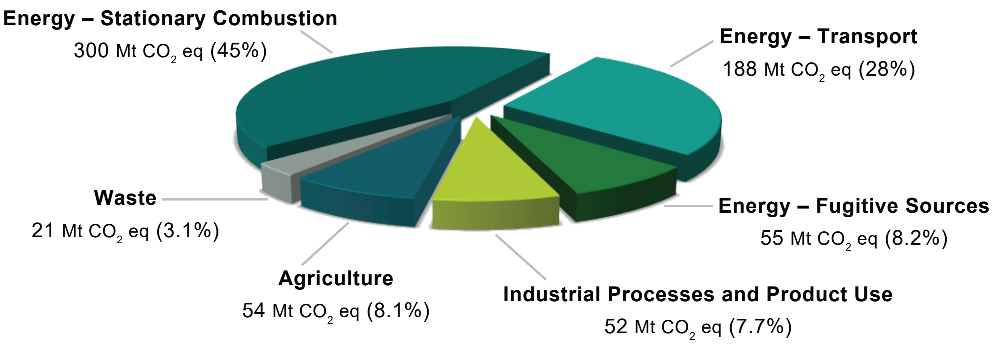


ES

Emission Breakdown

In 2021, the Energy sector (consisting of Stationary Combustion Sources, Transport and Fugitive Sources) emitted 543 Mt, or 81% of Canada's total GHG emissions (Figure ES–3). The remaining emissions were largely generated by the Agriculture and IPPU sectors (8.1% and 7.7%, respectively), with contributions from the Waste sector (3.1%). The LULUCF sector removed 17 Mt from the atmosphere.

Figure ES–3 **Breakdown of Canada's Emissions by Intergovernmental Panel on Climate Change Sector (2021)**

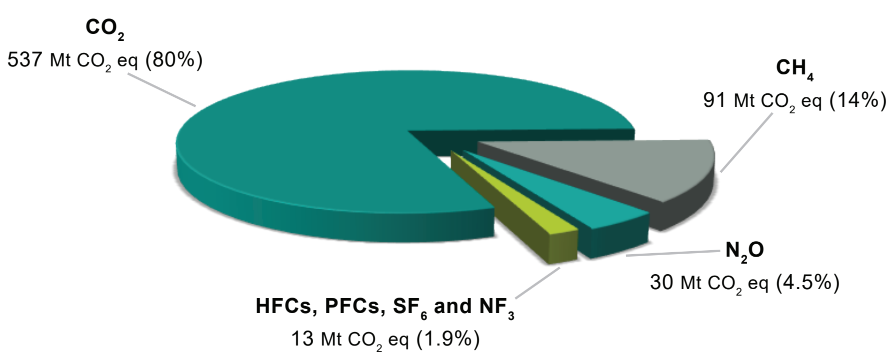


Total: 670 Mt CO_2 eq

Note: Totals may not add up due to rounding.

Canada's emissions profile is similar to that of most industrialized countries, in that CO_2 is the largest contributor to total emissions, accounting for 537 Mt or 80% of total emissions in 2021 (Figure ES–4). The majority of CO_2 emissions in Canada result from the combustion of fossil fuels. CH_4 emissions in 2021 amounted to 91 Mt or 14% of Canada's total. These emissions consist largely of fugitive emissions from oil and natural gas systems (37 Mt), agriculture (28 Mt) and landfills (18 Mt). N_2O emissions mostly arise from agricultural soil management, accounting for 30 Mt or 4.5% of Canada's emissions in 2021. Emissions of synthetic gases (HFCs, PFCs, SF_6 and NF_3) accounted for slightly less than 2% of national emissions.

Figure ES–4 **Breakdown of Canada's Emissions by GHG (2021)**



Total: 670 Mt CO_2 eq

Note: Totals may not add up due to rounding.

Methodological 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 a 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.

Environment and Climate Change Canada (ECCC) continuously consults and works with scientists and experts in federal, provincial and territorial agencies, industry, research institutions and consultants, to improve inventory quality. Improved understanding, refined or more comprehensive data are used to develop and integrated in more accurate methods. The implementation of methodological improvements leads to the recalculations of previous estimates to maintain a consistent trend in emissions and removals.

The 2023 edition of the GHG inventory incorporates methodological improvements in the estimations of waste landfills (-5.0 Mt in 2020), and on-road (-16 Mt in 2020) and off-road (+15 Mt in 2020) transport emissions, among others. A new source was also included—post-meter fugitive emissions (approximately 1.9 Mt in 2021), which includes leaks from residential and commercial natural gas appliances, natural gas-fueled vehicles and at power plants and industrial facilities that consume natural gas. Overall, the recalculations resulted in -9.0 Mt in 2005 and -14 Mt in 2020.

Chapter 8 of the present report provides greater detail on the impact of current inventory improvements on the overall emission trends and also, on planned improvements. Significant improvements to inventory estimates are anticipated in future editions of this report, notably for managed forest land. These changes include new and updated data on historical harvest areas in Canada (1890 to 1989) that change both the level of and the trend in emissions and removals from the land sector and impact, in particular, the five provinces with the largest forest products industries. For additional detail on LULUCF planned improvements, refer to the Improvement Plan for Forest and Harvested Wood Products Greenhouse Gas Estimates.

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

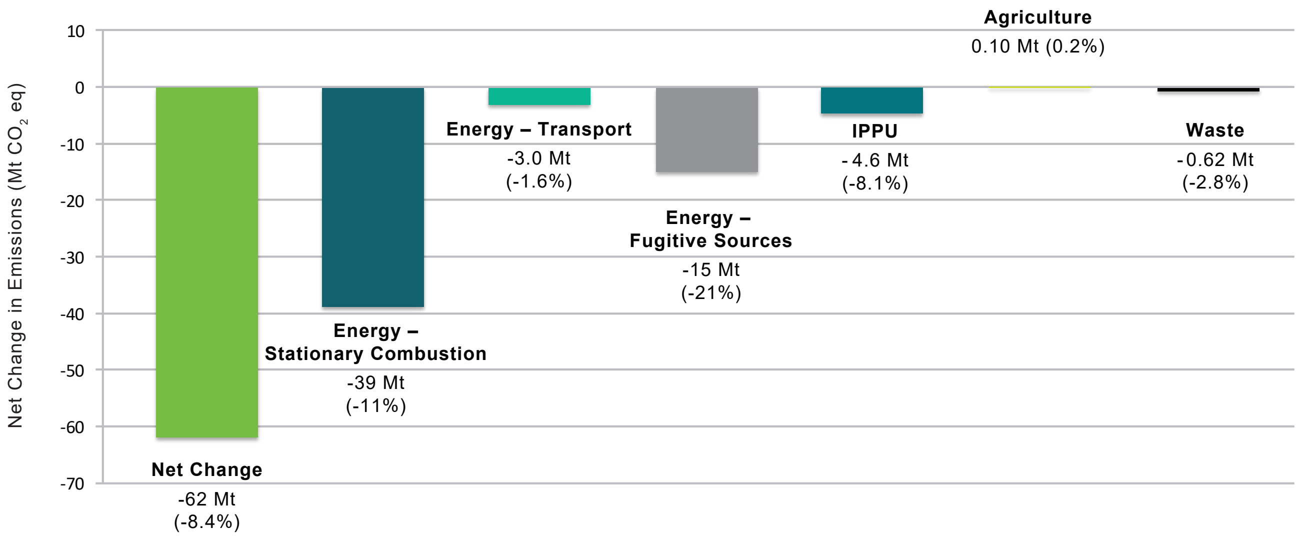
Trends in Emissions

Over the 2005–2021 period, total emissions have decreased by 62 Mt or 8.4%. The Energy sector dominated, with emission decreases of 39 Mt (12%) in Stationary Combustion Sources, 15 Mt (21%) in Fugitive Sources, and 3.0 Mt (1.6%) in Transport (Table ES–1). Over the same period, emissions have decreased by 4.6 Mt (8.1%) in the IPPU sector and 0.62 Mt (2.8%) in the Waste sector. The Agriculture sector emissions have remained relatively stable with a 0.10 Mt or 0.2% increase (Figure ES–5).

Chapter 2 provides more information on GHG emissions trends since 1990 and 2005 and their drivers.[5] Further breakdowns of emissions and a complete time series can be found at open.canada.ca.

5 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 (2005–2021)**



Energy – 2021 GHG Emissions (543 Mt)

In 2021, GHG emissions from the IPCC Energy sector (543 Mt) were 9.5% lower than in 2005 (600 Mt). Within the Energy sector, a 40 Mt (64%) increase in combustion emissions from Oil and Gas Extraction and a 5.2 Mt (11%) increase in Other Transportation emissions were offset by a 64 Mt (52%) decrease in emissions from Public Electricity and Heat Production, a 15 Mt (21%) decrease in Fugitive Sources, a 7.2 Mt (15%) decrease in emissions from stationary fuel consumption in Manufacturing Industries, a 6.9 Mt (34%) decrease in emissions from Petroleum Refining, a 6.8 Mt (16%) decrease in emissions in the Residential sector, and a 6.7 Mt (5%) decrease in Road Transportation.

Stationary Combustion Sources (300 Mt)

Decreasing electricity generation from coal and oil usage (by 66% and 81%, respectively) was a large driver of the 64 Mt (52%) decrease in emissions associated with Public Electricity and Heat Production between 2005 and 2021.

Reduced coal consumption in Alberta and Ontario respectively accounted for 53% and 39% of the overall decrease. Significant reductions in coal consumption also occurred in Saskatchewan (19% of provincial consumption), Nova Scotia (21%), New Brunswick (49%) and Manitoba (100%). Decreased oil consumption for electricity generation in New Brunswick (87%) and Nova Scotia (91%) accounted for 91% of the total reduction in oil consumption. Emission fluctuations over the period reflect variations in the mix of electricity generation sources. Over the time period, the amount of low-emitting generation in the mix has increased.[6]

The 40 Mt increase in emissions from stationary fuel consumption in Oil and Gas Extraction is consistent with a 215% rise in crude bitumen and synthetic crude oil production from Canada's oil sands operations since 2005.

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 6.9 Mt (34%) in Petroleum Refining Industries emissions.

GHG emissions from fuel consumption in Manufacturing Industries decreased by 7.2 Mt (15%) between 2005 and 2021, consistent with a 16% decrease in energy use (StatCan, n.d.[c]). The decrease occurred in Other Manufacturing (-3.8 Mt or -24%), Pulp and Paper (-1.7 Mt or -20%), Cement (-1.6 Mt or -29%), Non-Ferrous Metals (-0.65 Mt or -17%), and Iron and Steel (-0.35 Mt or -6.3%), in contrast with an increase in Chemicals (0.94 Mt or 11%).

The 6.8 Mt (16%) decrease in emissions in the Residential category between 2005 and 2021 is largely driven by decreasing consumption of light fuel oil in all provinces and territories, except Manitoba (10% increase). Quebec and Ontario account for 84% of the decrease in emissions from light fuel oil, with the other provinces and territories making up the remaining 16%.

6 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 (188 Mt)

The majority of 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 generating greater emissions. Despite a reduction in kilometres driven per vehicle, the total vehicle fleet in 2021 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, Transport emissions decreased 31 Mt, bringing 2020 Transport emissions below 2005 levels. From 2020 to 2021, Transport emissions increased by 9.0 Mt, keeping them slightly below 2005 levels.

Fugitive Sources (55 Mt)

Fugitive Sources are comprised of flaring, venting and other 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, over 200,000 oil and gas wells have been drilled and the number of producing wells has increased by 8%. Crude oil and natural gas production has also increased by 35%, mostly due to Canada's Oil Sands. Even with the increased output and activity, Fugitive Sources emissions have decreased by 15 Mt (21%). This includes a 5.7 Mt (8.1%) decrease between 2005 and 2019 largely the result of measures to increase the conservation of natural gas (comprised mainly of CH_4), as well as a 9.0 Mt (14%) decrease between 2019 and 2020 that coincides with federal and provincial measures to reduce methane emissions from the upstream oil and gas industry. No significant change was observed between 2020 and 2021 (-0.23 Mt or -0.42%).

Industrial Processes and Product Use – 2021 GHG Emissions (52 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 52 Mt (7.8%) to Canada's 2021 emissions.

Between 2005 and 2021, process emissions from most IPPU categories decreased. A notable exception is the 6.4 Mt (125%) increase in emissions from the use of HFCs to replace chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). However, since 2018, HFC emissions have been decreasing, primarily due to a reduction in HFC imports.

Some industrial facilities that experienced temporary shutdowns in 2020 returned to regular production levels in 2021, resulting in process emission increases of 0.67 Mt (10%) for Cement Production and of 0.12 Mt (10%) for Lime Production, compared to 2020 emission values.

Since 2005, process emissions for the iron and steel industry have reduced by 2.3 Mt (23%) primarily due to decline in use of metallurgical coke as reductant during the pig iron production process. The aluminium industry has also decreased its process emissions by 2.8 Mt (33%) 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. Closure of primary magnesium plants in 2007 and 2008 also accounted for 1.1 Mt (89%) of the overall process emission drop (-6.3 Mt or -31%) seen in Metal Production between 2005 and 2021.

The overall decrease of 4.6 Mt (45%) 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. A smaller proportion (1.0 Mt) of the decrease can be attributed to the nitric acid industry, mainly from N_2O emissions abatement installations at a nitric acid production facility. Variations throughout the time series in petrochemical industry-related emissions can be attributed to facility closures and changes in production capacities at existing facilities, such as the closure of two methanol facilities in 2005 and 2006, and an increase in ethylene production in 2016.

Agriculture – 2021 GHG Emissions (54 Mt)

The Agriculture sector covers non-energy GHG emissions related to the production of crops and livestock. Emissions from Agriculture accounted for 54 Mt, or 8.1% of total GHG emissions for Canada in 2021.

In 2021, Agriculture accounted for 31% of national CH_4 emissions and 75% of national N_2O emissions.

The main drivers of the emissions trend in the Agriculture sector are the fluctuations in livestock populations and the application of inorganic nitrogen fertilizers to agricultural soils in the Prairie provinces. Since 2005, fertilizer use has increased by 93%, while major livestock populations peaked in 2005, then decreased sharply until 2011. In 2021, emissions from livestock feed consumption and digestion (enteric fermentation) accounted for 45% of total agricultural emissions, and the application of inorganic nitrogen fertilizers accounted for 20% of total agricultural emissions. Emissions from the decomposition of crop residue decreased by 1.2 Mt (23%) from 2020 to 2021, as a result of drought conditions that lead to a sharp decline in crop production on the prairies.

Waste – 2021 GHG Emissions (21 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from Waste contributed 21 Mt (3.1%) to Canada's total emissions in 2021.

The primary sources of emissions in 2021 for the Waste sector are Solid Waste Disposal (Landfills) including municipal solid waste (MSW) (17 Mt) and Wastewater Treatment and Discharge (2.6 Mt). More generally, landfills (MSW and industrial wood waste) accounted for 85% of Waste emissions, while Biological Treatment of Solid Waste (composting), Wastewater Treatment and Discharge, and Incineration and Open Burning of Waste together accounted for the remaining 15%.

In 2021, CH_4 emissions from MSW landfills made up 82% of all Waste emissions and decreased by 5.3% between 2005 and 2021. Of the 30 Mt CO_2 eq of CH_4 generated by MSW landfills in 2021, 17 Mt CO_2 eq (58%) were emitted to the atmosphere, while 11 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 1.9 Mt (6%) is assumed to be oxidized through landfill cover materials.

The Key Contribution of Facility Data to GHG Estimates

Greenhouse gas emissions associated with industrial activity in Canada largely rely on data reported by facilities to Canada's Federal and Provincial governments.

Since 2004, ECCC's Greenhouse Gas Reporting Program (GHGRP) collects and publishes facility-reported GHG emission information annually. Industrial process emissions reported to the GHGRP are directly incorporated in the NIR's IPPU sector for cement, lime and aluminum 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 on-going 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 for the estimation of fuel combustion emissions for space heating to electricity generation, to 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 facilities via legislated reports on hydrofluorocarbon (HFC) import and export 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 – 2021 (Net GHG Removals of 17 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 2021, this net flux amounted to net removals of 17 Mt that, when included with emissions from other sectors, decreases Canada's total GHG emissions by 2.6%.

Net fluxes from the LULUCF sector over recent years have fluctuated between removals of 49 Mt and 39 Mt in 2009 and 2014, respectively, to a small net source of emissions of 24 kt in 2015. 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.

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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 8.2 Mt in 2005 to a net sink of 21 Mt in 2009 (lowest harvest year), and remained a net sink of 9.1 Mt in 2021. Approximately 34% of HWP emissions in 2021 resulted from long-lived wood products reaching the end of their economic life decades after the wood was harvested. Emission and removal patterns in both HWP and Forest Land have therefore been influenced by recent forest management trends and by the long-term impact of forest management practices in past decades.

Cropland has contributed to net removals in the land sector over the reporting period, with the exception of drought years on the prairies in early 2000s that result in net emissions in 2003 (7.8 Mt). 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 summerfallow. Interannual variability occurs throughout the time series, reflecting weather-related impacts to crop production. Since 2005, the 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 interpretation of recent trends is impacted by occasional peak yields and subsequently peak removals in 2009 (-36 Mt) and 2014 (-43 Mt).

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 2021 have fluctuated around 16 Mt.

Using Atmospheric Measurements to Improve Inventory Estimates

In accordance with UNFCCC reporting requirements 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 modeling 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). Results suggest that bottom-up inventory methods may underestimate some sources of fugitive methane emissions in oil and gas operations. Despite on-going 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 would 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 components to total facility emissions; “top-down” approaches have only recently achieved this level of resolution (Johnson et al., 2021; Johnson et al., 2023).

ECCC is actively working with researchers to understand the discrepancies between “bottom-up” and “top-down” approaches with the goal of 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	2016	2017	2018	2019	2020	2021
	Mt CO_2 eq						
TOTAL[a, b]	**732**	**705**	**712**	**725**	**724**	**659**	**670**
ENERGY	**600**	**577**	**586**	**596**	**596**	**532**	**543**
a. Stationary Combustion Sources	**339**	**315**	**318**	**321**	**322**	**298**	**300**
Public Electricity and Heat Production	125	82	79	71	70	62	60
Petroleum Refining Industries	20	16	15	15	16	13	13
Oil and Gas Extraction	63	94	98	104	104	99	103
Mining	4.3	4.5	5.1	6.6	6.3	6.0	6.4
Manufacturing Industries	48	43	43	43	43	39	41
Construction	1.4	1.3	1.3	1.4	1.4	1.4	1.5
Commercial and Institutional	32	32	34	35	37	36	35
Residential	43	39	40	42	41	38	37
Agriculture and Forestry	2.2	3.2	3.1	3.2	3.5	3.0	3.1
b. Transport	**191**	**196**	**202**	**209**	**210**	**179**	**188**
Aviation	7.7	7.5	7.9	8.7	8.6	4.7	5.6
Road Transportation	123	128	129	132	132	111	116
Railways	6.6	6.4	7.3	7.4	7.5	6.9	6.8
Marine	4.0	3.3	3.5	3.5	4.3	3.8	4.4
Other Transportation	49	51	55	57	58	52	55
c. Fugitive Sources	**70**	**66**	**66**	**66**	**64**	**55**	**55**
Coal Mining	1.4	1.3	1.2	1.3	1.4	1.1	1.2
Oil and Natural Gas	69	65	65	65	63	54	54
d. CO_2 Transport and Storage	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
INDUSTRIAL PROCESSES AND PRODUCT USE	**57**	**54**	**52**	**54**	**53**	**50**	**52**
a. Mineral Products	**10**	**7.9**	**8.6**	**8.7**	**8.8**	**8.2**	**9.0**
b. Chemical Industry	**10**	**6.8**	**6.3**	**6.4**	**6.2**	**5.9**	**5.7**
c. Metal Production	**20**	**15**	**15**	**15**	**14**	**13**	**14**
d. Production and Consumption of Halocarbons, SF_6 and NF_3	**5.1**	**11**	**11**	**12**	**12**	**12**	**11**
e. Non-Energy Products from Fuels and Solvent Use	**10**	**12**	**11**	**11**	**11**	**10**	**11**
f. Other Product Manufacture and Use	**0.54**	**0.60**	**0.63**	**0.70**	**0.67**	**0.72**	**0.72**
AGRICULTURE	**54**	**53**	**52**	**53**	**54**	**55**	**54**
a. Enteric Fermentation	**31**	**24**	**24**	**24**	**24**	**24**	**24**
b. Manure Management	**8.7**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**
c. Agricultural Soils	**13**	**18**	**17**	**19**	**19**	**20**	**19**
d. Field Burning of Agricultural Residues	**0.04**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.04**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**1.4**	**2.5**	**2.4**	**2.6**	**2.7**	**3.0**	**3.1**
WASTE	**22**	**21**	**21**	**21**	**21**	**21**	**21**
a. Solid Waste Disposal (Landfills)	**18**	**17**	**17**	**17**	**17**	**17**	**17**
b. Biological Treatment of Solid Waste	**0.24**	**0.32**	**0.33**	**0.36**	**0.36**	**0.36**	**0.36**
c. Wastewater Treatment and Discharge	**1.9**	**2.8**	**2.7**	**2.8**	**2.7**	**2.7**	**2.6**
d. Incineration and Open Burning of Waste	**0.35**	**0.20**	**0.19**	**0.18**	**0.18**	**0.16**	**0.15**
e. Industrial Wood Waste Landfills	**1.0**	**0.78**	**0.76**	**0.75**	**0.73**	**0.71**	**0.70**
LAND USE, LAND-USE CHANGE AND FORESTRY	**- 5.5**	**- 11**	**- 16**	**- 11**	**- 19**	**- 13**	**- 17**
a. Forest Land	**-136**	**-136**	**-135**	**-133**	**-136**	**-131**	**-133**
b. Cropland	**-22**	**-17**	**-23**	**-22**	**-18**	**-16**	**-18**
c. Grassland	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
d. Wetlands	**3.1**	**3.1**	**3.1**	**2.8**	**3.1**	**3.5**	**3.3**
e. Settlements	**1.5**	**2.3**	**2.2**	**2.1**	**1.9**	**2.1**	**2.0**
f. Harvested Wood Products	**148**	**137**	**137**	**139**	**130**	**128**	**128**

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 removals reported in LULUCF.
b. This summary data is presented in more detail at open.canada.ca.

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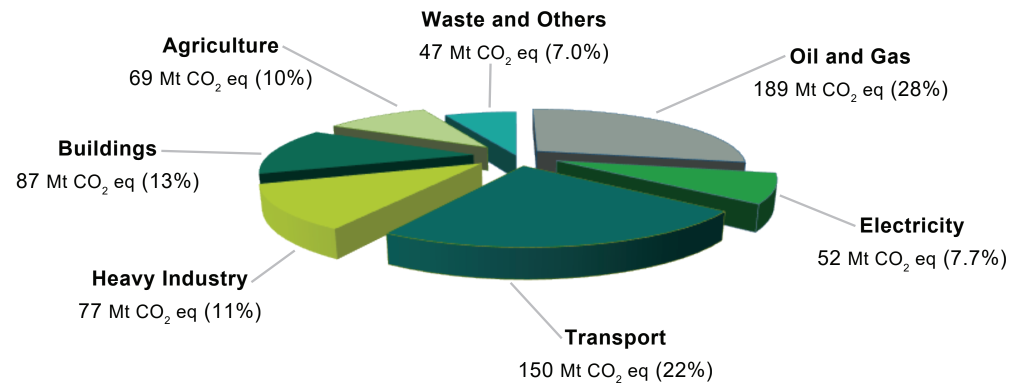
ES.5. Canadian Economic Sectors

For the purposes of analyzing economic trends and policies, 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 is 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 (12%), 5.0 Mt (7.7%) and 2.3 Mt (2.7%), respectively, since 2005 (Figure ES–6 and Table ES–2). These increases have been more than offset by emission decreases in Electricity (-66 Mt or -56%), Heavy Industry (-12 Mt or -14%), and Waste and others (-5.1 Mt or -9.8%). Since 2005, Transport emissions have generally increased, with an important drop since 2020. Emissions in this economic sector are now below 2005 levels (-6.7 Mt or -4.3%).

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 (2021)**



Total: 670 Mt CO_2 eq

Note: Totals may not add up due to rounding.

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

	2005	2016	2017	2018	2019	2020	2021
	Mt CO_2 eq						
NATIONAL GHG TOTAL	**732**	**705**	**712**	**725**	**724**	**659**	**670**
Oil and Gas	168	191	194	202	201	183	189
Electricity	118	74	73	63	62	54	52
Transport	157	162	165	169	170	143	150
Heavy Industry	89	78	77	80	79	74	77
Buildings	85	85	88	92	93	89	87
Agriculture	64	66	67	69	69	70	69
Waste and Others	52	48	49	50	50	46	47

Notes:
Totals may not add up due to rounding.
Additional detail in section 4 of Chapter 2.

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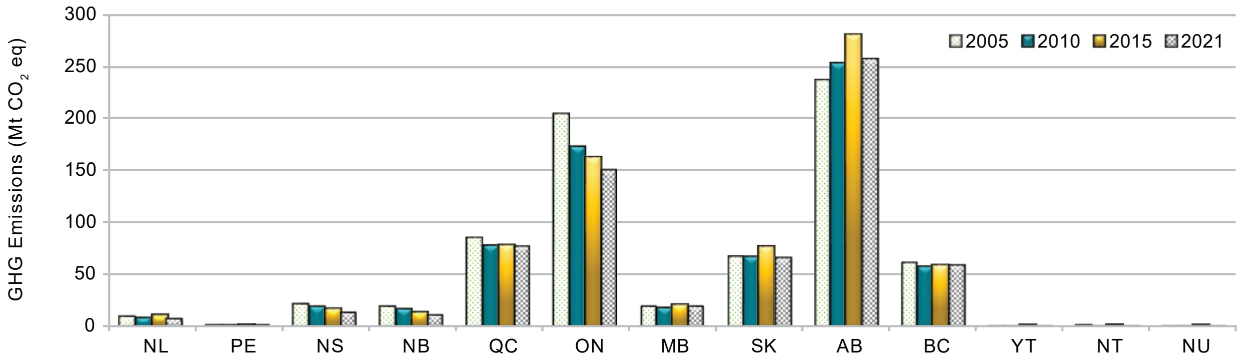
ES.6. Provincial and Territorial GHG Emissions

Emissions vary significantly by province and territory as a result 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 20 Mt (8.6%) since 2005, primarily as a result of the expansion of oil and gas operations (Figure ES–7). In contrast, Ontario's emissions have decreased by 53 Mt (26%) since 2005, owing primarily to the closure of the last coal-fired electricity generation plants in 2014.

Between 2005 and 2021, emissions have decreased in most sub-national jurisdictions, including in Nova Scotia (-8.2 Mt or -36%), Quebec (-8.1 Mt or -9.4%), New Brunswick (-7.7 Mt or -39%), British Columbia (-2.2 Mt or -3.6%), Newfoundland and Labrador (-1.9 Mt or -18%), Saskatchewan (-0.7 Mt or -1.0%), the Northwest Territories (-0.44 Mt or -25%), and Prince Edward Island (-0.25 Mt or -13%). Emissions have increased in Manitoba (0.40 Mt or 2.0%), Yukon (0.09 Mt or 16%) and Nunavut (0.04 Mt or 7.2%).

Figure ES–7 **GHG Emissions by Province and Territory in 2005, 2010, 2015 and 2021**



ES.7. 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 UNFCCC Reporting Guidelines (Chapter 1, section 1.2).

Structure of Submission

The UNFCCC requirements include the annual compilation and submission of both the NIR and the CRF tables. The CRF tables are a series of standardized data tables containing mainly numerical information submitted electronically. The NIR contains the information to support the CRF 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 (Introduction) provides an overview of Canada's legal, institutional and procedural arrangements for producing the inventory (i.e., the national inventory arrangements), quality assurance and quality control procedures, and a description of Canada's facility emission reporting system. Chapter 2 provides an analysis of Canada's GHG emission trends in accordance with the UNFCCC reporting 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 UNFCCC reporting requirements. Chapter 8 presents a summary of recalculations and planned improvements.

ES

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.

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 available on the Government of Canada's Open Data website at open.canada.ca.

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CHAPTER 1

INTRODUCTION

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. A strong body of science evidence, based on a wide range of indicators, suggests that the climate is changing and the climate system is warming. Although climate change can be caused by both natural processes and human activities, the human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases (GHGs) are the highest in history (IPCC, 2014). 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. Collective action in pursuit of the global temperature goal is being implemented; however, it is recognized that this goal will only reduce and not eliminate the risks and impacts of climate change.

Climate change refers to a long-term shift in weather conditions. In order to understand climate change, it is important to differentiate between weather and climate. Weather is the state of the atmosphere at a given time and place, and the term "weather" is mostly used when reporting these conditions over short periods of time. Climate, on the other hand, is the average pattern of weather, usually taken over a 30-year period, in a particular region.

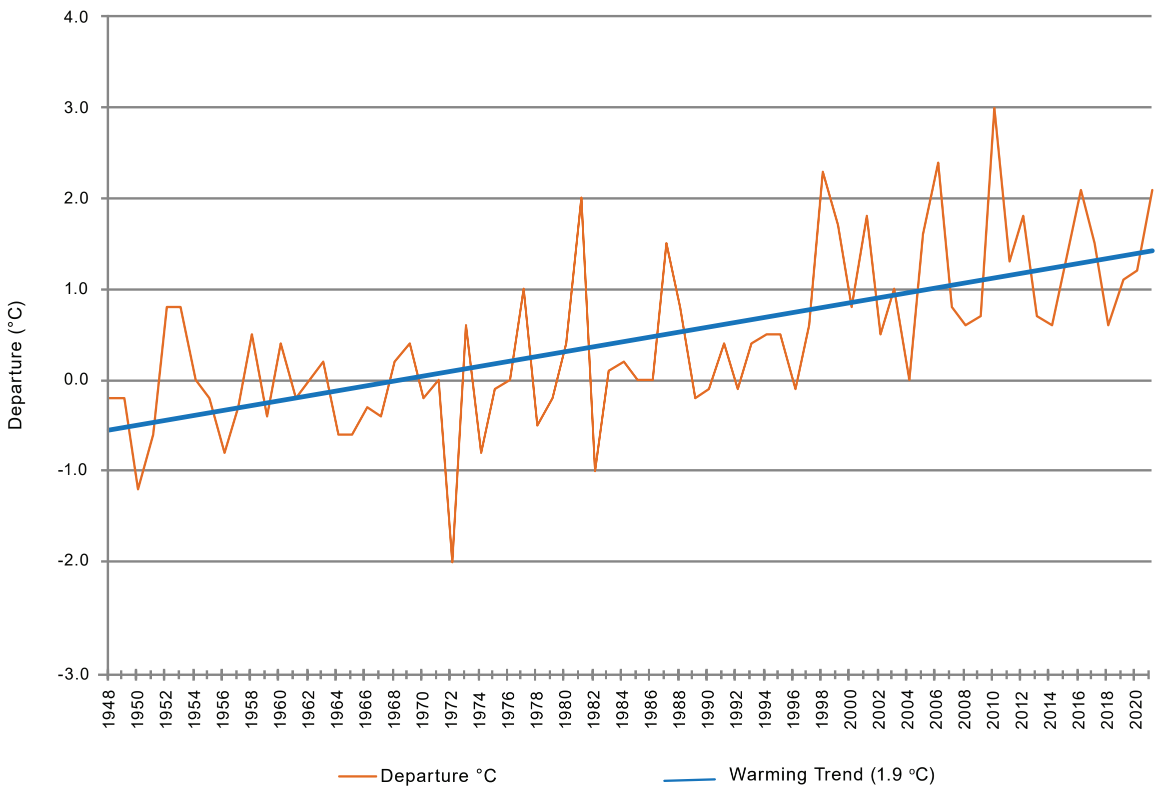
It is now well known that atmospheric concentrations of GHGs have grown significantly since pre-industrial times across the globe. Since 1750, the concentration of atmospheric carbon dioxide (CO_2) has increased by 148%; methane (CH_4), by 260%; and nitrous oxide (N_2O), by 123%. There are numerous anthropogenic activities and economic sectors involved. CO_2 emissions are caused primarily by the use of fossil fuels to generate electricity, power industrial equipment and as feedstock for industrial processes, power trains, planes and automobiles and to heat residential, commercial and institutional spaces. The main sources of CH_4 outpourings are agriculture, fossil fuel exploitation and biomass burning. Finally, N_2O emissions are released predominantly by biomass burning, fertilizer use, and various industrial processes (WMO, 2020).

Recent climate changes have had widespread impacts on human and natural systems (IPCC, 2014). In Canada, the impacts of climate change may be felt 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 2021 was 2.1°C above the baseline average (defined as the mean over the 1961–1990 reference period) (see Figure 1–1). Averaged annual temperatures have remained above the baseline average since 2005, with a warming trend of 1.9°C over the past 74 years (ECCC, 2022).

1.1.1. 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 facilitate the achievement of its objective and implementation of its provisions, the UNFCCC sets out a number of guiding principles and commitments. It requires governments to gather and share information on GHG emissions, national policies and best practices; to launch

Figure 1–1 **Annual Canadian Temperature Departures and Long-Term Trend, 1948–2021**



Note:
Data source: ECCC (2022)

national strategies for reducing GHG emissions and adapting to expected impacts of climate change; and to cooperate in adapting to those impacts. Specifically, Articles 4 and 12 and Decision 24/CP.19 of the Convention commit all Parties to develop, periodically update,[1] publish, and make available to the Conference of the Parties (COP) their national inventories of anthropogenic[2] emissions by sources, and removals by sinks, of all GHGs not controlled by the Montreal Protocol[3] according to the specific requirements, with the exception of hydrofluorocarbons (HFCs).

This National Inventory Report (NIR) documents Canada's annual GHG emissions estimates for the 1990−2021 period. The NIR, along with the Common Reporting Format (CRF) tables, comprise Canada's 2023 submission to the UNFCCC. The NIR and the CRF tables have been 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 greenhouse gas inventories* (hereafter referred to as the UNFCCC Reporting Guidelines), adopted by the Conference of the Parties at its nineteenth session in 2013.

1.1.2. Greenhouse Gases

This report documents estimates of Canada's emissions and removals of the following GHGs: CO_2, CH_4, N_2O, perfluorocarbons (PFCs), HFCs, sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). In addition, and in keeping with the UNFCCC Reporting Guidelines, Annex 7 provides the online location for information on ozone and aerosol precursors: carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO_x).

1 Annex I Parties are required to submit a national inventory annually by April 15.

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

3 The Montreal Protocol on Substances that Deplete the Ozone Layer is an international environmental agreement designed to reduce the global production and consumption of ozone-depleting substances. The United Nations Environment Programme (UNEP) is assisting the Parties in the achievement of the Montreal Protocol objectives (UNEP, n.d.).

Carbon Dioxide

CO_2 is a colourless, odourless, incombustible gas formed during respiration, combustion, decomposition of organic substances, and the reaction of acids with carbonates. It is present in the Earth's atmosphere at low concentrations and acts as a GHG. The global carbon cycle is made up of large carbon flows and reservoirs. Through these, CO_2 is constantly being removed from the air by direct absorption in water, as well as by plants through photosynthesis. In turn, it is naturally released into the air by plant and animal respiration, the decay of plant and soil organic matter, and outgassing from water surfaces. Small amounts of CO_2 are also injected directly into the atmosphere through volcanic emissions and slow geological processes such as the weathering of rock (Hengeveld et al., 2005). Although the proportion of human-caused releases of CO_2 is relatively small in relation to the amounts that enter and leave the atmosphere due to the natural active flow of carbon (proportion of 1/20) (Hengeveld et al., 2005), human influences now appear to be significantly affecting this natural balance. This is evident in the steady increase in atmospheric CO_2 concentrations measured since pre-industrial times across the globe (Hengeveld et al., 2005). Anthropogenic sources of CO_2 emissions include the combustion of fossil fuels and biomass for energy production, building heating and cooling, transportation; land-use changes including deforestation; and other industrial processes such as cement manufacture.

Methane

CH_4 is a colourless, odourless, flammable gas and is the simplest hydrocarbon. It is present in the Earth's atmosphere at low concentrations and acts as a GHG. CH_4, usually in the form of natural gas, is used as feedstock in the chemical industry (e.g. hydrogen and methanol production), and as fuel for various purposes (e.g. heating homes and operating vehicles). CH_4 is produced naturally during the decomposition of plants or other organic matter in the absence of oxygen and is released from wetlands (including rice paddies) and through the digestive processes of certain insects and other animals, such as termites, sheep and cattle. CH_4 is also released from industrial processes, fossil fuel extraction, coal mining, incomplete fossil fuel combustion, and waste decomposition in landfills.

Nitrous Oxide

N_2O is a colourless, sweet-smelling, non-flammable gas that is heavier than air. Used as an anaesthetic in dentistry and surgery and a propellant in aerosol cans, N_2O is most commonly produced by heating ammonium nitrate (NH_4NO_3). It is also released naturally from the oceans, from soils through bacterial activity, and animal waste. Other sources of N_2O emissions include the industrial production of nylon and nitric acid, the combustion of fossil fuels and biomass, soil cultivation practices, and the use of commercial and organic fertilizers.

Perfluorocarbons

PFCs are a group of human-made chemicals composed of carbon and fluorine only. These powerful GHGs were introduced as alternatives to ozone-depleting substances (ODSs), such as chlorofluorocarbons (CFCs), in manufacturing semiconductors. PFCs are also used as solvents in the electronics industry and as refrigerants in some specialized refrigeration systems. In addition to being released during consumption, they are emitted as a by-product during aluminium production.

Hydrofluorocarbons

HFCs are a class of human-made chemical compounds that contain fluorine, carbon and hydrogen, and are powerful GHGs. Since HFCs do not deplete the ozone layer, they are commonly used as replacements for ODSs such as CFCs, hydrochlorofluorocarbons (HCFCs) and halons, in various applications including refrigeration, fire extinguishing, semiconductor manufacturing and foam blowing.

Sulphur hexafluoride

SF_6 is a synthetic gas that is colourless, odourless, and non-toxic, except when exposed to extreme temperatures. It acts as a GHG due to its very high heat-trapping capacity. SF_6 is primarily used in the electricity industry as an insulating gas for high-voltage equipment. It is also utilized as a cover gas in the magnesium industry to prevent oxidation (combustion) of molten magnesium. In smaller amounts, SF_6 is used in semiconductor manufacturing in the electronics industry and as a tracer gas for gas dispersion studies in industrial and laboratory settings.

Nitrogen Trifluoride

NF_3 is a colourless, non-flammable gas that is used in the electronics industry as a replacement for PFCs and SF_6. It has a higher percentage of conversion to fluorine—the active agent in the industrial process—than PFCs and SF_6 for the same amount, in electronics production. It is used in the manufacture of semiconductors, liquid crystal display (LCD) panels and photovoltaics. NF_3 is broken down in situ into nitrogen and fluorine gases, and the resulting fluorine radicals are the active cleaning agents that attack the poly-silicon. NF_3 is also employed in hydrogen fluoride and deuterium fluoride lasers, which are types of chemical lasers (UNFCCC, 2010).

1

1.1.3. Global Warming Potentials

Each 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 the chemical transformation of the original gas produces GHGs 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 takes into account 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 has been developed to allow the comparison of the ability of each GHG to trap heat in the atmosphere relative to CO_2, as well as the characterization of GHG emissions in terms of how much CO_2 would be required to produce a similar warming effect over a given time period. This is called 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.

The Intergovernmental Panel on Climate Change (IPCC) develops and updates the GWPs for all GHGs generally every 6 to 7 years. 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. Consistent with Decision 24/CP19, the 100-year GWP values provided by the IPCC in its Fourth Assessment Report (Table 1–1) are used in this report. In accordance with the modalities, procedures and guidelines (MPGs) of the enhanced transparency framework under the Paris Agreement (Annex to decision 18/CMA.1), in the 2024 edition of the NIR, the GWP values used will be updated to the ones provided in the IPCC Fifth Assessment Report (IPCC, 2014). For example, the 100-year GWP for CH_4 used in this inventory is 25; consequently, an emission of 100 kilotonnes (kt) of CH_4 is equivalent to 25 x 100 kt = 2500 kt CO_2 eq.

1.2. Canada's National Inventory Arrangements

Canada's inventory arrangements for estimating anthropogenic emissions from sources, and removals by sinks, of all GHGs not controlled under the Montreal Protocol 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 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:

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An overview of the inventory process used by the Pollutant Inventories and Reporting Division is provided in section 1.2.2 (Process for Inventory Preparation).

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).

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]	CH_4	25	12 ± 1.8
Nitrous oxide	N_2O	298	114
Sulphur hexafluoride	SF_6	22 800	3 200
Nitrogen trifluoride	NF_3	17 200	740
Hydrofluorocarbons (HFCs)			
HFC-23	CHF_3	14 800	270
HFC-32	CH_2F_2	675	4.9
HFC-41	CH_3F	92	2.4
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1 640	15.9
HFC-125	CHF_2CF_3	3 500	29
HFC-134	CHF_2CHF_2	1 100	9.6
HFC-134a	CH_2FCF_3	1 430	14
HFC-143	CH_2FCHF_2	353	3.5
HFC-143a	CH_3CF_3	4 470	52
HFC-152	CH_2FCH_2F	53	0.60
HFC-152a	CH_3CHF_2	124	1.4
HFC-161	CH_3CH_2F	12	0.3
HFC-227ea	CF_3CHFCF_3	3 220	34.2
HFC-236cb	$CH_2FCF_2CF_3$	1 340	13.6
HFC-236ea	CHF_2CHFCF_3	1 370	10.7
HFC-236fa	$CF_3CH_2CF_3$	9 810	240
HFC-245ca	$CH_2FCF_2CHF_2$	693	6.2
HFC-245fa	$CHF_2CH_2CF_3$	1 030	7.6
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794	8.6
Perfluorocarbons (PFCs)			
Perfluoromethane	CF_4	7 390	50 000
Perfluoroethane	C_2F_6	12 200	10 000
Perfluoropropane	C_3F_8	8 830	2 600
Perfluorobutane	C_4F_{10}	8 860	2 600
Perfluorocyclobutane	$c\text{-}C_4F_8$	10 300	3 200
Perfluoropentane	C_5F_{12}	9 160	4 100
Perfluorohexane	C_6F_{14}	9 300	3 200
Perfluorodecalin	$C_{10}F_{18}$	7 500	1 000
Perfluorocyclopropane	$c\text{-}C_3F_6$	17 340	1 000

Notes:

a. Source: IPCC (2012)

b. The GWP for methane includes indirect effects from enhancements of ozone and stratospheric water vapour.

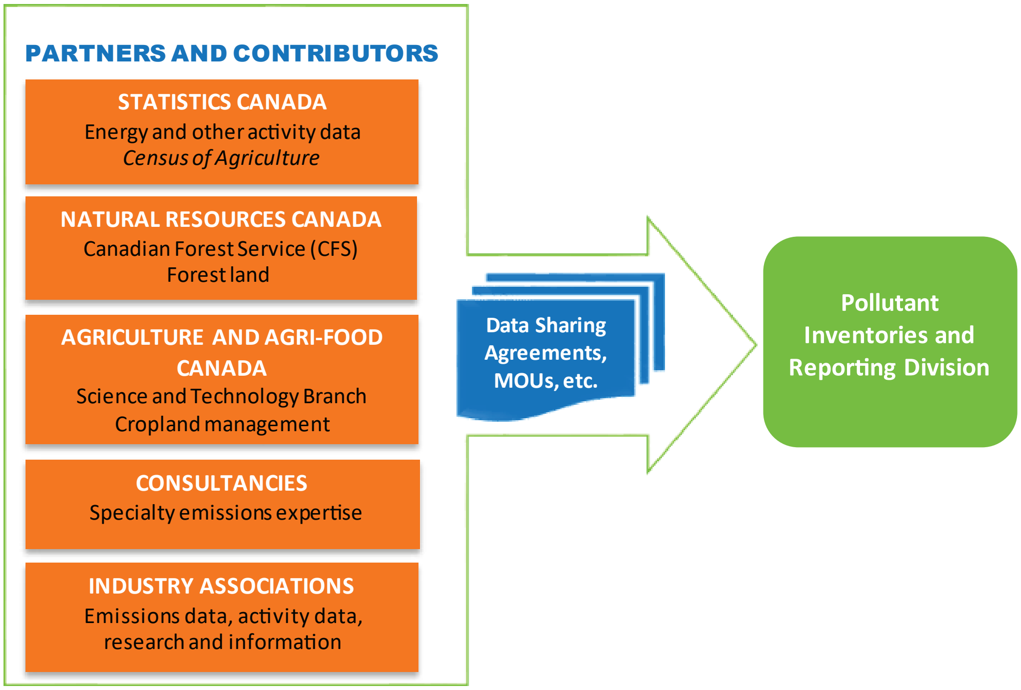
1.2.1. Institutional Arrangements

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 supporting 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 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: An MOU or a 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). The energy balance is comprised of various Statistics Canada surveys, including the annual Industrial Consumption of Energy (ICE) survey, which is a comprehensive poll of energy consumption by 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 of Simon Fraser University review quality and technical issues related to the data from the Report on Energy Supply and Demand and from the Industrial Consumption of Energy surveys, 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.

1.2.1.3. Other Agreements

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.

Under its Greenhouse Gas Reporting Program (GHGRP), ECCC collects emissions data annually from facilities that emit large quantities of GHGs. These facility-level GHG data are used directly in the national inventory estimates for a few 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, see section 1.3.4.1.

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 ACC 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.

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

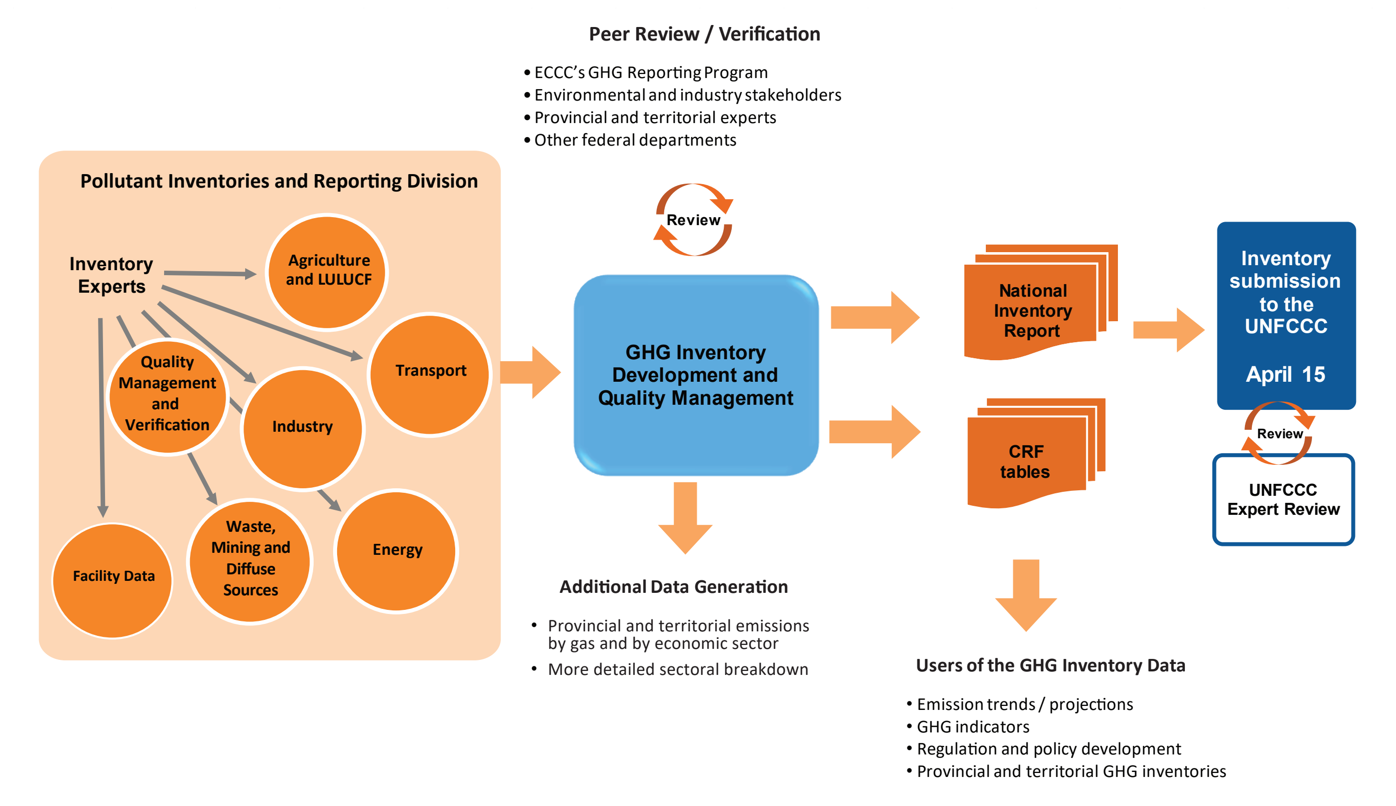
Canada's inventory is developed, compiled and published annually by ECCC's Pollutant Inventories and Reporting Division, with input from numerous experts and scientists across Canada. Figure 1–3 identifies the various stages of the inventory preparation process.

The inventory is built on a continuous process of methodological improvements, refinements and reviews, in accordance with quality management and improvement plans. The Quality Management and Verification Section of the Pollutant Inventories and Reporting Division is responsible for preparing the inventory development 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 February, when inventory experts plan their work on the 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 May 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 and other members of the Pollutant Inventories and Reporting Division, according to UNFCCC Reporting Guidelines. 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.

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 prior to April 15 of each year. Once finalized, the NIR is translated and made available in French.

Figure 1–3 **Inventory Preparation Process**



A number of overlapping steps occur during the inventory process. For example, around February and March, while the team responsible for the publication of the report is finishing the drafting and layout of the current NIR, inventory experts are already starting to work on methodology improvements for the next edition.

All documents relevant to the development and publication of Canada's GHG inventory are archived in a manner consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (hereafter referred to as the 2006 IPCC Guidelines) (IPCC, 2006) and Canada's *Policy on Information Management* (Treasury Board of Canada, 2012). 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

Confidential information is defined as information that could directly or indirectly identify an individual person, business or organization. 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 is not disclosed.

1.2.5. Changes in the National Inventory Arrangements Since the Previous Annual GHG Inventory Submission

There have been no changes to the national inventory arrangements since the previous annual GHG inventory submission.

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 is able to meet the UNFCCC reporting requirements 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.

In order to ensure that a high-quality inventory is produced each and 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; inventory improvement plan; information creation, documentation and archiving processes; standardized process for implementing methodological change; identification of key roles and responsibilities; and timeline for completing the various NIR-related tasks and activities.

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.

Documentation of QA/QC procedures is at the core of the plan. Standard checklists are used for the consistent, systematic documentation of all QA/QC activities in the annual inventory preparation and submission process. 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. Minor updates to the checklists were made in 2015 (Environment Canada, 2015).

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 a number of 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 and making preparations for subsequent QA. The Tier 2 QC checks may be documented with a standard checklist or an in-depth study to provide a comprehensive assessment.

1

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. As with QC, QA is undertaken every year on components of the inventory. 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. QA is undertaken to assess the activity data, methodology and emission factors used in developing estimates, and is preferably carried out prior to making a decision on implementing a methodological change.

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.

Since many improvements will stretch over multiple years, Canada has developed an Inventory Improvement Plan, which identifies and tracks planned 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). The Inventory Improvement Plan contains all planned improvement activities that will further refine and enhance the transparency, completeness, accuracy, consistency and comparability of Canada's GHG inventory and is updated on an annual basis. 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] 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* 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 using a phased approach. 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. In 2017, the Government of Canada implemented Phase 1 of the expansion by lowering the reporting threshold from 50 kt to 10 kt for all facilities. Phase 1 also required manufacturers of lime, cement, aluminium, iron and steel as well as facilities involved in CO_2 capture, transport, injection and geological storage activities to use prescribed methods outlined in the Canada's Greenhouse

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

6 The notice published in the *Canada Gazette* requiring the reporting of 2021 emissions information can be found at: https://www.gazette.gc.ca/rp-pr/p1/2021/2021-12-18/html/sup2-eng.html.

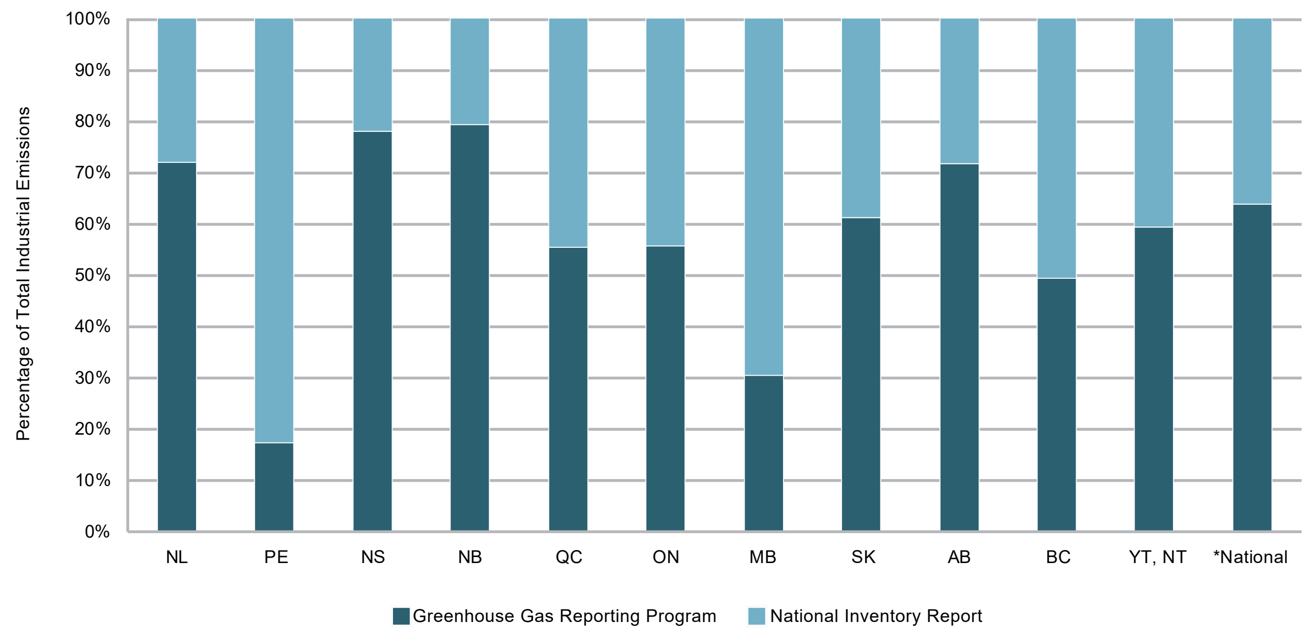
Gas Quantification Requirements manual (ECCC, 2021) to quantify their emissions and to provide additional information on their calculations. Under Phase 2 of the expansion (2018 data), facilities in nine additional industry sectors were required to report additional information and use the prescribed quantification methods. These sectors include ethanol, ammonia, nitric acid and hydrogen production; electricity and heat generation; mining operations; petroleum refineries; pulp and paper production; and base metal production.

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 information has been collected and published by the GHGRP for the period 2004 to 2021. In 2021, a total of 1733 facilities (mostly industrial) disclosed their GHG emissions under the program. The GHGRP website[7] provides public access to this GHG emission information (GHG 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 2021, total facility-reported GHG emissions represented 43% of Canada's total GHG emissions (670 Mt) and 64% 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).

Figure 1–4 **2021 Facility-Reported Emissions as a Percentage of Industrial Greenhouse Gas Emissions by Province and Territory**



Notes:

For this figure, Canada's industrial GHG emissions include the following GHG categories from the *National Inventory Report, Greenhouse Gas Sources and Sinks in Canada 1990–2021*: 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.

The GHGRP provides Canadians with information about large GHG emitters across Canada and yearly changes in their emission levels, which is 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).

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

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.ai Electricity generation, solid fuels	Amount of CO_2 captured	Direct reporting	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.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 1s2
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 1s2
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.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	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

8 The notice that required the reporting of 2021 emissions information can be found at : https://www.gazette.gc.ca/rp-pr/p1/2021/2021-12-18/html/sup2-eng.html.

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.

Prior to the integration of any FRD, a number of 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.

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 2021 Reported Emissions* (ECCC, 2023).

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. Canada's inventory has undergone both centralized and in-country reviews, with the last in-country one taking place in 2014.[9] Once finalized, review reports are posted online by the UNFCCC Secretariat.[10]

1.5. Methodologies and Data Sources

The inventory is structured to match the reporting requirements of the UNFCCC 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 methods described have been grouped, as closely as possible, by UNFCCC sector and subsector.

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.

While not mandatory, the UNFCCC Reporting Guidelines 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.[11]

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. Emissions from landfills are determined using a simulation model to account for the slow, long-term generation and release of these emissions.

9 More information on the UNFCCC's review process and guidelines is available online at http://unfccc.int/national_reports/annex_i_ghg_inventories/review_process/items/2762.php.

10 Annual Inventory Review Reports are available online at https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports/inventory-review-reports/inventory-review-reports-2021#:~:text=Annual%20Inventory%20Review%20Reports%20are,reporting%20provisions%20under%20the%20Kyoto.

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

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 considered to be 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 take into account results of QA/QC procedures, reviews and verification, are planned and implemented on a continuous basis. It should be noted that 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 the recalculation of GHG estimates for the entire time series, from 1990 to the most recent year available. For a further discussion of recalculations and improvements, see Chapter 8.

1.6. Key Categories

The 2006 IPCC Guidelines (IPCC, 2006) define procedures (in the form of decision trees) for selecting estimation methods. The decision trees formalize the choice of the estimation method most suited to national circumstances, considering the available knowledge and resources (both financial and human). Generally, the precision and accuracy of inventory estimates can be improved by using the most rigorous (highest tier) methods; however, owing to practical limitations, the exhaustive development of all emissions categories is not possible. Therefore, identifying and prioritizing key categories is good practice, to make the most efficient use of the resources available.

Consequently, in a national inventory system, key categories are prioritized because their estimates have a significant influence on the country's total direct GHG emissions, in terms of the absolute level of emissions (level assessment), the trend in emissions from the base year to the current year (trend assessment), or both. Whenever feasible, key categories should be estimated with more refined country-specific methods and be subjected to enhanced QA/QC.

For the 1990–2021 GHG inventory, level and trend key category assessments were performed according to the recommended IPCC Tier 1 approach found in Volume 1, Section 4.3.1, of the 2006 IPCC Guidelines. The emission and removal categories used for the key category assessments generally follow those in the CRF tables. However, they have been aggregated in some cases and are specific to the Canadian inventory.

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
4. IPPU – Adipic Acid Production, N_2O
5. IPPU – Product Uses as Substitutes for Ozone Depleting Substances, HFCs

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

1. LULUCF – Forest Land Remaining Forest Land, CO_2
2. Stationary Fuel Combustion – Manufacturing Industries and Construction, CO_2
3. LULUCF – Harvested Wood Products, CO_2
4. Fuel Combustion – Road Transportation, CO_2
5. Stationary Fuel Combustion – Energy Industries, CO_2

Details and results of the key category assessments are presented in Annex 1.

1.7. Inventory Uncertainty

While national GHG inventories should be accurate, complete, comparable, transparent and consistent, estimates will always inherently involve some uncertainty. Uncertainties[12] 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 a given 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 inventory as a whole 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 2021. The five emissions source categories that contribute the most to uncertainty at the national level, for 2021, 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. Agriculture – Indirect Agriculture Soils, N_2O
5. Fugitive Sources – Venting, CO_2

When the LULUCF emissions and removals are included, the uncertainty in the national total was found to be ±8% for 2021 and ±14% for the base year. For 2021, 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. Agriculture – Indirect Agriculture Soils, N_2O

1.8. 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 UNFCCC. 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[13]

As part of the NIR improvement plans, 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).

12 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).

13 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 (UNFCCC, 2014).

CHAPTER 2

GREENHOUSE GAS EMISSIONS TRENDS

2.1. Summary of GHG Emissions Trends

In 2021, the most recent year for which data are available for this report, Canada's greenhouse gas (GHG) emissions were 670 megatonnes of carbon dioxide equivalent (Mt CO_2 eq)[1]. This represents a decrease of 62 Mt or 8.4% from 2005 emissions and an increase of 12 Mt (1.8%) from 2020; in addition, emissions remained 53 Mt (7.4%) 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 2021.

Recent year emission fluctuations are described here, while the remainder of this chapter keep the focus on trends and their drivers. More information on the emission trends are also available in each sectoral chapter (Chapters 3 to 7). The COVID-19 pandemic contributed to an abrupt decrease of 64 Mt (9.0%) of total GHG emissions between 2019 and 2020. These changes occurred in numerous subsectors, most notably in Transport (-31 Mt or -15%), Stationary Combustion (-24 Mt or -7.4%), and Fugitive Sources (-9.0 Mt or -14%). Between 2020 and 2021, emissions increased by 12 Mt (1.8%). The major contributors to the overall increase were the Transport subsector and Oil and Gas Extraction category with increases of 9.0 Mt (5.0%) and 4.0 Mt (4.0%), respectively. During that same time period, emissions from the Residential Stationary Combustion Sources category and Agriculture Soils subsector decreased respectively by 1.5 Mt (4.0%) and 1.4 Mt (7.0%).

Further, between 2019 and 2020, the decrease in Transport emissions included decreases in Light-Duty Gasoline Vehicles and Trucks (-15 Mt or -17%) and Domestic Aviation (-3.8 Mt or -45%). These are linked to a decrease in the vehicle kilometres traveled (VKT) in the light-duty vehicles and trucks categories, and a decrease in air traffic in 2020 relative to 2019. Between 2020 and 2021, Road Transportation was responsible for the majority of the emissions increase in Transport (5.2 Mt or 4.7%). Emissions from Light-Duty Vehicles and Trucks increased by 2.4 Mt (3.3%). Although VKT decreased, the total vehicle fleet in 2021 increased, leading to more kilometres driven overall.

Within Stationary Combustion Sources, between 2019 and 2020, decreased in Public Electricity and Heat Production (-8.1 Mt or -12%) were due to reduced coal consumption which was partially offset by an increase in natural gas consumption. Decreases in Manufacturing Industries (-3.8 Mt or -8.7%) can be partially attributed to temporary and permanent plant closures, during the first year of the pandemic. Between 2020 and 2021, combustion emissions from Oil and Gas Extraction increased by 4.0 Mt (4.0%), consistent with a rise in crude bitumen (13%) and synthetic crude oil production (6%) from oil sands operations and increased natural gas production (4%). Emissions from Manufacturing Industries also increased by 1.2 Mt (3%). In contrast, emissions in the Residential category decreased by 1.5 Mt (4.0%) between 2020 and 2021, largely driven by a continued decreasing consumption of light fuel oil. Public Electricity and Heat Production also decreased by 1.1 Mt (1.7%) between 2020 and 2021, due to further reductions in coal consumption.

Temporary plant shutdowns during the first pandemic year can also partially explain the decrease between 2019 and 2020 in the Industrial and Processes and Product Use (IPPU) sector (-2.5 Mt or -4.8%). Between 2020 and 2021, the IPPU sector emissions increased by 1.6 Mt (3.1%) mostly due to a return to pre-pandemic production levels in some sectors. For Fugitive Sources, emission decreases between 2019 and 2020 included venting (-6.8 Mt or -21%), and leaks from oil (-1.3 Mt or -9.9%) and natural gas production and processing facilities (-1.1 Mt or -9.1%). Fugitive Sources emissions remained stable between 2020 and 2021.

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.

Within the Agricultural Soils subsector, between 2020 and 2021, emissions from Direct and Indirect Sources decreased by 1.1 Mt (7.4%) and 0.2 Mt (5.4%), respectively, mainly due to a sharp decrease in crop production following drought conditions on the prairies.

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 declined by 42% since 1990 and by 29% 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 fuel switching, increases in efficiency, the modernization of industrial processes, and structural changes in the economy.

Figure 2–1 **Canadian GHG Emission Trend (excluding Land Use, Land-Use Change and Forestry) (1990–2021)**

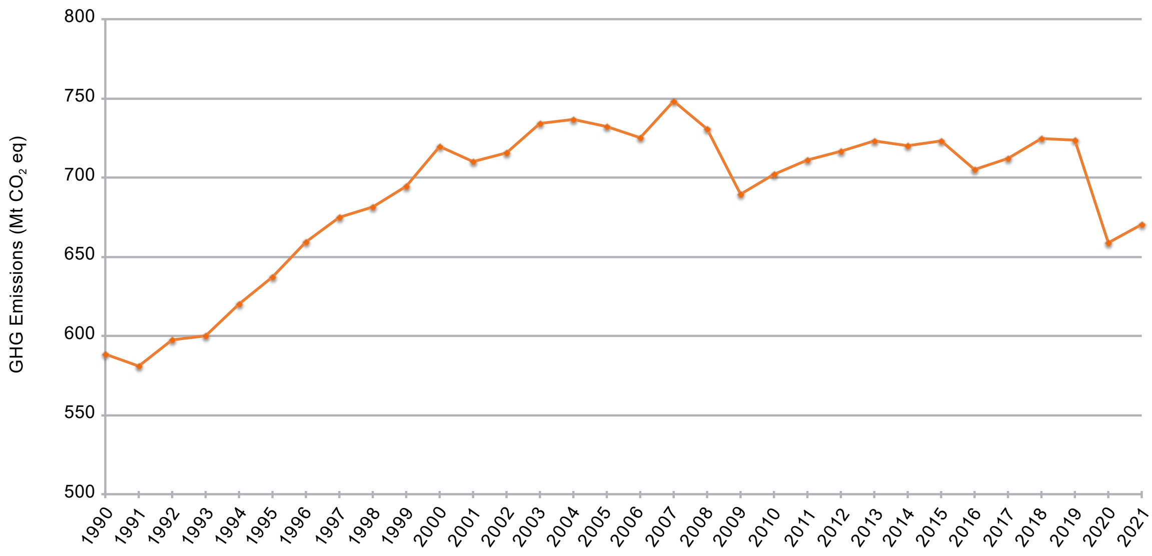
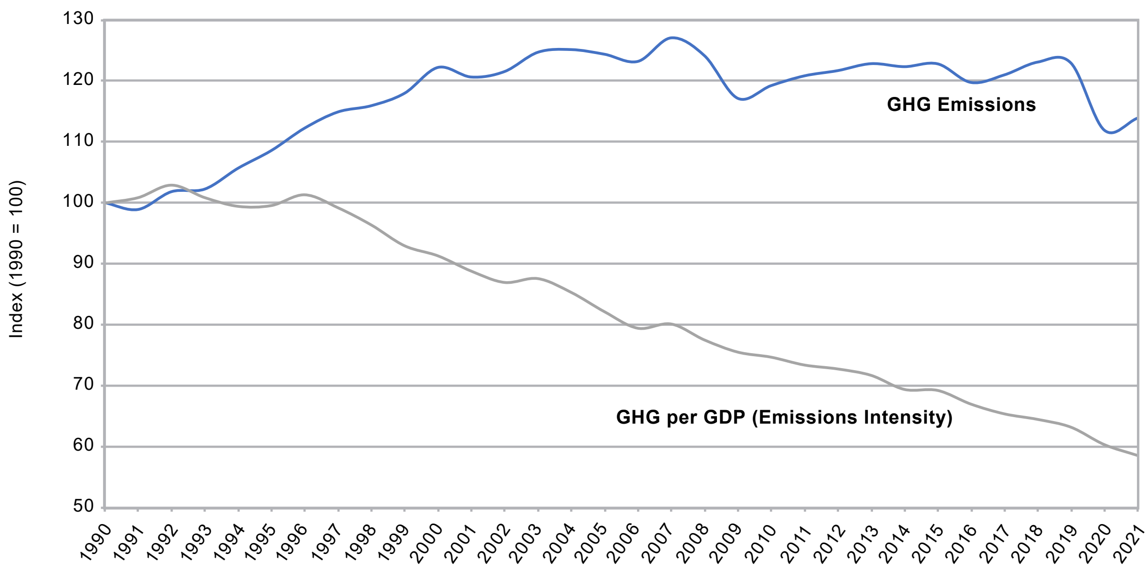


Figure 2–2 **Indexed Trend in GHG Emissions and GHG Emissions Intensity (excluding Land Use, Land-Use Change and Forestry) (1990–2021)**



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

Table 2–1 **Trends in GHG Emissions and Economic Indicators, Selected Years**								
Year	1990	2005	2016	2017	2018	2019	2020	2021
Total GHG (Mt)	**589**	**732**	**705**	**712**	**725**	**724**	**659**	**670**
Change since 2005 (%)	NA	NA	-3.7%	-2.7%	-1.0%	-1.2%	-10%	-8.4%
Change since 1990 (%)	NA	24%	20%	21%	23%	23%	12%	14%
GDP[a] (Billion 2012$)	**1 092**	**1 654**	**1 953**	**2 022**	**2 086**	**2 126**	**2 027**	**2 126**
Change since 2005 (%)	NA	NA	18%	22%	26%	29%	23%	29%
Change since 1990 (%)	NA	51%	79%	85%	91%	95%	86%	95%
GHG Intensity (Mt/$B GDP)	**0.54**	**0.44**	**0.36**	**0.35**	**0.35**	**0.34**	**0.32**	**0.32**
Change since 2005 (%)	NA	NA	-19%	-20%	-22%	-23%	-27%	-29%
Change since 1990 (%)	NA	-18%	-33%	-35%	-36%	-37%	-40%	-42%

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

2

Canada accounts for approximately 1.6% of global GHG emissions (Climate Watch, 2023 for the year 2019), making Canada the 10th largest emitter of GHGs. While Canada's per capita emissions have declined since 2005 from 22.7 t CO_2 eq/capita to 17.5 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 2021 can be found on open.canada.ca (ECCC, 2023).

2.1.1. Provincial and Territorial GHG Emissions Trends

Emissions vary significantly by province and territory as a result 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.

Figure 2–3 **GHG Emissions by Province and Territory in 2005, 2010, 2015 and 2021**

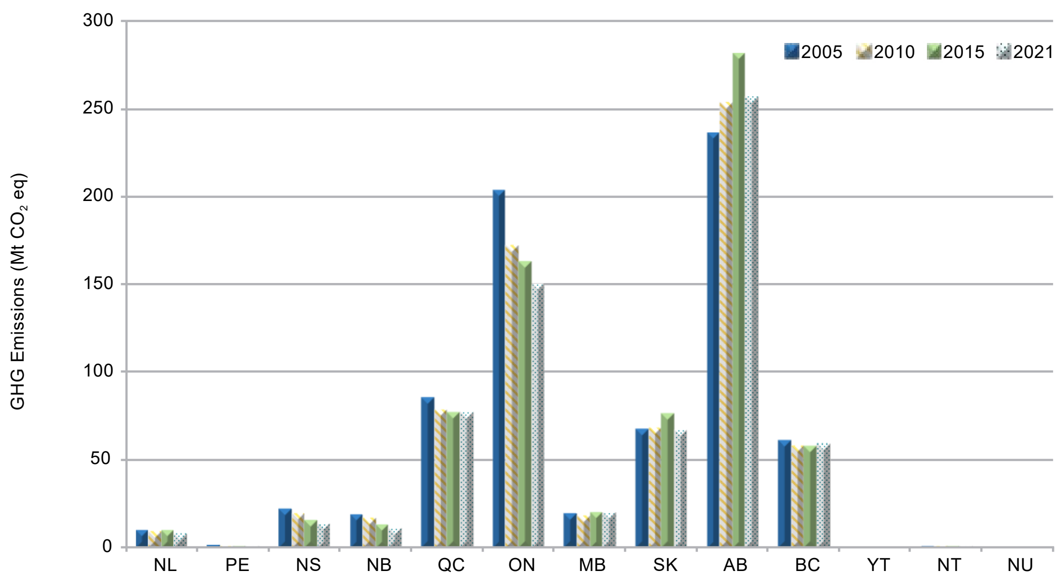


Table 2–2 **GHG Emissions by Province and Territory, Selected Years**

	GHG Emissions (Mt CO_2 eq)								Change (%)
Year	1990	2005	2016	2017	2018	2019	2020	2021	2005–2021
GHG Total (Canada)	**589**	**732**	**705**	**712**	**725**	**724**	**659**	**670**	**-10%**
NL	9.4	10	11	11	11	11	8.8	8.3	-14%
PE	1.8	1.9	1.6	1.6	1.6	1.6	1.6	1.6	-16%
NS	19	23	15	16	16	16	15	15	-36%
NB	16	20	15	14	13	13	11	12	-43%
QC	84	86	77	79	81	82	74	77	-13%
ON	179	204	160	156	163	163	147	151	-28%
MB	18	20	21	21	22	22	21	21	4.3%
SK	42	68	74	76	77	75	65	67	-4.0%
AB	165	236	267	273	274	275	254	256	7.8%
BC	50	62	61	62	64	63	59	59	-4.6%
YT	0.55	0.56	0.53	0.56	0.64	0.69	0.60	0.65	6.2%
NT	NA	1.7	1.3	1.4	1.4	1.4	1.2	1.3	-30%
NU	NA	0.58	0.74	0.74	0.74	0.75	0.59	0.63	1.1%

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

Historically, Alberta and Ontario have been the highest-emitting provinces. Since 2005, emission patterns in these two provinces have diverged. Emissions in Alberta have increased by 20 Mt (8.6%) since 2005, primarily as a result 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 (-25 Mt). In contrast, Ontario's emissions have decreased by 53 Mt (26%) since 2005, owing primarily to the closure of the last coal-fired electricity generation plants in 2014.

Between 2005 and 2021, emissions have decreased in most sub-national jurisdictions, including in Nova Scotia (-8.2 Mt or -36%), Quebec (-8.1 Mt or -9.4%), New Brunswick (-7.7 Mt or -39%), British Columbia (-2.2 Mt or -3.6%), Newfoundland and Labrador (-1.9 Mt or -18%), Saskatchewan (-0.7 Mt or -1.0%), the Northwest Territories (-0.44 Mt or -25%), and Prince Edward Island (-0.25 Mt or -13%). Emissions have increased in Manitoba (0.40 Mt or 2.0%), the Yukon (0.09 Mt or 16%) and Nunavut (0.04 Mt or 7.2%).

2.2. GHG Emissions Trends by Gas

Canada's GHG emissions profile is similar to that of most industrialized countries, in that carbon dioxide (CO_2) is the largest contributor to total emissions, accounting for 537 Mt or 80% of total emissions in 2021 (Figure 2–4 and ECCC, 2023). As a result, trends in CO_2 emissions follow the same pattern as total GHG emissions (Figure 2–1). The majority of the CO_2 emissions in Canada result from the combustion of fossil fuels (Figure 2–4 and ECCC, 2023).

Methane (CH_4) emissions in 2021 amounted to 91 Mt of CO_2 eq or 14% of Canada's total. These emissions consist largely of fugitive emissions from oil and natural gas systems (37 Mt or 41% of total CH_4 emissions), agriculture (28 Mt or 31% of total CH_4 emissions), and landfills (municipal solid waste disposal and industrial wood waste) (18 Mt or 20% of total CH_4 emissions). CH_4 emissions have increased steadily since 1990, peaking in 2006 at 116 Mt (39% increase), then fluctuated until 2018 and decreased in recent years to reach an emission level close to 1992 (90 Mt) in 2021 (91 Mt) (Figure 2–5). From 1990 to 2006, emissions from fugitive oil and gas increased by 22 Mt, agriculture by 8.9 Mt and landfills by 2.3 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].

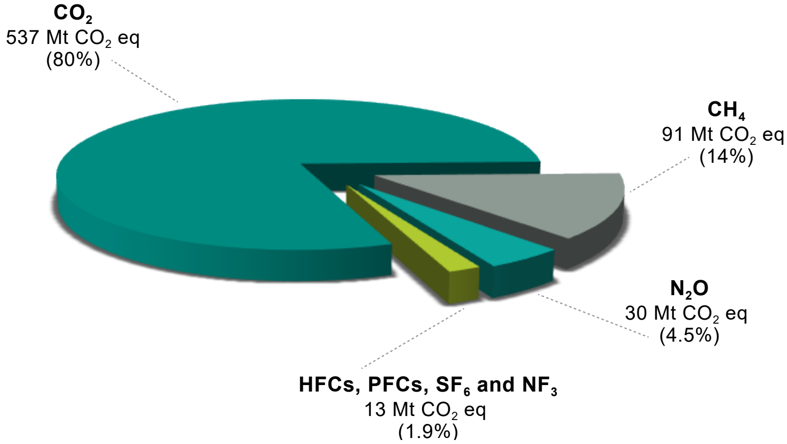
From 2006 to 2019, emissions decreased from 116 to 101 Mt. Of this 15 Mt decrease in emissions, 8.5 Mt occurred in the oil and gas industry due to reductions in venting emissions (-5.9 Mt), and the combination of improved leak detection and repair (LDAR) programs with a 9% decrease in natural gas production, both of which contributed a 2.6 Mt decrease in fugitive leak emissions from oil and gas systems. Agricultural CH_4 emissions decreased by 5.6 Mt (17%) between 2006 and 2011, mainly due to a 20% 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 1.4 Mt (7.3%) over this period

3 From 1990 to 2021, production of crude bitumen and synthetic crude oil from Canada's Oil Sands increased by over 775% with CO_2-eq emissions increasing by over 450%. However, CH_4 emissions from the Oil Sands increased by only 80% and the contribution to total Oil and Gas CH_4 emissions increased from 5.1% in 1990 to 8.3% in 2021, showing that the Oil Sands is not a significant source of CH_4 as compared to conventional oil and gas production.

is from a mixture of decreases in methane generation from wood waste landfills (225 kt or 24% decrease), and from increased capture and recovery of landfill gas from municipal landfills (2.5 Mt or 31% decrease), offset by an increase in methane generated (1.2 Mt or 4% increase).

The significant decrease (10 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 9.2 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 slightly between 2020 and 2021 (-0.9 Mt or -1.0%)

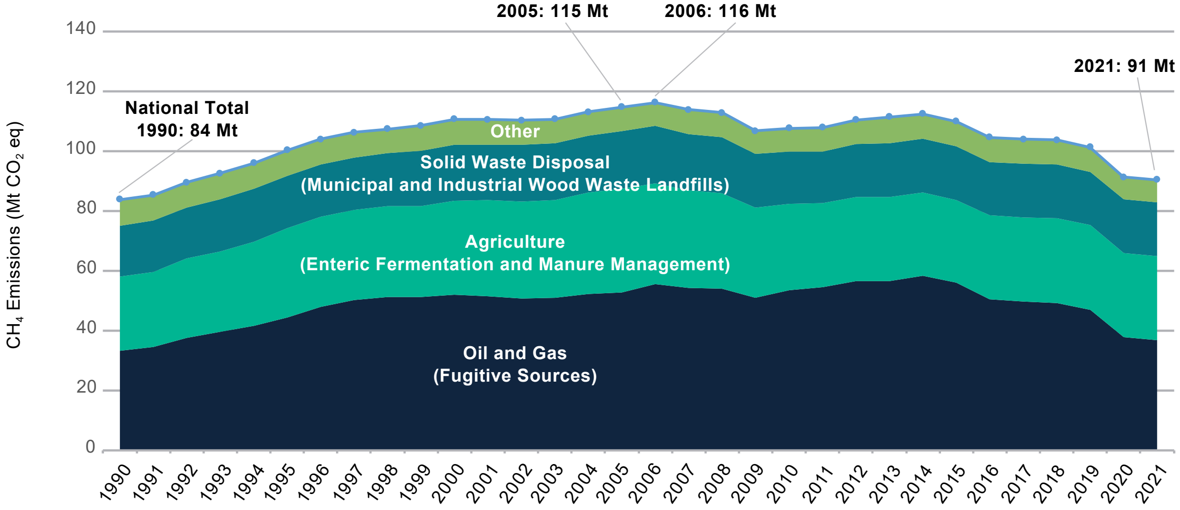
Figure 2–4 **Breakdown of Canada's Emissions by GHG (2021)**



Total: 670 Mt CO_2 eq

Note: Totals may not add up due to rounding.

Figure 2–5 **Methane Emissions Trends in Canada (1990–2021)**



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

Nitrous oxide (N_2O) emissions accounted for 30 Mt (4.5%) of Canada's emissions in 2021, down 4.2 Mt (12%) from 1990 levels and 2.1 Mt (6.4%) from 2005 levels. The primary source of N_2O emissions is the application of nitrogen fertilizers to agricultural soils. In 2021, the Agriculture sector accounted for 75% of national N_2O emissions, up from 52% in 1990 and 27% in 2005. Since 2005, nitrogen fertilizer use has increased by 93% and N_2O emissions from nitrogen fertilizer use have increased by 94%. Since 1990, a 10 Mt decrease in N_2O emissions has occurred due to the cessation of adipic acid production in Canada.

Emissions of synthetic gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), SF_6 and NF_3) accounted for 13 Mt, or 1.9%, of Canada's emissions in 2021. From 1990 to 2021, emissions of HFCs rose by 10 Mt (1100%), while emissions of PFCs and SF_6 decreased by 6.8 Mt (90%) and 2.9 Mt (90%), respectively. Similar trends are observed since 2005, with a 6.3 Mt (124%) increase in HFC emissions, and 3.1 Mt (80%) 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 for refrigeration and air conditioning 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, and a decline in the number of magnesium smelters and casters.

2.3. GHG Emissions Trends by IPCC Sector

The IPCC (Intergovernmental Panel on Climate Change) 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 2021, the Energy sector accounted for 543 Mt, or 81%, of Canada's total GHG emissions with the remainder being shared between Agriculture (54 Mt or 8.1%), IPPU (52 Mt or 7.8%) and Waste (21 Mt or 3.1%). 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 1990–2021 period, with increases of 42 Mt (29%) in Transport, 22 Mt (8.1%) in Stationary Combustion, and 7.0 Mt (15%) 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 5.0 Mt (8.8%). Emissions in the Waste sector have increased by 2.1 Mt (11%) since 1990. In 1990, net removals from the LULUCF sector were 65 Mt, but the net sink has declined since then amounting to net removals of 17 Mt in 2021. Over the time series, the net decrease in LULUCF net removals was 47 Mt (73%) (Figure 2–6 and Table 2–3).

Over the 2005–2021 period, total emissions have decreased by 62 Mt or 8.4%. Two sources of the Energy sector dominated this trend, with emission decreases of 39 Mt (11%) in stationary combustion and 15 Mt (21%) in fugitives. Over the same period, emissions have decreased by 4.6 Mt (8.1%) in the IPPU sector and 0.6 Mt (2.9%) 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 9.0 Mt (5.0%) between 2020 to 2021, bringing them slightly below 2005 levels. The Agriculture sector emissions have remained relatively stable with a 0.10 Mt or 0.2% increase (Figure 2–7). The net fluxes in the LULUCF sector have fluctuated between net removals of 49 Mt in 2009 and 39 Mt in 2014 to a small net source of emissions of 24 kt in 2015, representing a net increase in removals of 12 Mt between 2005 and 2021 (Figure 2–6).

Several emission sources, while not major contributors to Canada's overall GHG emissions, have changed significantly since 1990; these include an 11 Mt (or 1078%) increase in emissions from the Production and Consumption of Halocarbons, SF_6 and NF_3, a 5.2 Mt (89%) increase from the Non-Energy Products from Fuels and Solvent Use, a 1.9 Mt (162%) increase in CO_2 emissions from the application of lime, urea and carbon-containing fertilizers, a 0.28 Mt (388%) increase in emissions from Biological Treatment of Solid Waste. Also included are decreases of 2.8 Mt (95%) from SF_6 Used in Magnesium Smelters and Casters, of 0.76 Mt (78%) from Nitric Acid Production and of 0.19 Mt (84%) from Field Burning of Agricultural Residues.

Between 2005 and 2021, some of the noteworthy changes in emission sources that are minor contributors to the national total include a 6.4 Mt (or 125%) increase in emissions from the Production and Consumption of Halocarbons, SF_6 and NF_3, a 1.7 Mt (119%) increase in CO_2 emissions from the application of lime, urea and carbon-containing fertilizers, a 0.9 Mt (41%) increase in Agriculture and Forestry Stationary Combustion Sources, a 1.1 Mt (89%) decrease in emissions of SF_6 Used in Magnesium Smelters and Casters and a 1.0 Mt (82%) decrease in Nitric Acid Production emissions.

Figure 2–6 **Trends in Canadian GHG Emissions by IPCC Sector (1990–2021)**

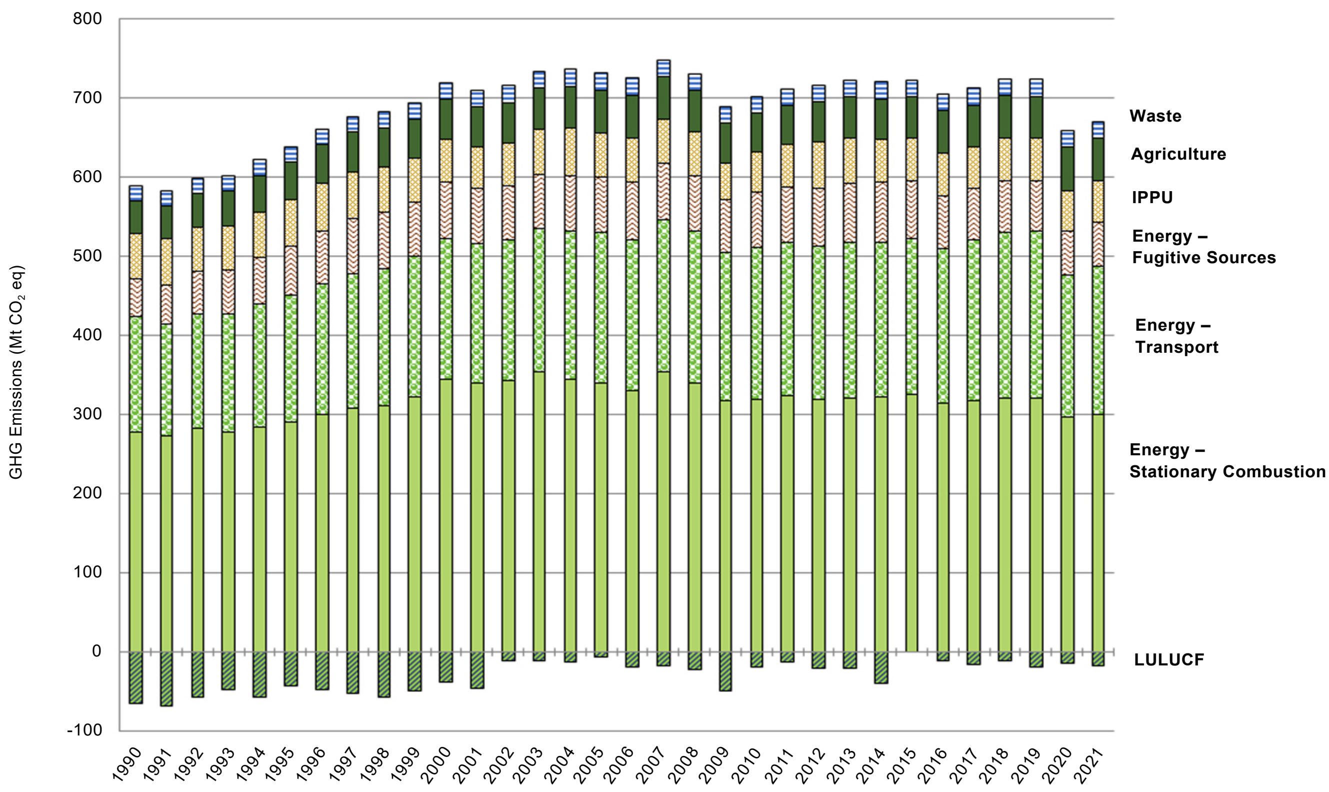


Figure 2–7 **Changes in GHG Emissions by IPCC Sector (2005–2021)**

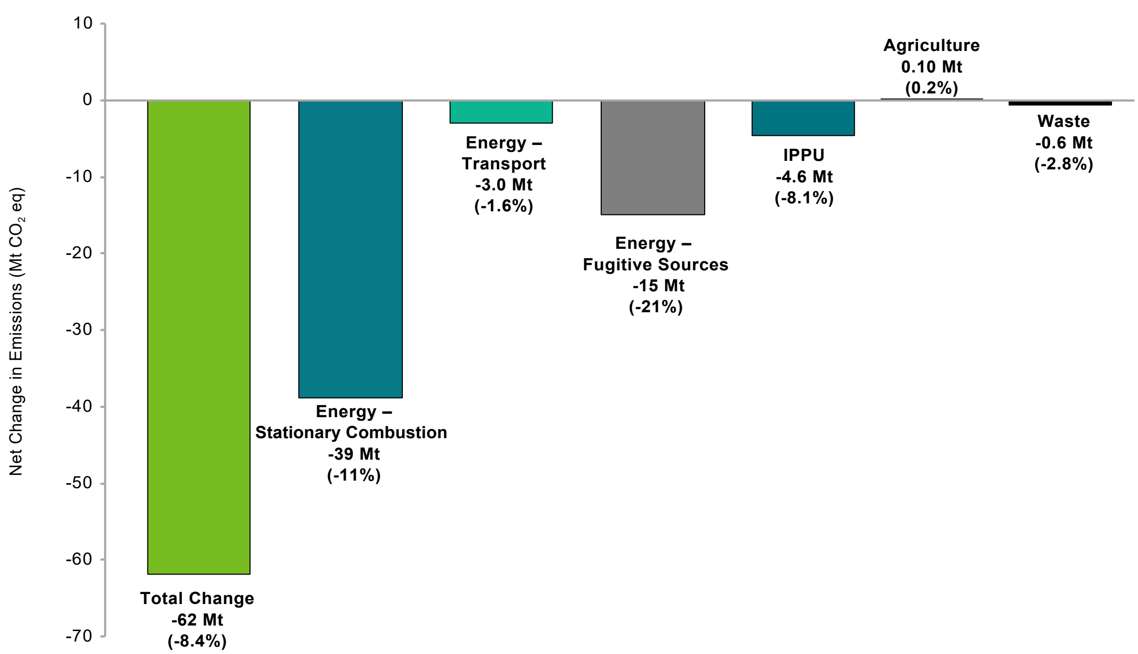


Table 2–3 **Canada's GHG Emissions by IPCC Sector (1990–2021)**

Greenhouse Gas Categories		1990	2005	2016	2017	2018	2019	2020	2021
		Mt CO_2 eq							
TOTAL[a, b]		**589**	**732**	**705**	**712**	**725**	**724**	**659**	**670**
ENERGY		**472**	**600**	**577**	**586**	**596**	**596**	**532**	**543**
a.	**Stationary Combustion Sources**	**278**	**339**	**315**	**318**	**321**	**322**	**298**	**300**
	Public Electricity and Heat Production	95	125	82	79	71	70	62	60
	Petroleum Refining Industries	17	20	16	15	15	16	13	13
	Oil and Gas Extraction	31	63	94	98	104	104	99	103
	Mining	4.7	4.3	4.5	5.1	6.6	6.3	6.0	6.4
	Manufacturing Industries	56	48	43	43	43	43	39	41
	Construction	1.9	1.4	1.3	1.3	1.4	1.4	1.4	1.5
	Commercial and Institutional	26	32	32	34	35	37	36	35
	Residential	44	43	39	40	42	41	38	37
	Agriculture and Forestry	2.4	2.2	3.2	3.1	3.2	3.5	3.0	3.1
b.	**Transport**	**145**	**191**	**196**	**202**	**209**	**210**	**179**	**188**
	Aviation	7.5	7.7	7.5	7.9	8.7	8.6	4.7	5.6
	Domestic Aviation (Civil)	7.3	7.5	7.3	7.7	8.4	8.3	4.6	5.4
	Military	0.23	0.26	0.26	0.23	0.25	0.24	0.18	0.20
	Road Transportation	92	123	128	129	132	132	111	116
	Light-Duty Gasoline Vehicles	44	41	34	34	33	32	25	24
	Light-Duty Gasoline Trucks	25	41	50	52	53	55	47	50
	Heavy-Duty Gasoline Vehicles	4.8	4.6	4.4	4.4	4.5	4.5	4.2	4.3
	Motorcycles	0.20	0.46	0.87	0.90	0.92	0.95	0.77	0.77
	Light-Duty Diesel Vehicles	0.37	0.67	0.64	0.61	0.59	0.50	0.31	0.32
	Light-Duty Diesel Trucks	0.89	0.75	0.58	0.64	0.72	0.74	0.60	0.72
	Heavy-Duty Diesel Vehicles	16	34	37	37	39	38	33	35
	Propane and Natural Gas Vehicles	0.76	0.02	0.08	0.11	0.13	0.17	0.18	0.19
	Railways	6.9	6.6	6.4	7.3	7.4	7.5	6.9	6.8
	Marine	3.1	4.0	3.3	3.5	3.5	4.3	3.8	4.4
	Domestic Navigation	2.2	3.1	3.0	3.2	3.2	4.0	3.6	4.1
	Fishing	0.87	0.87	0.16	0.15	0.16	0.16	0.15	0.18
	Military Water-Borne Navigation	0.03	0.03	0.13	0.10	0.09	0.10	0.08	0.08
	Other Transportation	36	49	51	55	57	58	52	55
	Off-Road Agriculture and Forestry	8.7	9.9	12	14	14	14	13	13
	Off-Road Commercial and Institutional	4.2	4.5	5.2	5.7	5.9	6.0	5.3	5.8
	Off-Road Manufacturing, Mining and Construction	12	16	17	19	20	20	17	18
	Off-Road Residential	0.37	1.2	1.1	1.0	1.0	1.0	1.0	0.94
	Off-Road Other Transportation	3.5	7.6	7.9	8.0	8.0	7.9	7.6	7.7
	Pipeline Transport	6.9	10	7.7	7.6	8.4	8.5	7.7	8.7
c.	**Fugitive Sources**	**48**	**70**	**66**	**66**	**66**	**64**	**55**	**55**
	Coal Mining	2.8	1.4	1.3	1.2	1.3	1.4	1.1	1.2
	Oil and Natural Gas	45	69	65	65	65	63	54	54
d.	**CO_2 Transport and Storage**	**-**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
INDUSTRIAL PROCESSES AND PRODUCT USE		**57**	**57**	**54**	**52**	**54**	**53**	**50**	**52**
a.	**Mineral Products**	**8.5**	**10**	**7.9**	**8.6**	**8.7**	**8.8**	**8.2**	**9.0**
	Cement Production	5.8	7.6	6.1	6.9	7.0	7.2	6.7	7.4
	Lime Production	1.8	1.8	1.4	1.4	1.4	1.3	1.2	1.3
	Mineral Product Use	0.86	0.91	0.39	0.33	0.32	0.31	0.30	0.31
b.	**Chemical Industry**	**18**	**10**	**6.8**	**6.3**	**6.4**	**6.2**	**5.9**	**5.7**
c.	**Metal Production**	**24**	**20**	**15**	**15**	**15**	**14**	**13**	**14**
d.	**Production and Consumption of Halocarbons, SF_6 and NF_3**	**1.0**	**5.1**	**11**	**11**	**12**	**12**	**12**	**11**
e.	**Non-Energy Products from Fuels and Solvent Use**	**5.8**	**10**	**12**	**11**	**11**	**11**	**10**	**11**
f.	**Other Product Manufacture and Use**	**0.37**	**0.54**	**0.60**	**0.63**	**0.70**	**0.67**	**0.72**	**0.72**
AGRICULTURE		**41**	**54**	**53**	**52**	**53**	**54**	**55**	**54**
a.	**Enteric Fermentation**	**22**	**31**	**24**	**24**	**24**	**24**	**24**	**24**
b.	**Manure Management**	**6.1**	**8.7**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**	**7.8**
c.	**Agricultural Soils**	**11**	**13**	**18**	**17**	**19**	**19**	**20**	**19**
d.	**Field Burning of Agricultural Residues**	**0.22**	**0.04**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.03**
e.	**Liming, Urea Application and Other Carbon-Containing Fertilizers**	**1.2**	**1.4**	**2.5**	**2.4**	**2.6**	**2.7**	**3.0**	**3.1**
WASTE		**19**	**22**	**21**	**21**	**21**	**21**	**21**	**21**
a.	**Solid Waste Disposal (Landfills)**	**16**	**18**	**17**	**17**	**17**	**17**	**17**	**17**
b.	**Biological Treatment of Solid Waste**	**0.07**	**0.24**	**0.32**	**0.33**	**0.36**	**0.36**	**0.36**	**0.36**
c.	**Wastewater Treatment and Discharge**	**1.6**	**1.9**	**2.8**	**2.7**	**2.8**	**2.7**	**2.7**	**2.6**
d.	**Incineration and Open Burning of Waste**	**0.26**	**0.35**	**0.20**	**0.19**	**0.18**	**0.18**	**0.16**	**0.15**
e.	**Industrial Wood Waste Landfills**	**0.89**	**1.0**	**0.78**	**0.76**	**0.75**	**0.73**	**0.71**	**0.70**
LAND USE, LAND-USE CHANGE AND FORESTRY		**-65**	**-5.5**	**-11**	**-16**	**-11.3**	**-19**	**-13**	**-17**
a.	**Forest Land**	**-203**	**-136**	**-136**	**-135**	**-133**	**-136**	**-131**	**-133**
b.	**Cropland**	**1.0**	**-22**	**-17**	**-23**	**-22**	**-18**	**-16**	**-18**
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**	**3.1**	**2.8**	**3.1**	**3.5**	**3.3**
e.	**Settlements**	**1.9**	**1.5**	**2.3**	**2.2**	**2.1**	**1.9**	**2.1**	**2.0**
g.	**Harvested Wood Products**	**131**	**148**	**137**	**137**	**139**	**130**	**128**	**128**

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 removals reported in LULUCF

b. This summary data is presented in more detail at open.canada.ca.

2.3.1. Energy Sector (2021 GHG emissions, 543 Mt)

In 2021, the Energy sector contributed 81% 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 detailed description of each.

2.3.1.1. Stationary Combustion Sources (2021 GHG Emissions, 300 Mt)

Stationary Combustion Sources accounts for 55% of emissions from the Energy sector. In 2021, emissions totalled 300 Mt, an increase of 8% from the 1990 emissions level of 278 Mt and a decrease of 11% from the 2005 emissions level of 339 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 2021 contributed 34% and 20%, respectively, of the total Stationary Combustion emissions. Manufacturing Industries, Residential Buildings, and Commercial and Institutional Buildings contributed 14%, 12% and 12%, respectively, of total Stationary Combustion emissions in 2021.

2

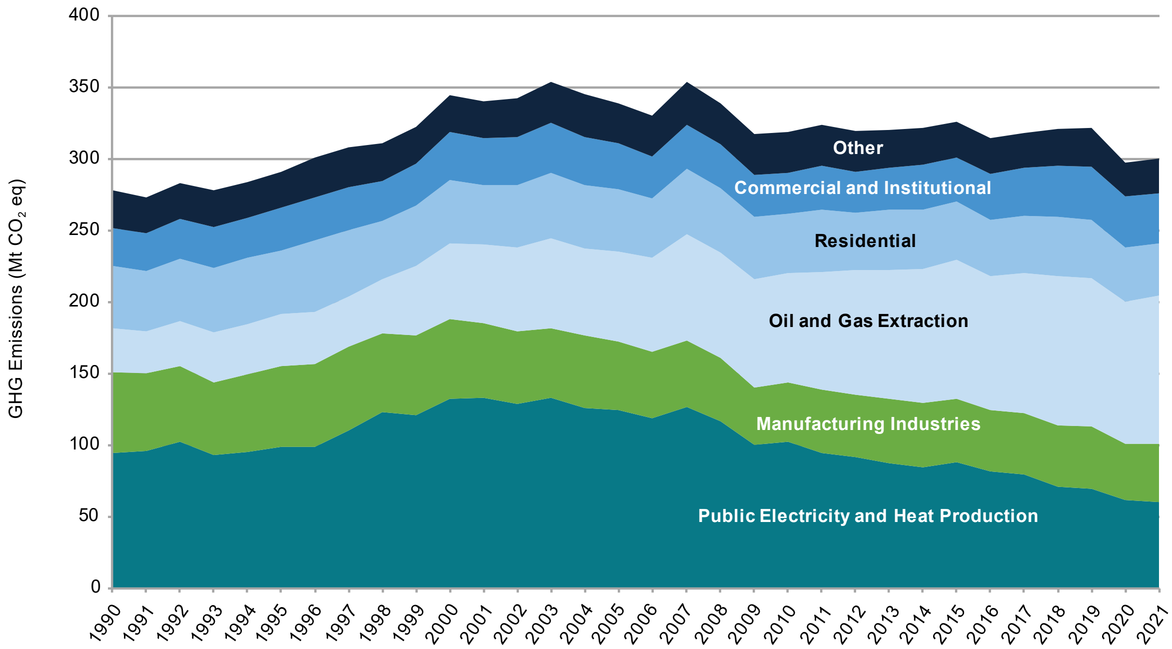
Public Electricity and Heat Production (2021 GHG emissions, 60 Mt)

Emissions from the Public Electricity and Heat Production category decreased by 36% between 1990 and 2021.

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 2021, electricity generation (driven by demand) increased by 33% (StatCan, 1990–), from 433 TWh[4] to 574 TWh. Despite the increase in demand over this period, GHG emissions dropped by 36% (34 Mt) between 1990 and 2021. Likewise, between 2005 and 2021, electricity generation rose by 4%, while corresponding emissions fell by 52% (64 Mt). Over both time 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 106% of the increased generation between 1990 and 2021 and for 84% of the total electricity generated in Canada in 2021. Hydroelectric generation alone accounted for 62% of the total electricity generated in 2021, followed by nuclear power generation at 15% and non-hydro-based renewables at 6%. The increased level of non-combustion sources in the generation mix in 2021 was the largest contributor to emission reductions since 1990 (21 Mt) and 2005 (38 Mt) (Figure 2–9).

Figure 2–8 **Trends in Canadian GHG Emissions from Stationary Combustion Sources (1990–2021)**



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

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.

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

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2016	2017	2018	2019	2020	2021	1990–2021	2005–2021
Stationary Combustion Sources	**278**	**339**	**315**	**318**	**321**	**322**	**298**	**300**	**8%**	**-11%**
Public Electricity and Heat Production	**95**	**125**	**82**	**79**	**71**	**70**	**62**	**60**	**-36%**	**-52%**
Petroleum Refining	**17**	**20**	**16**	**15**	**15**	**16**	**13**	**13**	**-24%**	**-34%**
Oil and Gas Extraction	**31**	**63**	**94**	**98**	**104**	**104**	**99**	**103**	**235%**	**64%**
Mining	**4.7**	**4.3**	**4.5**	**5.1**	**6.6**	**6.3**	**6.0**	**6.4**	**38%**	**47%**
Manufacturing Industries	**56**	**48**	**43**	**43**	**43**	**43**	**39**	**41**	**-28%**	**-15%**
Iron and Steel	4.9	5.5	5.6	6.0	6.4	6.1	4.6	5.2	4%	-6%
Non-Ferrous Metals	3.5	3.8	3.5	3.4	3.0	3.4	3.3	3.2	-10%	-17%
Chemicals	8.3	8.3	11	10	9.4	10	9.5	9.2	11%	11%
Pulp, Paper and Print	14	8.6	6.0	6.4	7.1	7.2	6.5	6.9	-53%	-20%
Cement	4.0	5.4	3.9	4.2	4.2	4.0	3.6	3.9	-3%	-29%
Other Manufacturing	21	16	13	13	13	13	12	12	-42%	-24%
Construction	**1.9**	**1.4**	**1.3**	**1.3**	**1.4**	**1.4**	**1.4**	**1.5**	**-22%**	**1%**
Commercial and Institutional	**26**	**32**	**32**	**34**	**35**	**37**	**36**	**35**	**35%**	**9%**
Residential	**44**	**43**	**39**	**40**	**42**	**41**	**38**	**37**	**-17%**	**-16%**
Agriculture/Forestry/Fishing	**2.4**	**2.2**	**3.2**	**3.1**	**3.2**	**3.5**	**3.0**	**3.1**	**28%**	**41%**

Note: Totals may not add up due to rounding.

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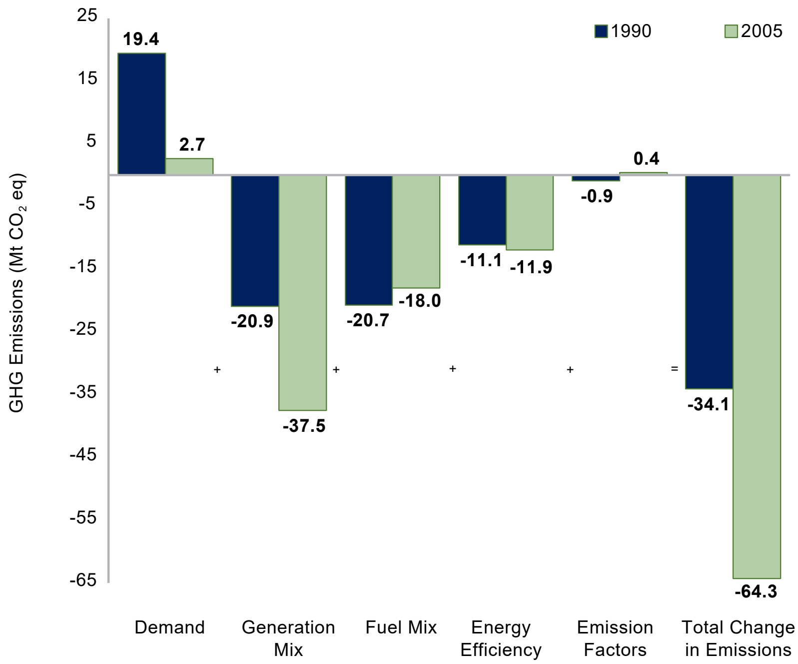
Figure 2–9 **Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 1990–2021 and 2005–2021**



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.

In addition, the fuel mix used for combustion generation has been steadily moving to less GHG-intensive fossil fuels. Between 2005 and 2021, the quantity of electricity generated by natural gas-fired units increased by 83% (25 TWh), while the amount generated by coal and refined petroleum products decreased by about 66% (62 TWh) and 81% (8.7 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 21 Mt between 1990 and 2021 and about 18 Mt between 2005 and 2021.

The efficiency of combustion equipment has also played a role in the GHG emission reductions. Energy efficiency improvements resulted in an approximately 11 Mt reduction in GHG emissions between 1990 and 2021 and a 12 Mt reduction between 2005 and 2021.

Oil and Gas Extraction (2021 GHG emissions, 103 Mt)

Stationary combustion emissions from Oil and Gas Extraction increased by 72 Mt (235%) between 1990 and 2021 and by 40 Mt (64%) between 2005 and 2021. 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 200% increase in the production of non-upgraded crude bitumen and synthetic crude oil from the oil sands industry since 2005 (AER, 2022) and the increased use of more energy-intensive extraction techniques, such as horizontal drilling, hydraulic fracturing and enhanced oil recovery.

2

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 82% (StatCan, 1990–), and in-situ thermal production has increased by over 400% (AER, 2022). In general, while emission increases from Oil and Gas Extraction may originate from multiple activities, they tend to be consistent with the 480% 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 decreased by 6% (StatCan, 1990–) while conventional oil production, including primary production of crude bitumen in oil sands areas, has increased by only 7% (AER, 2022, StatCan, n.d.[c], n.d.[d]).

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 (2021 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 2021, GHG emissions from the Manufacturing Industries category were 41 Mt, which represents a 28% (16 Mt) decrease from 1990 and a 15% (7.2 Mt) decrease since 2005. The decrease between 2005 and 2021 is driven by Other Manufacturing (-3.8 Mt), Pulp, Paper and Print (-1.7 Mt), Cement (-1.6 Mt), Non-Ferrous Metals (-0.6 Mt), and Iron and Steel (-0.3 Mt), offset by an increase in Chemicals (1.4 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 2021 it only made up 67%; replacing the natural gas with wood combustion, which together made up 94% of the fuel mix in 2021. In 1990, heavy fuel oil made up 17% of the fuel mix in the Pulp, Paper and Print subcategory while in 2021, 99% of the fuel mix consisted of less GHG-intensive fuels such as natural gas, spent pulping liquor and wood waste. In contrast, combustion emissions from chemical industries showed an increase in emissions of 0.9 Mt (11%). This is generally consistent with a 27%[5] growth in the production of chemicals between 1990 and 2021.

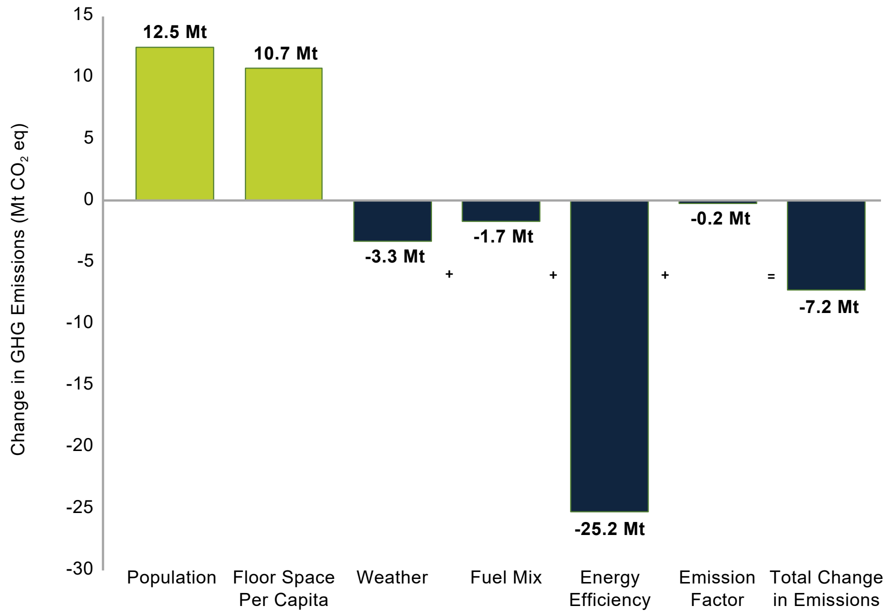
Residential, Commercial and Institutional (2021 GHG emissions, 72 Mt)

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 about 72 Mt of GHG emissions in 2021, a 2.9% increase since 1990.

Overall, Residential emissions decreased by 7.2 Mt (17%) between 1990 and 2021 and by 6.8 Mt (16%) between 2005 and 2021. In contrast, Commercial and Institutional emissions increased by 9.2 Mt (35%) from 1990 to 2021 and by 3.0 Mt (9.4%) from 2005 to 2021. 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).

5 Griffin B. 2023. Personal communication (email from Griffin B. to Kay J., Physical Scientist, PIRD, dated February 07, 2023). Canadian Energy and Emissions Data Centre.

Figure 2–10 **Factors Contributing to the Change in Stationary GHG Emissions from the Residential Category between 1990 and 2021**



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.

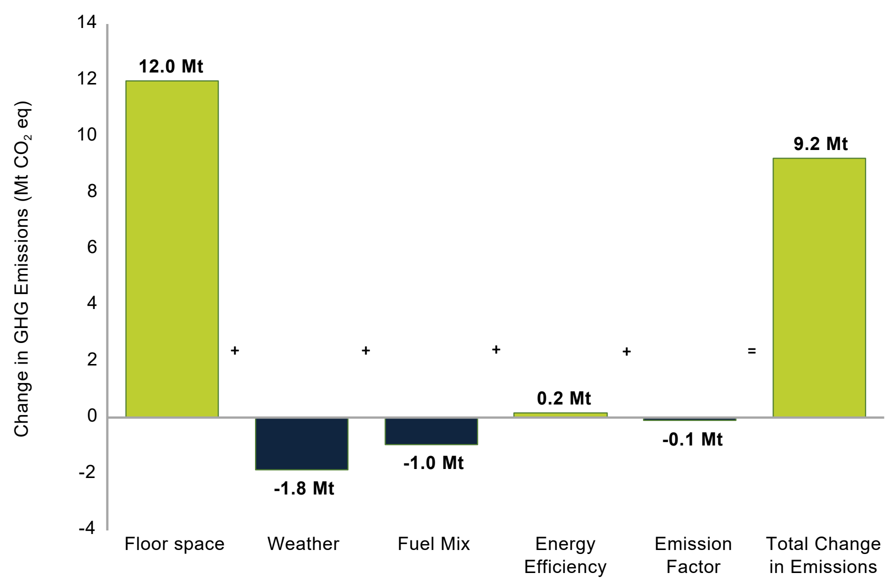
Weather – Weather refers to the fluctuations in weather conditions, particularly outdoor winter temperature.

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 2021**



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.

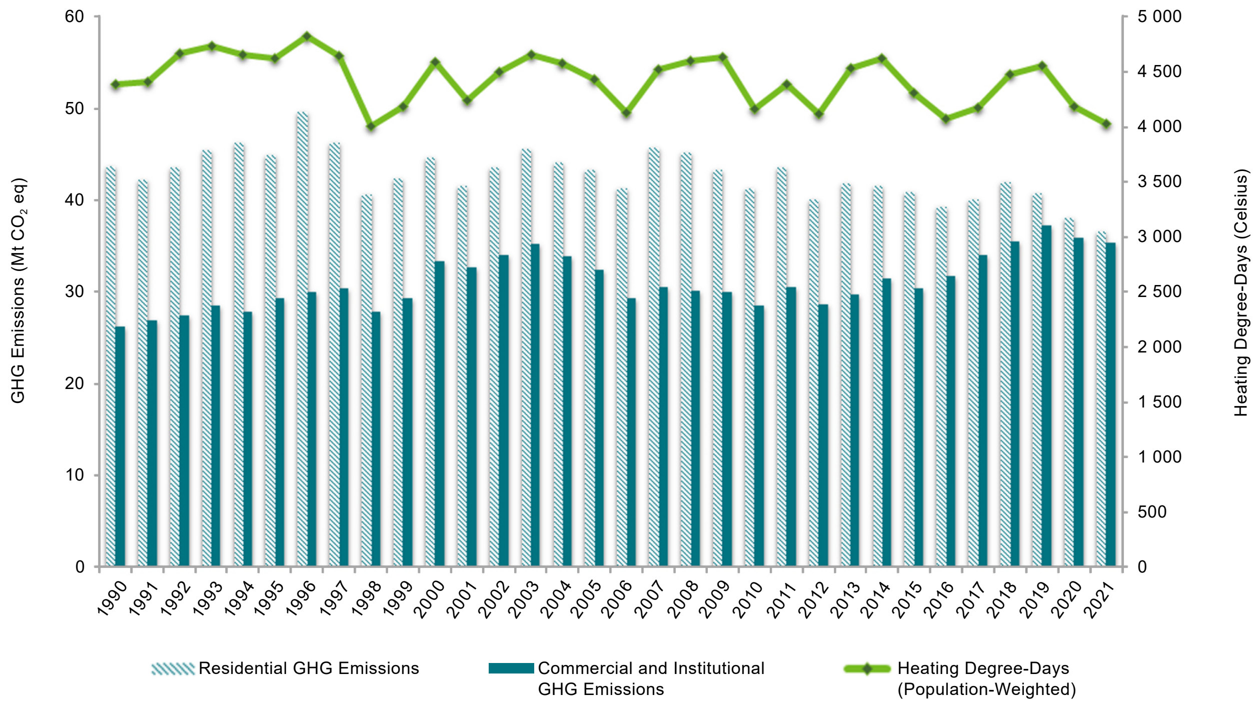
Weather – Weather refers to the fluctuations in weather conditions, particularly outdoor winter temperature.

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 (1990–2021)**



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 25.2 Mt decrease in emissions between 1990 and 2021. Decreasing consumption of light fuel oil in all provinces and territories but especially Quebec and Ontario, between 1990 and 2021 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[6]. The resulting 12 Mt increase in emissions was partially offset by improvements in the fuel mix, equivalent to a 1.0 Mt decrease in GHG emissions (Figure 2–11).

Weather patterns can have an effect on emissions when comparing one year to another, as suggested by the close tracking 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 inter-annual weather variability.

Other Stationary Combustion Sources (2021 GHG emissions, 24 Mt)

Other Stationary Combustion Sources comprise fuel combustion emissions from the Petroleum Refining Industries, Mining, Construction, and Agriculture and Forestry categories. From 1990 to 2021, the Petroleum Refining Industries category showed a decrease in GHG emissions of 4.2 Mt (24%), the Mining category showed an increase of 1.8 Mt (38%), the Construction category showed a decrease of 0.42 Mt (22%), and the Agriculture and Forestry category showed an increase of 0.68 Mt (28%).

6 Kaymak, D. 2022. Personal communication (email from Kaymak D. to Kay J., Physical Scientist, PIRD, dated November 22, 2022). Economic Analysis Directorate, Environment and Climate Change Canada.

2.3.1.2. Transport (2021 GHG emissions, 188 Mt)

Transport is a large and diverse sector, accounting for 188 Mt of GHG emissions or 35% of Canada's Energy sector emissions in 2021. 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 2021, Transport emissions rose by 29% (42 Mt), accounting for a significant portion of Canada's emissions growth. Between 2019 and 2020, Transport emissions dropped 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 2021, Transport emissions increased by 5.0% (9.0 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). Other Transportation (Off-Road and Pipelines) is the second-largest category, accounting for 29% of Transport emissions, 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 2021, the Aviation category increased by 18% (0.8 Mt). The Marine and Railways categories combined contributed to approximately 6.0% of the Transport emissions in 2021 and, overall, were stable over the 1990–2021 time series.

Road Transportation (2021 GHG emissions, 116 Mt)

Emissions from Road Transportation are influenced by several factors, including vehicle kilometres travelled (VKT), vehicle type, fuel efficiency, fuel type, emissions 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 2021, total VKT increased by 5.3%, the largest relative year-to-year increase reported since 1994.

The total vehicle fleet has increased by 51% since 1990 (26% since 2005), most notably for light-duty trucks which have steadily increased throughout the 1990–2021 time series (Table 2–6). The heavy-duty vehicle fleet steadily increased for the majority of the time series but has plateaued in recent years. The light-duty car fleet was relatively stable for the majority 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 2021 being 62% and 14% 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 2021, approximately 160 000 fully electric vehicles were in the vehicle fleet, a 49% growth from 2020.

Figure 2–13 **Trends in Canadian GHG Emissions from Transport (1990–2021)**

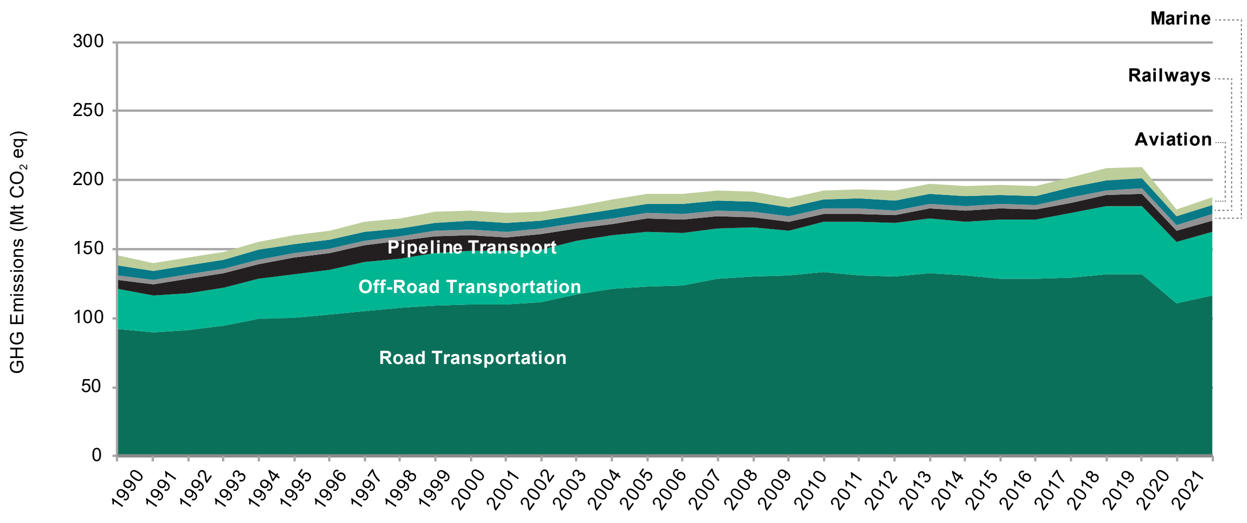


Table 2–5 **GHG Emissions from Transport, Selected Years**

CRF Code		GHG Emissions (Mt CO_2 eq)								Change (%)	
		1990	2005	2016	2017	2018	2019	2020	2021	1990–2021	2005–2021
1.A.3	**Transport**	**145**	**191**	**196**	**202**	**209**	**210**	**179**	**188**	**29%**	**-2%**
	Aviation	**7.5**	**7.7**	**7.5**	**7.9**	**8.7**	**8.6**	**4.7**	**5.6**	**-26%**	**-28%**
1.A.3.a	Domestic Aviation (Civil)	7.3	7.5	7.3	7.7	8.4	8.3	4.6	5.4	-26%	-28%
1.A.5.b	Military	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	-14%	-23%
	Road Transportation	**92**	**123**	**128**	**129**	**132**	**132**	**111**	**116**	**26%**	**-5%**
1.A.3.b.i	Light-Duty Gasoline Vehicles	44	41	34	34	33	32	25	24	-46%	-41%
1.A.3.b.ii	Light-Duty Gasoline Trucks	25	41	50	52	53	55	47	50	104%	23%
1.A.3.b.iii	Heavy-Duty Gasoline Vehicles	4.8	4.6	4.4	4.4	4.5	4.5	4.2	4.3	-10%	-7%
1.A.3.b.iv	Motorcycles	0.2	0.5	0.9	0.9	0.9	1.0	0.8	0.8	275%	67%
1.A.3.b.i	Light-Duty Diesel Vehicles	0.4	0.7	0.6	0.6	0.6	0.5	0.3	0.3	-12%	-52%
1.A.3.b.ii	Light-Duty Diesel Trucks	0.9	0.8	0.6	0.6	0.7	0.7	0.6	0.7	-19%	-5%
1.A.3.b.iii	Heavy-Duty Diesel Vehicles	16	34	37	37	39	38	33	35	124%	2%
1.A.3.b.v	Propane and Natural Gas Vehicles	0.8	0.0	0.1	0.1	0.1	0.2	0.2	0.2	-75%	723%
1.A.3.c	**Railways**	**6.9**	**6.6**	**6.4**	**7.3**	**7.4**	**7.5**	**6.9**	**6.8**	**-1%**	**4%**
	Marine	**3.1**	**4.0**	**3.3**	**3.5**	**3.5**	**4.3**	**3.8**	**4.4**	**42%**	**9%**
1.A.3.d	Domestic Navigation	2.2	3.1	3.0	3.2	3.2	4.0	3.6	4.1	88%	33%
1.A.4.c.iii	Fishing	0.9	0.9	0.2	0.2	0.2	0.2	0.2	0.2	-79%	-79%
1.A.5.b	Military Water-Borne Navigation	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	186%	201%
	Other Transportation	**36**	**49**	**51**	**55**	**57**	**58**	**52**	**55**	**52%**	**11%**
1.A.4.c.ii	**Off-Road Agriculture and Forestry**	**8.7**	**10**	**12**	**14**	**14**	**14**	**13**	**13**	**53%**	**35%**
1.A.4.a.ii	Off-Road Commercial and Institutional	4.2	4.5	5.2	5.7	5.9	6.0	5.3	5.8	37%	29%
1.A.2.g.vii	Off-Road Manufacturing, Mining and Construction	12	16	17	19	20	20	17	18	47%	12%
1.A.4.b.ii	Off-Road Residential	0.4	1.2	1.1	1.0	1.0	1.0	1.0	0.9	156%	-23%
1.A.3.e.ii	Off-Road Other Transportation	3.5	7.6	7.9	8.0	8.0	7.9	7.6	7.7	123%	2%
1.A.3.e.i	Pipeline Transport	6.9	10	7.7	7.6	8.4	8.5	7.7	8.7	26%	-14%

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
2016	10 751	10 838	1 953	24 258
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
Change since 1990	-18%	220%	80%	51%
Change since 2005	-15%	88%	19%	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.

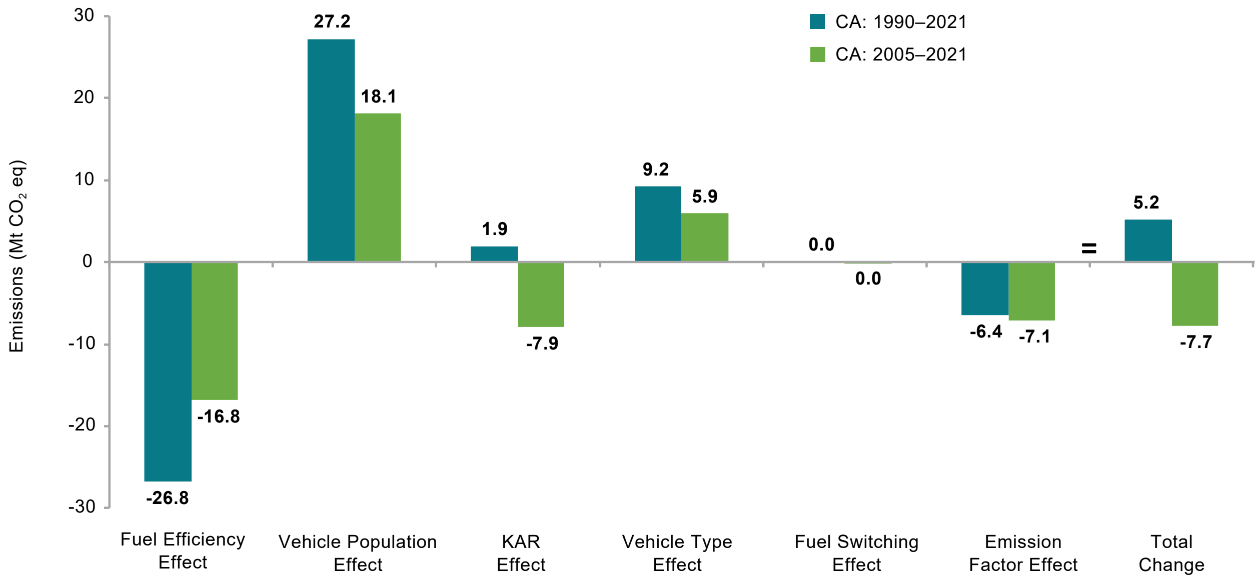
Light-Duty Gasoline Vehicles (2021 GHG emissions, 24 Mt)

Since 1990, emissions from Light-Duty Gasoline Vehicles (i.e. passenger cars) have steadily decreased and in 2021 were 46% (20 Mt) and 41% (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 (2021 GHG emissions, 50 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 2021 104% (26 Mt) and 23% (9.3 Mt) higher than those in 1990 and 2005, respectively. These increases are largely due to increased sales of light-duty trucks, offset by increased fleet-average fuel efficiency, the implementation of emission control technologies and increased use of biofuels (Figure 2–14). Light-Duty Gasoline Trucks contributed to the majority of the emissions growth reported for Road Transportation, making up 56% of the growth from 1990 to 2021 and 89% of the growth from 2005 to 2021.

Figure 2–14 **Factors Contributing to Change in Light-Duty Vehicle Emissions, 1990–2021 and 2005–2021**



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, 1990–2021 and 2005–2021.

Fuel efficiency effect refers to the change in emissions due to the change in fuel consumption ratios (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 (2021 GHG emissions, 35 Mt)

From 1990 to 2011, emissions from Heavy-Duty Diesel Vehicles steadily increased, which peaked 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 2021, emissions from these vehicles were estimated to be about 35 Mt, which is 124% (20 Mt) and 2.5% (0.9 Mt) higher than those in 1990 and 2005, respectively. These increases are largely due to the expansion of the heavy-duty vehicle fleet, particularly those with a gross vehicle weight rating below 4,536 kilograms. However, increases to the fleet-average fuel efficiency and decreases to average annual driving rates heavily mitigated emissions growth.

Other Transportation: Off-Road (2021 GHG emissions, 46 Mt)

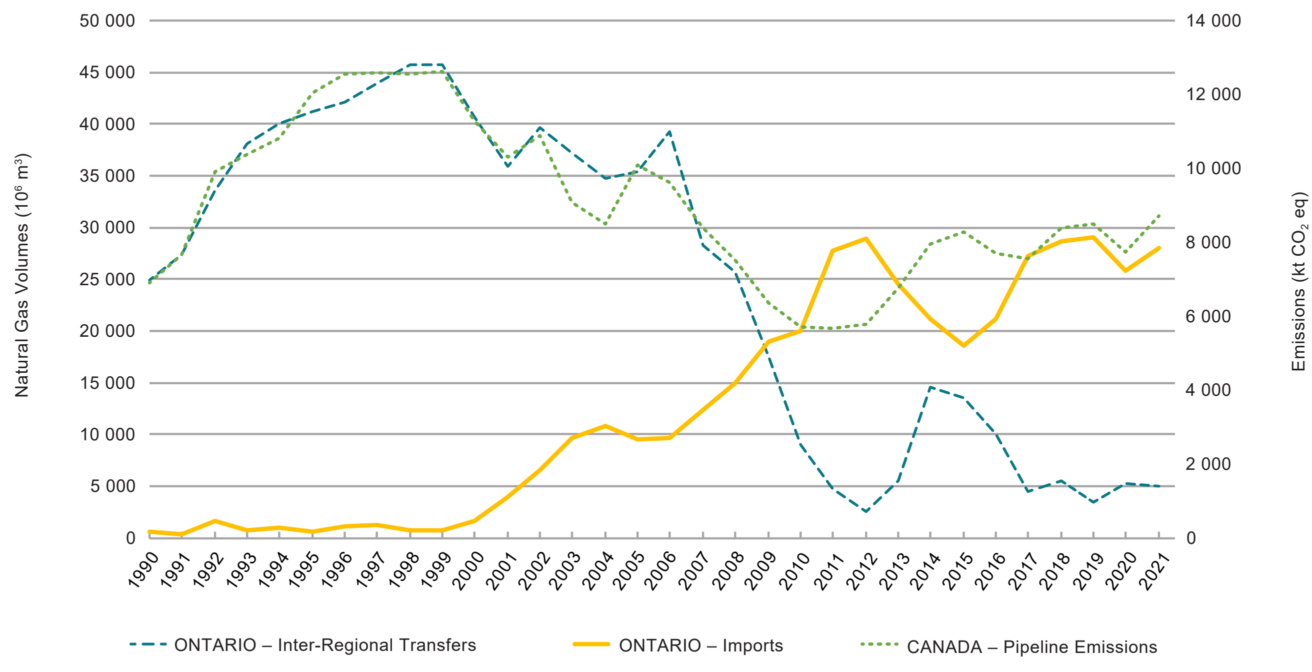
Off-road emissions primarily result from the combustion of diesel and gasoline in a wide variety of applications, including heavy mobile equipment used in the construction, mining and logging industries; agricultural tractors and combines; recreational vehicles, such as snowmobiles and all-terrain vehicles (ATVs); and residential equipment, such as lawnmowers and trimmers. In 2021, the Off-Road Manufacturing, Mining and Construction subcategory and the Off-Road Agriculture and Forestry subcategory accounted for 39% and 29% of off-road emissions, respectively. The net emissions for all off-road subcategories have increased by 58% (17 Mt) since 1990 and increased by 17% (6.6 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 (2021 GHG emissions, 8.7 Mt)

Pipeline emissions result from the combustion of natural gas at compressor stations used for natural gas transport. In 2021, over 99% of marketable natural gas production occurred in western Canada: Alberta (67%), British Columbia (30%) and Saskatchewan (2.3%). While these provinces account for approximately 65% of marketable natural gas consumption in Canada, Ontario, the most populous province, accounts for approximately 26% of natural gas consumption but produces less than 0.05% of natural gas (StatCan, 1990–). 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, 1990–) 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).

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

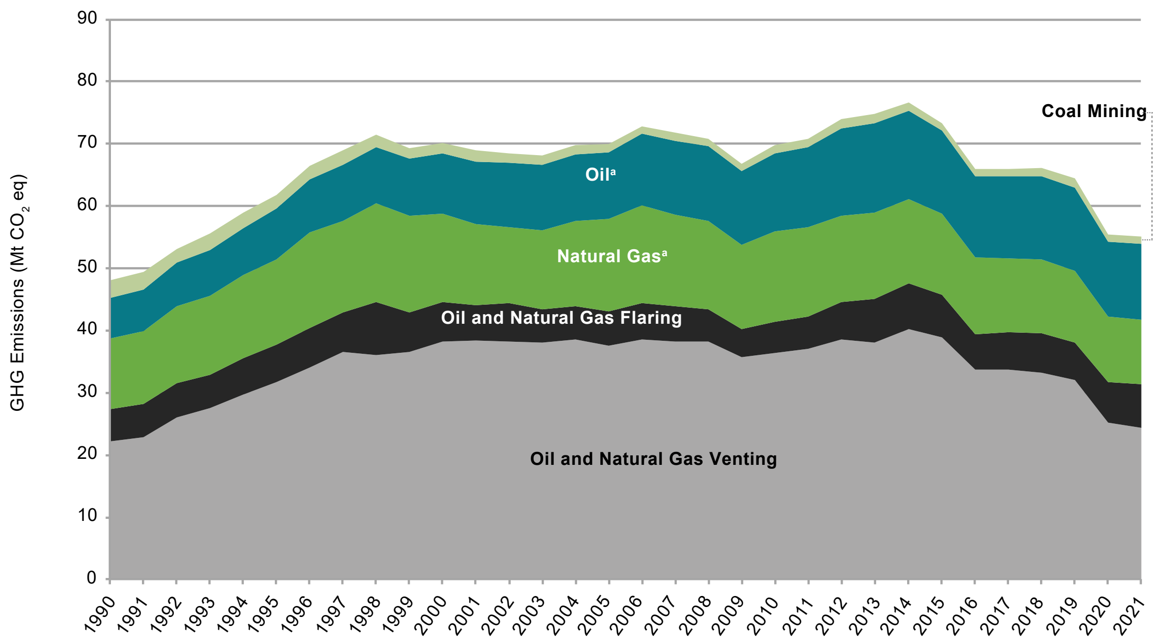


2.3.1.3. Fugitive Sources (2021 GHG Emissions, 55 Mt)

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 7 Mt (15%) between 1990 (48 Mt) and 2021 (55 Mt) (Table 2–7) with considerably more variation over the time series. Fugitive emissions peaked in 2014 at 77 Mt (Figure 2–16), almost 60% higher than 1990. Fugitive emissions from Oil and Natural Gas alone increased by 30 Mt (66%) over this period, while releases from Coal Mining decreased by 1.5 Mt (54%), mainly due to mine closures in eastern Canada.

Figure 2–16 **Trends in Canadian GHG Emissions from Fugitive Sources (1990–2021)**



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	2016	2017	2018	2019	2020	2021	1990–2021	2005–2021
Fugitive Sources[a]	**48**	**70**	**66**	**66**	**66**	**64**	**55**	**55**	**15%**	**-21%**
Coal Mining	**2.8**	**1.4**	**1.3**	**1.2**	**1.3**	**1.4**	**1.1**	**1.2**	**-58%**	**-16%**
Oil and Natural Gas	**45**	**69**	**65**	**65**	**65**	**63**	**54**	**54**	**19%**	**-21%**
Oil[b]	6.5	11	13	13	13	13	12	12	87%	14%
Natural Gas[b]	11	15	12	12	12	12	11	10	-9%	-30%
Venting	22	38	34	34	33	32	25	24	9%	-35%
Flaring	5.1	5.4	5.7	6.0	6.2	6.0	6.6	7.1	40%	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 2021, it accounted for only 20% of total oil and gas fugitive emissions. Since the vast majority of 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. 2014–2021: declining emissions

Fugitive oil and gas emissions increased steadily from 45 Mt in 1990 to 68 Mt in 2000 (51%) Additionally, over 120,000 oil and gas wells were drilled between 1990 and 2000 (CAPP, 2022). As the number of extraction and processing facilities in the oil and gas industry increases, the number of potential sources of fugitive emissions also grow, 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, as a result 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 6.9 Mt (10%) between 2000 and 2014, peaking in 2014 at 75 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, 2022; StatCan, n.d.[c], n.d.[d]) and the average production per natural gas well decreased by 62% in western Canada (CAPP, 2022; StatCan, n.d.[e], n.d.[f]).

From 2014 to 2019, emissions dropped by 12 Mt (16%), 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 8.7 Mt (14%). This drop coincides with several contributing factors, including:

1. Federal (ECCC, 2018) and equivalent[7] 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. Activity in the sector rebounded after the initial impacts of the COVID-19 pandemic in 2020. Between 2020 and 2021, natural gas production increased by 4%, the number of operating oil and gas wells increased by 3% and the number of wells drilled increased by over 50%. Increased compliance with the federal and provincial regulations likely offset the expected increases due to the production growth.

7 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 approaches, such as those used for this report, use engineering methods to estimate emissions for individual sources based on component-level emission factors and populations, process simulations, metered or calculated volumes of gas vented or flared, etc. to build inventory estimates from the "bottom-up."

Recent studies in Canada that have used atmospheric measurements to derive "top-down" estimates suggest that "bottom-up" inventories under-estimate 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). 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 the specific emission sources within a facility responsible for the emissions. Fully understanding the discrepancies between "bottom-up" and "top-down" approaches requires this level of detail. Recent advances in measurement technology are now able to identify specific sources in the atmospheric measurements (e.g. Johnson et al., 2021; 2023).

ECCC is actively working with researchers to understand the discrepancies between "bottom-up" inventory methods and atmospheric measurements with the goal of improving the accuracy of inventory estimates in future editions of this report.

2.3.1.4. Trends in CO_2 Transport and Storage

In 2016, CO_2 capture, transport and storage began in Alberta for the purpose of long-term geological storage, where the Quest project captures CO_2 from Shell's Scotford upgrader and transports it 65 kilometres north to a permanent storage site. Beginning in 2020, CO_2 from a Nutrien fertilizer facility began entering the Alberta CO_2 Trunk line for use in enhanced oil recovery in Alberta.

Almost all other current CO_2 transport and storage activities in Canada are associated with enhanced oil recovery operations at Weyburn, Saskatchewan. Beginning 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 inject a small amount of CO_2 from Boundary Dam into long-term permanent storage.

Table A10-3 (Annex 10) presents details of CO_2 capture volumes consistent with the origin of the captured CO_2 (an upgrading facility and coal power plant) and these volumes are subtracted from emissions reported under Mining and Upstream Oil and Gas Production, and Public Electricity and Heat Production, in Alberta and Saskatchewan, respectively.

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.

2.3.2. Industrial Processes and Product Use (2021 GHG emissions, 52 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 52 Mt (7.7%) to Canada's 2021 emissions, compared with 57 Mt (7.7%) in 2005, a decrease of approximately 4.6 Mt, or 8%. 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).

Increases in process emissions from 2020 to 2021 of 1.6 Mt (3.1%) were observed in some sub-sectors and categories, notably, the Iron and Steel Industry, Cement and Lime Production and the Non-Energy Products from Fuels and Solvent Use due to facilities returning to normal production levels following temporary shut downs in 2020. In 2021, the largest contributions to emissions in the sector originated from Metal Production (14 Mt), followed by the Production and Consumption of Halocarbons, SF_6 and NF_3 (mostly HFCs) (11 Mt), and Non-Energy Products from Fuels and Solvent Use (11 Mt) (Table 2–8).

Figure 2–17 **Trends in Canadian GHG Emissions from Industrial Processes and Product Use Sources (1990–2021)**

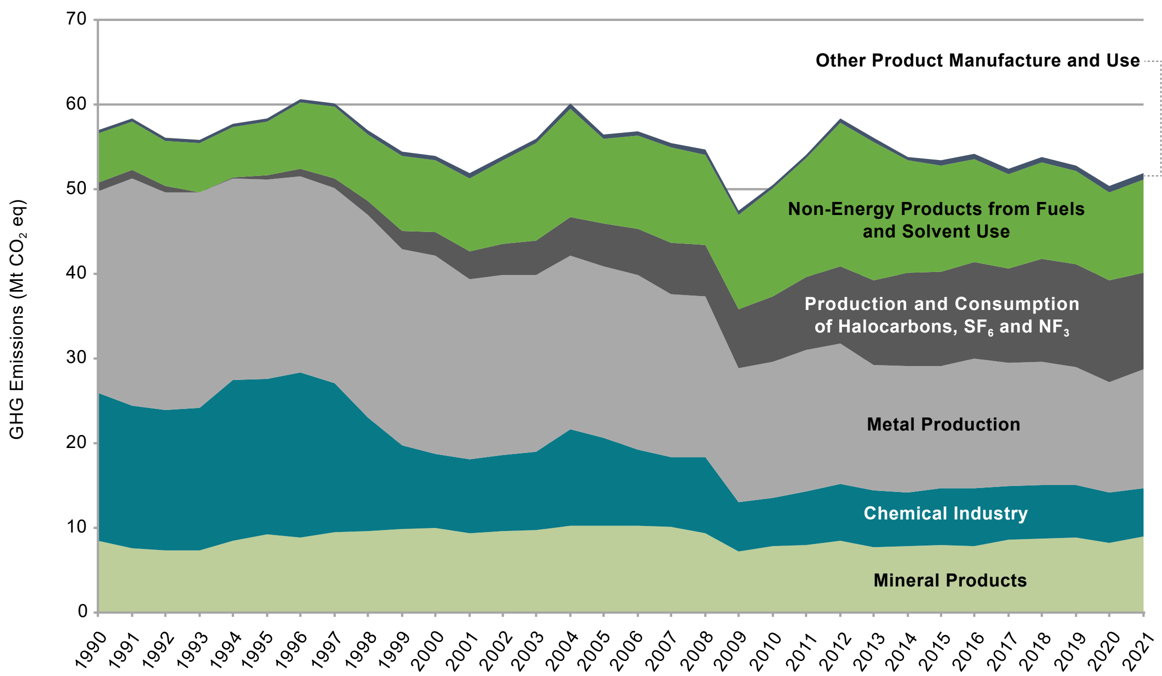


Table 2–8 **GHG Emissions from Industrial Processes and Product Use Categories, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2016	2017	2018	2019	2020	2021	1990–2021	2005–2021
Total – Industrial Processes	**57**	**57**	**54**	**52**	**54**	**53**	**50**	**52**	**-9%**	**-8%**
Mineral Products	**8.5**	**10**	**7.9**	**8.6**	**8.7**	**8.8**	**8.2**	**9.0**	**6%**	**-12%**
Cement Production	5.8	7.6	6.1	6.9	7.0	7.2	6.7	7.4	27%	-3%
Lime Production	1.8	1.8	1.4	1.4	1.4	1.3	1.2	1.3	-27%	-25%
Mineral Product Use	0.9	0.9	0.4	0.3	0.3	0.3	0.3	0.3	-64%	-66%
Chemical Industry	**18**	**10**	**6.8**	**6.3**	**6.4**	**6.2**	**5.9**	**5.7**	**-67%**	**-45%**
Ammonia Production	2.7	2.7	2.8	2.6	2.4	2.5	2.3	2.5	-7%	-6%
Nitric Acid Production	1.0	1.2	0.3	0.2	0.3	0.3	0.2	0.2	-78%	-82%
Adipic Acid Production	10	2.5	-	-	-	-	-	-	100%	100%
Petrochemical Production & Carbon Black Production	3.5	3.9	3.7	3.5	3.7	3.5	3.5	3.0	-15%	-24%
Metal Production	**24**	**20**	**15**	**15**	**15**	**14**	**13**	**14**	**-41%**	**-31%**
Iron and Steel Production	10	10	9.2	8.5	8.9	8.3	7.1	8.0	-24%	-23%
Aluminium Production	10	8.7	6.0	6.0	5.5	5.3	5.9	5.8	-43%	-33%
SF_6 Used in Magnesium Smelters and Casters	3.0	1.2	0.1	0.1	0.1	0.3	0.1	0.1	-95%	-89%
Production and Consumption of Halocarbons, SF_6 and NF_3	**1.0**	**5.1**	**11**	**11**	**12**	**12**	**12**	**11**	**1078%**	**125%**
Non-Energy Products from Fuels and Solvent Use	**5.8**	**10**	**12**	**11**	**11**	**11**	**10**	**11**	**89%**	**11%**
Other Product Manufacture and Use	**0.4**	**0.5**	**0.6**	**0.6**	**0.7**	**0.7**	**0.7**	**0.7**	**93%**	**33%**

Note: Totals may not add up due to rounding.

2

2.3.2.1. Mineral Products (2021 GHG Emissions, 9.0 Mt)

Cement Production dominates this subsector, accounting for 82% of emissions from Mineral Products in 2021. 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 an overall reduction of 1.3 Mt (12%) from 2005 to 2021.

2.3.2.2. Chemical Industry (2021 GHG Emissions, 5.7 Mt)

From 2005 to 2021, an emissions decrease of 4.6 Mt (45%) 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 2.5 Mt from 2005[8]. N_2O emissions abatement installations at a nitric acid production facility are mainly responsible for a decrease of 1.0 Mt (82%) in the subsector since 2005. Other changes included a decrease in Petrochemical and Carbon Black Production (0.93 Mt) due to facility closures and feedstock changes in ethylene production, as well as a small decrease (0.17 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 (2021 GHG Emissions, 14 Mt)

Emission reductions in the production of magnesium, aluminium, and iron and steel contributed to Metal Production overall reductions of 6.3 Mt (31%) between 2005 and 2021.

The aluminium industry decreased its PFC emissions by 3.1 Mt (81%), 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 2021, emissions in the iron and steel industry decreased by 2.3 Mt (23%). The main driver behind the decrease in emissions were reductions in the use of metallurgical coke as reductant for iron production.(StatCan, 2004–2012; CSPA, 2013–2019; ECCC, 2022).

8 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 (2021 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 6.3 Mt (124%) from 2005 to 2021. This can be explained by the replacement of ODSs by HFCs within the refrigeration and air conditioning markets since the Montreal Protocol came into effect in 1996. HFC emissions decreased by 0.72 Mt between 2018 and 2021 due in part to reduced bulk imports. 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 (2021 GHG Emissions, 11 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 1.1 Mt (11%) from 2005 to 2021. The observed change is mostly attributable to the emissions from the feedstock use of waxes, paraffin and unfinished products, which increased by 0.9 Mt (26%) over the period.

2

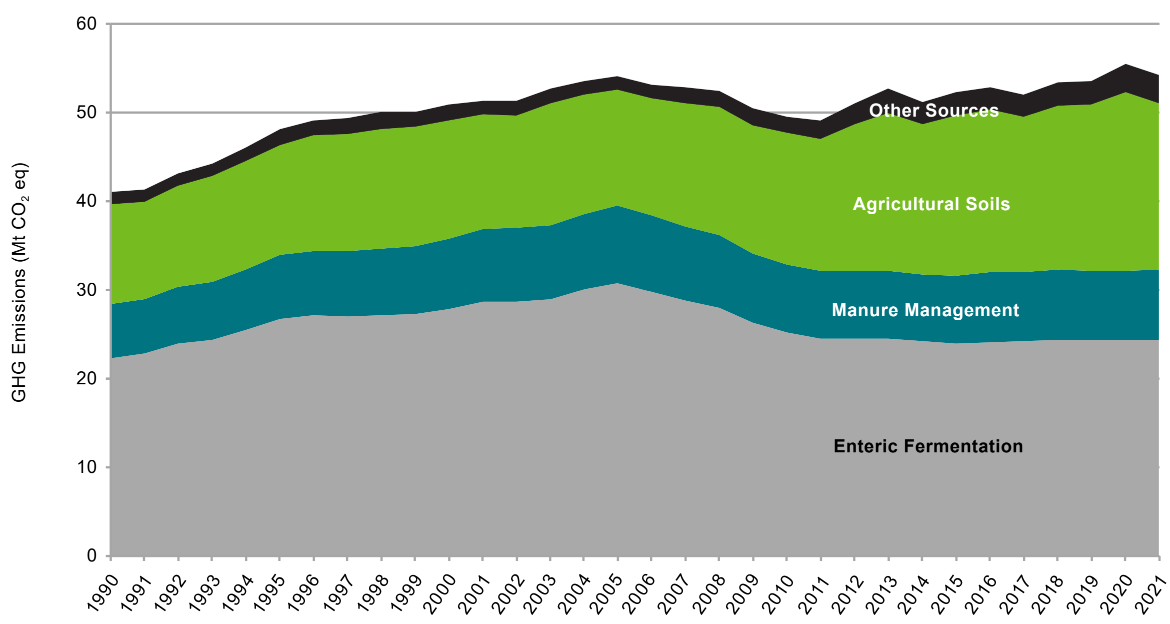
2.3.3. Agriculture Sector (2021 GHG Emissions, 54 Mt)

In 2021, emissions from the Agriculture sector accounted for 54 Mt, or 8.1%, of total GHG emissions in Canada, equivalent to 2005 levels, but corresponding to an increase of 13 Mt or 32% since 1990 (Figure 2–18 and Table 2–9). In 2021, the Agriculture sector accounted for 31% of national CH_4 emissions and 75% of national N_2O emissions, up from 30% 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.

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

Figure 2–18 **Trends in Canadian GHG Emissions from Agriculture Sources (1990–2021)**



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.

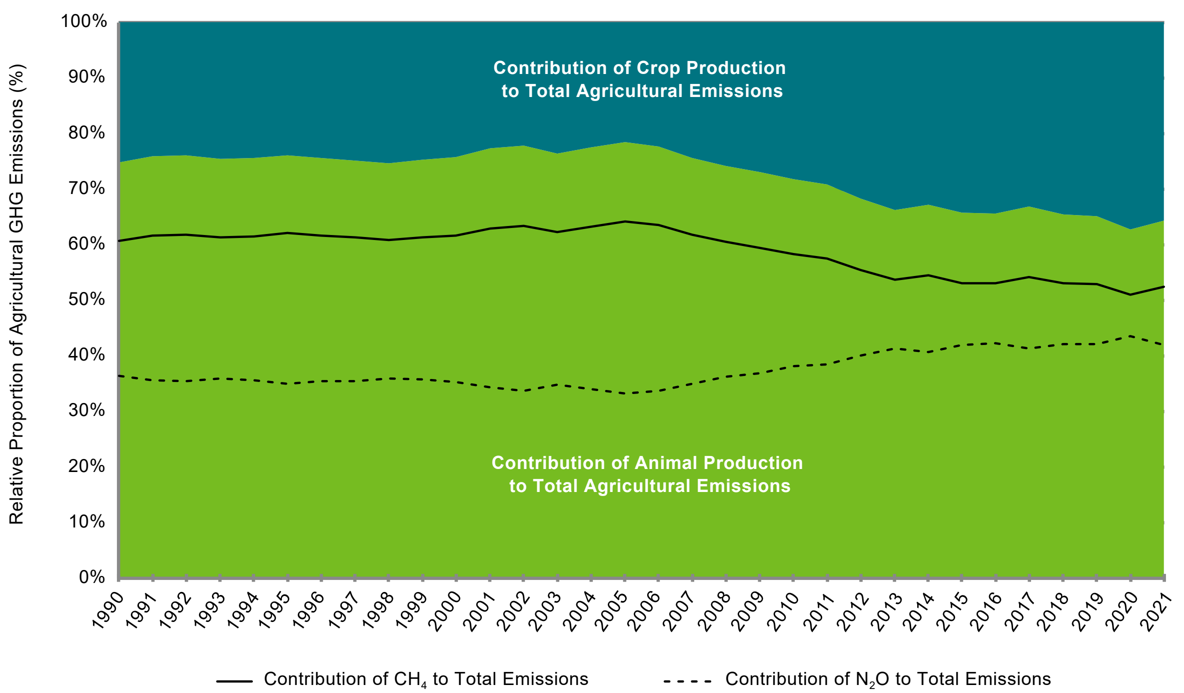
The main drivers of the emission trend in the Agriculture sector are the fluctuations in livestock populations and continuous increases in the application of inorganic nitrogen fertilizers, mainly in the Prairie provinces. Beef, swine and poultry populations in Canada in 2021 are 8%, 38% and 48% higher, 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 64% of total agricultural emissions in 2021, considerably lower than the proportion in 2005 (78%) (Figure 2–19). As a result of this shift, total agricultural emissions are approaching equivalent proportions of N_2O (mainly from crop production) and CH_4 (from livestock production), which is unprecedented. The shift in the industry from grazing cattle production to the production of annual crops 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).

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

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2016	2017	2018	2019	2020	2021	1990–2021	2005–2021
Agriculture	**41**	**54**	**53**	**52**	**53**	**54**	**55**	**54**	**32%**	**0%**
Enteric Fermentation	22	31	24	24	24	24	24	24	9%	-21%
Manure Management	6.1	8.7	7.8	7.8	7.8	7.8	7.8	7.8	29%	-10%
Agricultural Soils	11	13	18	17	19	19	20	19	66%	43%
Field Burning of Agricultural Residues	0.22	0.04	0.05	0.05	0.05	0.05	0.05	0.03	-84%	-18%
Liming, Urea Application and Other Carbon-Containing Fertilizers	1.2	1.4	2.5	2.4	2.6	2.7	3.0	3.1	162%	119%

Note: Totals may not add up due to rounding.

Figure 2–19 **Proportions of Canadian Agricultural GHG Emissions Emitted as CH_4 and N_2O, or Attributed to Livestock and Crop Production (1990–2021)**



2.3.3.1. Enteric Fermentation (2021 GHG Emissions, 24 Mt)

Emissions from enteric fermentation originate almost entirely (96%) from Cattle Production in Canada. From 1990 to 2021, emissions increased from 22 Mt to 24 Mt, or 9%. 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 26% due to a sharp decrease in prices after an outbreak of bovine spongiform encephalopathy (BSE, or mad cow disease) in 2003. In recent years beef populations and associated emissions have stabilized.

At the same time, emissions associated with dairy cows have fallen by approximately 10% since 1990, mainly due to a 30% reduction in the dairy cow population from 1990 to 2021 (StatCan, n.d.[g]). 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 (2021 GHG emissions, 7.8 Mt)

Emissions from animal manure management systems increased from 6.1 Mt in 1990 to 7.8 Mt in 2021 (or 29%), 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 (17% 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 2.5 Mt in 1990 to 3.9 Mt (59%) in 2021. N_2O emissions closely follow the trend in beef populations, increasing from 3.6 Mt in 1990 to 4.8 Mt (33%) in 2005 and subsequently declining to 3.9 Mt (24%) in 2021. 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 (2021 GHG Emissions, 19 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 11 Mt in 1990 to 19 Mt in 2021, an increase of 66%, 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 5.5 Mt in 1990 to 13 Mt in 2021, an increase of 133%, as inorganic nitrogen fertilizer consumption increased steadily from 1.2 Mt N to 3.0 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 2021. The first period was a result of the intensification of cropping systems and the reduction of summer fallow on the Canadian Prairies. The second period reflected an increase in grain prices that encouraged farmers to use more nutrient inputs and convert lands from perennial to annual crop production, coinciding with a reduction in grazing cattle operations on the Canadian Prairies. The increase in fertilizer use since 1990 also resulted in a 2.1 Mt (266%) increase in emissions of CO_2 from urea and urea ammonium nitrate.

Emissions from crop residue decomposition ranged from a minimum of 2.2 Mt in 2002 (a drought year) to a maximum of 4.5 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 3.4 Mt in 2021 as a result of severe drought conditions in the prairies that led to a sharp decline in crop production. Though crop production demonstrates high inter-annual 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 0.15 Mt to total emissions from soils. In 2021, the adoption of conservation tillage (approximately 17 million hectares of cropland since 1990) reduced emissions by 2.4 Mt, while increases in irrigation increased emissions by 1.2 Mt, for a net reduction in emissions of 1.2 Mt.

2.3.4. Land Use, Land-Use Change and Forestry Sector (2021 Net GHG Removals, 17 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 2021, LULUCF was estimated to remove 17 Mt from the atmosphere, compared with net removals of 65 Mt in 1990 and 5.5 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 a decrease of 11% in 1990, 0.8% in 2005 and 2.6% in 2021 (Figure 2–6).

The net fluxes reported in the LULUCF sector were negative (removals) for all years of the time series, except for a small net source in 2015, with a generally decreasing trend between 1990 and 2005 mainly driven by the decrease in net CO_2 removals from Forest Land from 1990 to 2007 (Table 2–10), partially attenuated by increasing net CO_2 removals in Cropland and a decrease in emissions from the conversion of forest to other land use over the first two decades of the time series. Relative to the strong sink observed in the land sector throughout the 1990s, Canada's recent tendency towards lower net removals from the atmosphere by the land sector are driven by a diminished Forest Land sink from sustained forest harvest and increased insect mortality as well as decreases in perennial cover in Cropland, and recent increases in rates of deforestation in some regions. Net fluxes from the LULUCF sector have fluctuated over recent years between high removal peaks of 49 Mt in 2009 and 39 Mt in 2014 to a small net source of emissions of 24 kt in 2015 (Figure 2–20).

2

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

Sectoral Category		Net GHG Flux (Mt CO_2 eq)[a]									
		1990	2005	2016	2017	2018	2019	2020	2021	Change 1990–2021	Change 2005–2021
Land Use, Land-Use Change and Forestry TOTAL		**-65**	**-5.5**	**-11**	**-16**	**-11**	**-19**	**-13**	**-17**	**47**	**-12**
a.	Forest Land	-200	-140	-140	-140	-130	-140	-130	-130	71	3.6
b.	Cropland	1.0	-22	-17	-23	-22	-18	-16	-18	-19	4.3
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	3.1	3.1	3.1	2.8	3.1	3.5	3.3	-2.1	0.2
e.	Settlements	1.9	1.5	2.3	2.2	2.1	1.9	2.1	2.0	0.2	0.5
g.	Harvested Wood Products	130	150	140	140	140	130	130	130	-3.2	-20

Notes:

Totals may not add up due to rounding.

a. Negative sign indicates net removals of CO_2 from the atmosphere.

2.3.4.1. Forest Land and Harvested Wood Products (2021 GHG Removals, 9.1 Mt)

The Forest Land and Harvested Wood Products categories combined include GHG fluxes between the atmosphere and Canada's managed forests and emissions from harvested wood products (HWP) originating from domestic harvest. The total net flux from managed forests and resulting HWP amounted to an estimated net removal of 9.1 Mt in 2021 (Figure 2–20), which combines net removals of 130 Mt from Forest Land and net emissions of 123 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 200 Mt in 1990 to 130 Mt in 2007. 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 0.8 million hectares in 1990 to 1.3 million hectares in 2004. Of that annual harvest area 9.5%, 8.6% and 5.7% was harvested as clearcut with slash burning and further, there were 72, 88 and 63 thousand hectares of commercial thinning in 1990, 2005 and 2021 respectively. The rest of annual harvest was clear cut leaving residue to decompose in place.

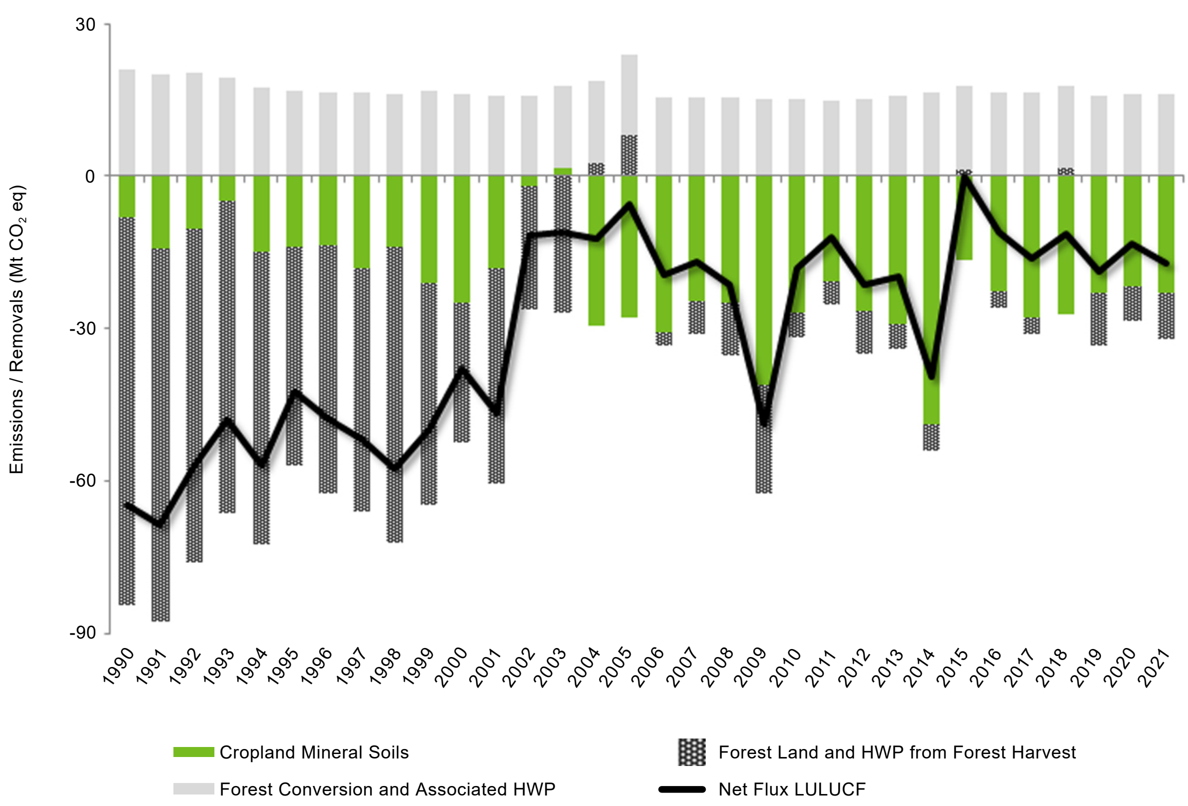
Since 2005, net removals have fluctuated between 140 and 130 Mt. Harvest levels have remained relatively constant in recent years, with 2021 levels still 32% below their peak in 2004. Emissions from slash burning have decreased in recent years reaching their lowest levels throughout the time series. 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 reduced the commercially mature forest area and as a consequence carbon removals.

The decrease in forest removals nationally is dominated by trends in the Montane Cordillera and Boreal Plains. 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. 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. On the Boreal Plains, sustained harvest, insect outbreaks and fire combined to reset large areas of previously productive forest to younger age-classes. 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 forest of these regions—primarily between 1997 and 2007—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.

Also recently, insect infestations that have impacted large areas in the Boreal Shield East and Atlantic Maritime since 2010 have started to have an effect on net emissions and removals in these regions that will likely continue over the next few decades. Although emissions and removals associated with severe natural disturbances are differentiated from anthropogenic fluxes, disturbances nevertheless influence reported GHG fluxes.

Emissions from HWP reflect the long-term storage of carbon in wood harvested in Canada's forests. Approximately one-third of HWP emissions (34% in 2021) result from long-lived wood products reaching the end of their useful life decades after the wood was harvested. End-of-life emissions for short-lived products, namely pulp and paper and bioenergy products, accounted for 28% and 35% of HWP emissions, respectively, in 2021. These same products accounted for 30% and 40% in 1990 and 35% and 40% in 2005. It is also important to note, however, that there was greater wood processing waste in 1990 accounting for 15% of HWP emissions prior to the common practice in recent years of using wood waste for bioenergy production. In general, emissions from short-lived wood products more closely track recent trends in forest harvest rates; as a result, emissions from HWP from forests fluctuated between 120 Mt in 2009 (lowest harvest year) and 2021, and a peak of 150 Mt in 1995.

Figure 2–20 **LULUCF Sector Net GHG Flux and Major Emission and Removal Components, 1990–2021**



2.3.4.2. Forest Conversion (2021 GHG Emissions, 16 Mt)

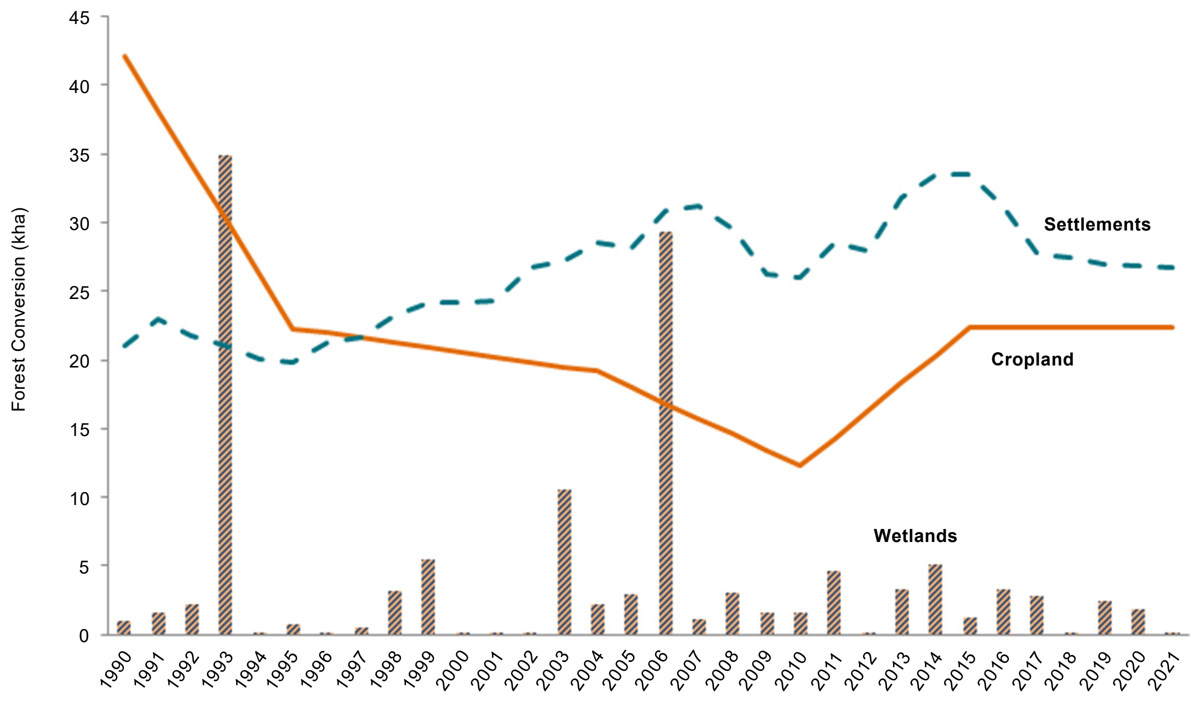
Forest conversion[9] is not a reporting category per se, since it overlaps with the subcategories of Land Converted to Cropland, Land Converted to Wetlands and Land Converted to Settlements. It also includes the emissions from HWP resulting from forest conversion activities since 1990. Emissions due to forest conversion fell from 21 Mt in 1990 to 16 Mt in 2021.

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 (23 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.

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 2021, 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 (11 kha per year) followed by the Boreal Shield East (4.1 kha per year).

Forest clearing for agricultural expansion (Cropland) is the second-largest driver of forest conversion, accounting for 45% of all forest area lost in 2021. 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).

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



9 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.

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 202 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.

2.3.4.3. Cropland (2021 GHG Removals, 18 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 1.0 Mt in 1990, and net removals of 22 Mt and 18 Mt in 2005 and 2021, respectively, to the land sector estimates. This land category has observed net removals over the reporting period with the exception of important drought years on the prairies in early 2000s that resulted in peak in emissions in 2002 (4.0 Mt) and 2003 (7.8 Mt) . Interannual variability occurs throughout the time series, reflecting weather-related impacts to crop production.

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. 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 (-43 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 (2021 GHG emissions, 5.4 Mt)

Other LULUCF sources/sinks include Wetlands, Settlements and Grassland, which contributed 3.3 Mt, 2.0 Mt and 0.001 Mt, respectively, to their combined net emissions of 5.4 Mt reported in 2021, 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 5.4 Mt in 1998 and 6.8 Mt in 2015). 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 (2021 GHG Emissions, 21 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from the Waste sector contributed 21 Mt (3.1%) to Canada's total emissions in 2021, comparable to emission levels of 19 Mt in 1990 (3.2% of total emissions) and of 22 Mt (2.9%) in 2005 (Figure 2–22 and Table 2–11). In 2021, landfilling (including municipal solid waste and industrial wood waste disposal) accounted for 18 Mt (or 85% 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 0.36 Mt, 2.6 Mt and 0.15 Mt, respectively.

Figure 2–22 **Trends in Canadian GHG Emissions from Waste (1990–2021)**

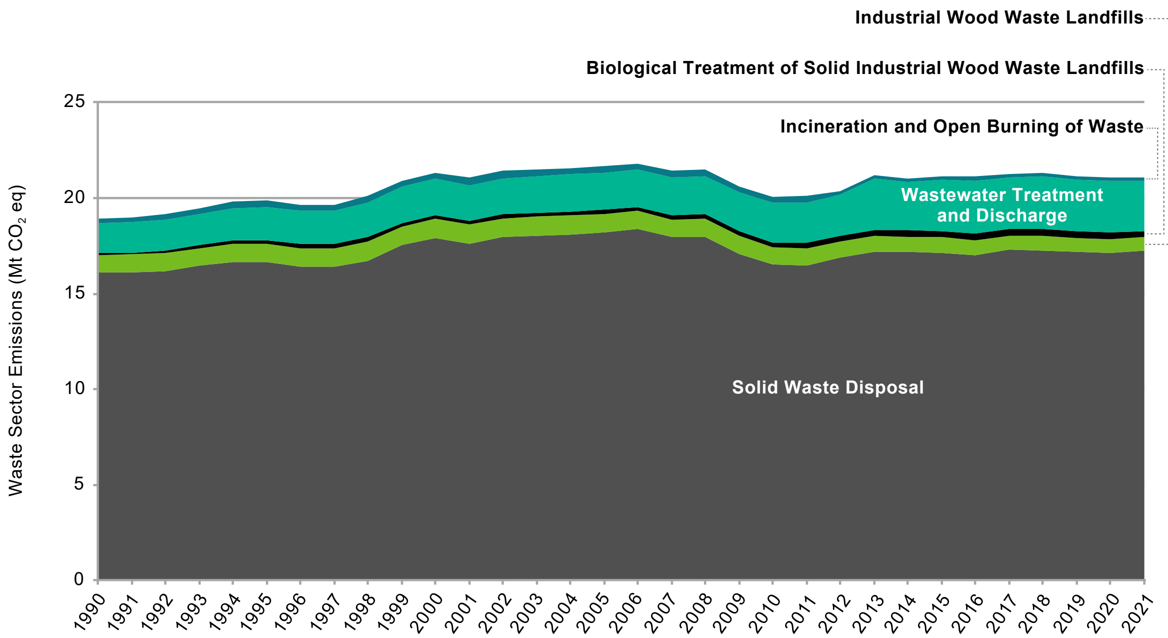


Table 2–11 **GHG Emissions from Waste, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2016	2017	2018	2019	2020	2021	1990–2021	2005–2021
Waste Sector	**19**	**22**	**21**	**21**	**21**	**21**	**21**	**21**	**11%**	**-3%**
Solid Waste Disposal (Landfills)	16	18	17	17	17	17	17	17	7%	-5%
Biological Treatment of Solid Waste	0.07	0.24	0.32	0.33	0.36	0.36	0.36	0.36	388%	47%
Wastewater Treatment and Discharge	1.6	1.9	2.8	2.7	2.8	2.7	2.7	2.6	67%	37%
Incineration and Open Burning of Waste	0.26	0.35	0.20	0.19	0.18	0.18	0.16	0.15	-43%	-56%
Industrial Wood Waste Landfills	0.89	0.97	0.78	0.76	0.75	0.73	0.71	0.70	-22%	-28%

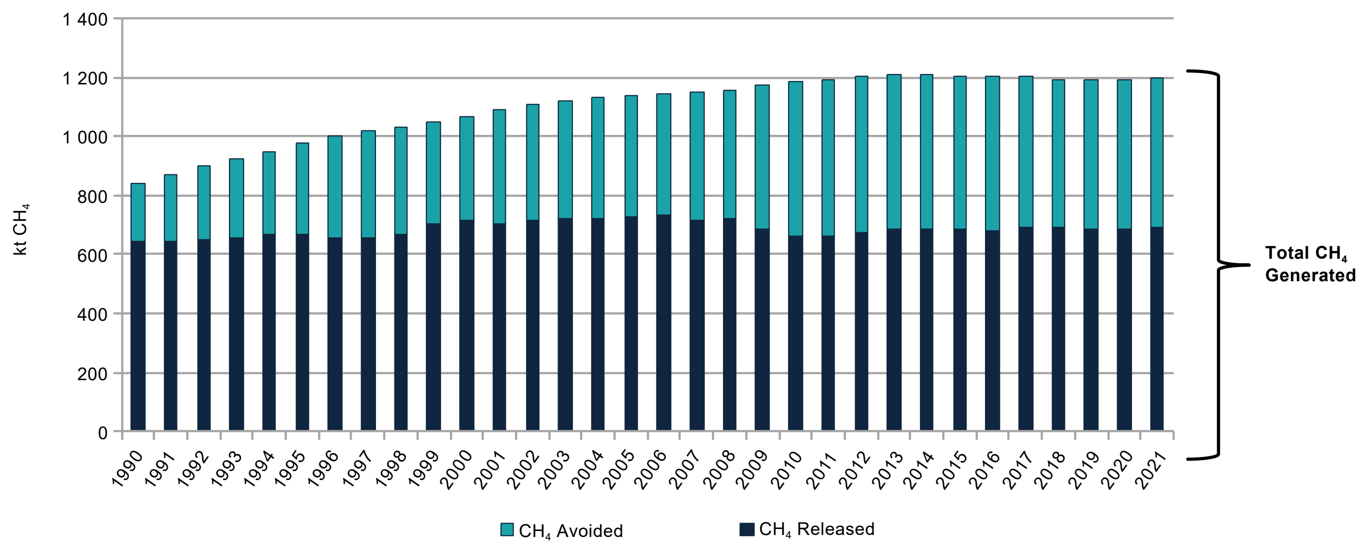
Note: Totals may not add up due to rounding.

2.3.5.1. Solid Waste Disposal and Industrial Wood Waste Landfills (2021 GHG Emissions, 18 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 2021, emissions from MSW landfills were 17 Mt, while emissions from wood waste landfills were 0.7 Mt. Emissions from MSW landfills increased by 7% from 1990 to 2021 and have decreased by 5% from 2005 to 2021. Emissions from wood waste landfills decreased by 22% from 1990 to 2021 and by 28% from 2005 to 2021. 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 2021, 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 (2021 GHG Emissions, 3.1 Mt)

Over the 1990–2021 time series, 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 64% (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 2021 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 (1990–2021) 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

Emissions trends since 2005 have remained consistent with those described for IPCC sectors, with emission increases in the Oil and Gas and Building economic sectors (21 Mt or 12%, and 2.3 Mt or 2.7%, respectively) being offset by decreases in other sectors, notably Electricity (-66 Mt or -56%), Heavy Industry (-12 Mt or -14%); and Waste and others (-5.1 Mt or -9.8%).

Oil and Gas

In 2021, the Oil and Gas sector produced the largest share of GHG emissions in Canada (28%) (Figure 2–24). Between 1990 and 2021, emissions from this sector increased by 89 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 2021, emissions from this sector have generally increased steadily from 100 Mt in 1990 to 203 Mt in 2015. From 2015 to 2019, emissions were relatively stable with some inter-annual 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 18 Mt (9%) between 2019 and 2020. The majority of the increase between 1990 and 2021 is due to considerable expansion in Canada's oil sands. Since 1990, oil sands production has increased by approximately 775% and emissions have increased by over 70 Mt (460%) (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 6 Mt (3%) as the industry rebounded from the early impacts of the pandemic.

Transport

Canada's Transport sector is the second-largest contributor to Canada's GHG emissions, accounting for 22% of total emissions in 2021 (Figure 2–24). Between 1990 and 2021, emissions rose by 32 Mt (27%). Since then, emissions from this sector have continued to increase gradually, with the exception of a decrease between 2019 and 2020 largely due to fewer kilometers driven. Transport emissions in 2021 remained below 2005 levels (-6.7 Mt or -4.3% since 2005). Section 2.3 discusses the main drivers of historical emissions trends associated with passenger and freight transport.

Electricity

In 2021, the Electricity sector (excluding industrial and commercial cogeneration) contributed 7.7% to total Canadian emissions (Figure 2–24). Between 1990 and 2021, emissions decreased by 43 Mt (45%). Emissions from the Electricity sector increased in parallel with the rising demand for electricity both domestically and to satisfy exports to the United States over the earlier years of the reporting period, but have fallen significantly during the latter years. Electricity emissions decreased by 66 Mt or 56% 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 2021, the Heavy Industry sector contributed 11% to Canada's total emissions (Figure 2–24). Emissions from this sector were responsible for 17% 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 12 Mt (14%) between 2005 and 2021.

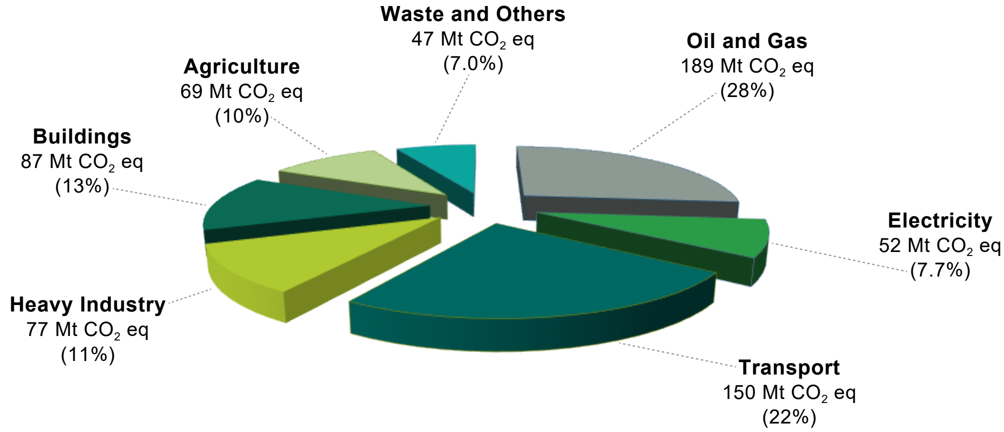
Buildings

In 2021, 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 15 Mt (21%) between 1990 and 2021. Since 2005, emissions increased by 2.3 Mt or 2.7%. 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 49 Mt in 1990 to 69 Mt in 2021 (Figure 2–24). Emissions from the Waste and others sector decreased by 7.7 Mt (14%) since 1990. Overall, Waste emissions increased over the time series, from 19 Mt in 1990 to 21 Mt in 2021. 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 (2021)**



Total: 670 Mt CO_2 eq

Note: Totals may not add up due to rounding.

TRENDS IN THE OIL AND GAS SECTOR

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

In 2021, the largest contributor to O&G emissions was the Oil Sands category (85 Mt, or 45%), followed by Natural Gas Production and Processing (50 Mt, or 26%), Conventional Oil Production (26 Mt, or 14%) and Petroleum Refining (16 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 2021, the production of total crude oil increased by 180%. 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 775% since 1990, accounting for 85% of total crude oil production growth. In contrast, conventional crude oil production (including primary extraction in designated oil sands areas) increased by 32% over the same period. Consistent with the production increases, emissions from Conventional Oil Production increased by 5 Mt (about 25%), while emissions from oil sands increased by 70 Mt (460%).

Emissions from Natural Gas Production and Processing have increased by 18 Mt (55%) since 1990, consistent with a 48% increase in gross production volumes. The majority of this growth has occurred in northeastern British Columbia, which has accounted for 80% of the national production growth.

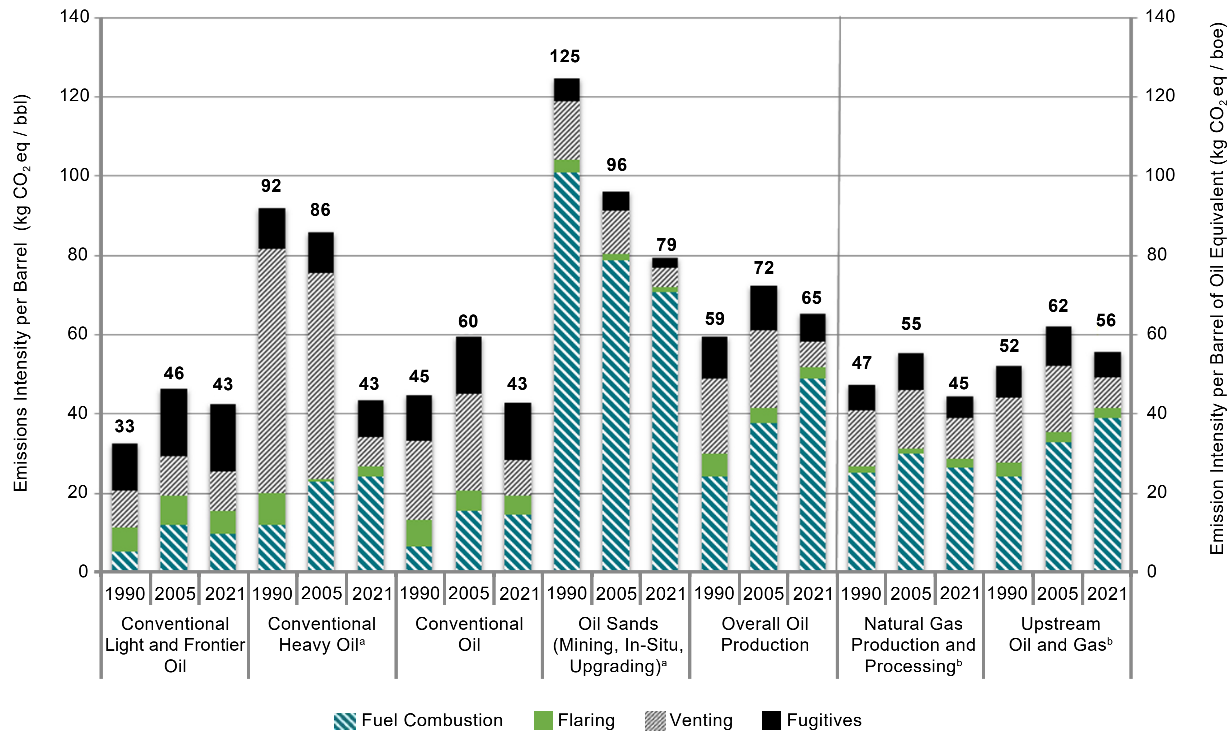
Emission Intensity

The emission intensity of overall oil production in Canada has increased by about 10% between 1990 and 2021, from 59 to 65 kg CO_2 eq per barrel (Figure 2–25). However, the overall emission intensity peaked in 2010 at around 80 kg CO_2-eq per barrel and has decreased since that time. Contributors to this trend in emission intensity 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 2021), which is indicative of increased oil sands production that requires large quantities of steam, generally produced from combusting natural gas.

In contrast, venting, flaring and fugitive emissions per barrel of oil extracted have decreased by 66%, 54% and 32%, respectively. 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.

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 125 kg CO_2 eq per barrel in 1990 to 79 kg CO_2 eq per barrel in 2021. 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 160% while SCO production increased by only 41%. 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, CO_2 emissions from the hydrogen plant at the Scotford Upgrader have been captured and transported to an underground storage site. In 2021, Scotford captured 1.05 Mt of CO_2, reducing the emissions intensity of overall oil sands operations by approximately 1.3%.

Figure 2–25 **Emissions Intensity by Source Type for Oil and Gas (1990, 2005 and 2021)**



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 (2022), SK MER (1990–2008, 2009–2011, 2012–), StatCan (n.d.[c], n.d.[d]); Oil Sands: AER (2022), Cenovus (2022).

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

	1990	2005	2016	2017	2018	2019	2020	2021
	Mt CO_2 eq							
NATIONAL GHG TOTAL	**589**	**732**	**705**	**712**	**725**	**724**	**659**	**670**
Oil and Gas	**100**	**168**	**191**	**194**	**202**	**201**	**183**	**189**
Upstream Oil and Gas	81	145	171	175	183	181	166	172
Natural Gas Production and Processing	32	65	57	54	56	54	49	50
Conventional Oil Production	21	33	35	35	35	34	26	26
Conventional Light Oil Production	13	17	22	23	24	23	18	18
Conventional Heavy Oil Production	8.2	14	11	10	9.5	8.8	6.8	7.0
Frontier Oil Production	0.26	1.7	1.5	1.5	1.8	1.8	1.6	1.4
Oil Sands (Mining, In-situ, Upgrading)	15	35	69	76	81	83	81	85
Mining and Extraction	2.2	5.7	11	13	15	16	15	16
In-situ	4.5	12	37	41	43	43	41	45
Upgrading	8.4	17	21	22	24	25	25	25
Oil, Natural Gas and CO_2 Transmission	12	12	9.7	9.6	10	11	9.8	11
Downstream Oil and Gas	20	23	21	19	19	20	17	17
Petroleum Refining	18	22	20	18	18	19	16	16
Natural Gas Distribution	1.6	1.3	1.1	1.1	1.1	1.2	1.1	1.2
Electricity	**95**	**118**	**74**	**73**	**63**	**62**	**54**	**52**
Transport	**118**	**157**	**162**	**165**	**169**	**170**	**143**	**150**
Passenger Transport	80	95	99	100	102	103	83	86
Cars, Trucks and Motorcycles	71	85	88	89	90	91	75	78
Bus, Rail and Aviation	8.4	10	11	12	12	12	7.5	8.4
Freight Transport	31	48	49	50	52	52	47	50
Heavy-Duty Trucks, Rail	26	43	44	45	47	46	41	43
Aviation and Marine	4.7	5.4	4.4	4.7	4.8	5.5	5.4	6.1
Other: Recreational, Commercial and Residential	8.1	13	14	15	15	15	14	14
Heavy Industry	**99**	**89**	**78**	**77**	**80**	**79**	**74**	**77**
Mining	7.2	8.1	8.7	9.6	11	10	10	11
Smelting and Refining (Non-Ferrous Metals)	18	15	11	11	9.9	10	10	10
Pulp and Paper	15	9.0	6.6	7.0	7.9	8.3	7.0	7.6
Iron and Steel	17	16	15	15	16	15	12	14
Cement	10	13	10	11	11	11	10	11
Lime and Gypsum	2.8	3.5	2.5	2.6	2.4	2.3	2.2	2.2
Chemicals and Fertilizers	29	25	24	21	21	22	21	21
Buildings	**72**	**85**	**85**	**88**	**92**	**93**	**89**	**87**
Service Industry	28	40	43	45	47	49	48	47
Residential	45	45	42	43	45	44	41	40
Agriculture	**49**	**64**	**66**	**67**	**69**	**69**	**70**	**69**
On-Farm Fuel Use	8.2	9.5	13	14	15	15	14	14
Crop Production	10	12	18	17	19	19	21	19
Animal Production	31	42	35	35	35	35	35	35
Waste and Others	**55**	**52**	**48**	**49**	**50**	**50**	**46**	**47**
Waste	19	22	21	21	21	21	21	21
Coal Production	4.3	2.8	3.0	2.8	3.1	3.4	2.6	2.6
Light Manufacturing, Construction and Forest Resources	31	28	24	25	25	25	22	23

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 2021, the Energy sector accounted for 543 Mt (81%) of Canada's total greenhouse gas (GHG) emissions (Table 3–1). The Energy sector includes all activities associated with energy production and its use. Total GHG emissions for this sector includes, with exceptions, all carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from fuel combustion, fugitive sources, and carbon capture, transport and storage (CCTS) activities.[1]

Emissions resulting from stationary fuel combustion include the use of fossil and biomass fuels by the electricity generating industry, the oil and gas industry, the manufacturing and construction industry, and the residential and commercial sectors. Canada does not use peat as a combustion fuel. Data from the non-energy use of peat appears in the Land Use, Land-Use Change, and Forestry (LULUCF) sector (Chapter 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). Only the CH_4 and N_2O emissions from the combustion of biomass fuels, such as biodiesel, residential fuel wood and spent pulping liquor, are included in the Energy sector, while CO_2 emissions appear as a memo item in the Common Reporting Format (CRF) tables.

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

GHG Source Category	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Energy Sector	**472 000**	**513 000**	**593 000**	**600 000**	**582 000**	**596 000**	**577 000**	**586 000**	**596 000**	**596 000**	**532 000**	**543 000**
Fuel Combustion Activities (1.A)	**423 000**	**451 000**	**523 000**	**530 000**	**512 000**	**523 000**	**511 000**	**520 000**	**530 000**	**532 000**	**476 000**	**488 000**
Energy Industries (1.A.1)	143 000	152 000	203 000	208 000	199 000	202 000	193 000	192 000	190 000	190 000	174 000	177 000
Manufacturing Industries and Construction (1.A.2)	74 700	75 600	78 800	69 400	63 100	66 900	64 700	67 600	70 000	70 500	63 700	66 100
Transport (1.A.3)	119 000	133 000	145 000	158 000	161 000	161 000	160 000	163 000	167 000	168 000	141 000	149 000
Other Sectors (1.A.4)	86 600	90 400	96 200	94 400	88 400	92 300	92 500	97 600	102 000	103 000	96 800	95 400
Other (Not Specified Elsewhere) (1.A.5)	262	259	293	286	283	376	387	335	333	342	267	281
Fugitive Emissions from Fuels (1.B)	**48 000**	**62 000**	**70 000**	**70 000**	**70 000**	**73 000**	**66 000**	**66 000**	**66 000**	**64 000**	**55 000**	**55 000**
CO_2 Transport and Storage (1.C)	**NO**	**NO**	**0.09**	**0.09**	**0.09**	**0.22**	**0.27**	**0.27**	**0.28**	**0.28**	**0.49**	**0.65**

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/fossil fuels used as feedstock.

GHG emissions from the combustion of fuel for the majority of transport activities, such as Domestic Aviation, Road Transportation, Railways, Domestic Navigation, Pipeline Transport and Other Transportation (Off-road), are included in the Transport category. Emissions from international aviation and international navigation activities appear as a memo item in the CRF tables. Off-road emissions from vehicles and machinery along with fishing vessels appear in separate and distinct mobile subcategories within Manufacturing Industries and Construction (1.A.2) or Other Sectors (1.A.4) according to CRF table allocation. Military aviation and navigation is reported under the Other (1.A.5) subcategory. Note that emissions presented in Chapter 3 are consistent with the Intergovernmental Panel on Climate Change (IPCC) and CRF categorization, which differs from the emissions allocation presented in Chapter 2, Annex 9 and Annex 11's summary tables, where emissions from off-road transportation, fishing, military aviation and military navigation are included under the general transport.

Fugitive emissions associated with the fossil fuel industry are intentional (e.g., venting) or unintentional (e.g., leaks, accidents) releases of GHGs that may result from production, processing, transmission and storage activities. The Fugitive Emissions category includes emissions from flaring activities by the oil and gas industry, since their purpose is not to produce heat or to generate mechanical work (IPCC, 2006).

Some CO_2 emissions are captured (e.g., during electricity generation, hydrogen production at refineries and chemical production at fertilizer plants), transported and injected for long-term geologic storage or enhanced oil recovery (EOR). In addition, Canada imports CO_2 for EOR operations. Volumes captured appear in CRF tables by energy category where they occur. CRF category 1.C includes releases of CO_2 to the atmosphere from CO_2 pipeline/distribution infrastructure and injection equipment used for the purpose of long-term geological storage. Fugitive estimates in CRF category 1.B include emissions from the use of CO_2 for EOR operations.

Continuous methodological improvements and revised activity data resulted in several recalculations of GHG emissions in the Energy sector; see Table 3–2. An overview of improvements are presented below, while each section of Chapter 3 presents the type of recalculation, with explanations of activities resulting in revised emission estimates; Chapter 8 provides a summary of recalculations for all sectors.

Overall, recalculations resulted in a decrease of 7.6 Mt compared to the 2022 UNFCCC submitted value for 2020. 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 (RESD) generally result in a recalculation of most combustion sources. Revisions to the 2020 RESD data have been incorporated (as per standard practice) as an update to the 2020 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:
  - 1995 to 2020 natural gas data
  - 2019 and 2020 heavy fuel oil data
  - 2010 to 2020 diesel fuel oil data
  - 1996 to 2020 still gas data
  - 2018 to 2020 coke (coal) data
  - 2018 to 2020 motor gasoline data

Table 3–2 **GHG Emission Change Due to Recalculations**

IPCC Categories	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
1 Energy Sector	**GHG Emissions (Mt CO_2 eq)**										
2022 submission	472	512	594	602	583	600	581	594	606	604	540
2023 submission	472	513	593	600	582	596	577	586	596	596	532
Total change due to recalculations	**-0.6**	**0.2**	**-0.4**	**-1.8**	**-1.7**	**-4.3**	**-4.6**	**-7.1**	**-10.0**	**-8.3**	**-7.6**
1.A – Fuel Combustion	0.8	1.8	1.2	0.9	0.1	-3.5	-2.8	-5.2	-7.9	-6.5	-13.3
1.B – Fugitive and 1.C – CO_2 Transport & Storage	-1.4	-1.5	-1.6	-2.7	-1.8	-0.8	-1.9	-2.0	-2.1	-1.9	5.7

Note: Totals may not add up due to rounding.

2 Statistics Canada annually publishes a revised, final version of the previous year's (preliminary) energy data. Currently, energy data for 2021 is preliminary and is subject to revision in late 2023.

- Revisions of non-RESD consists of:
  - 2019 and 2020 volumes of flared gas subtracted from stationary combustion to avoid double counting
  - 2018 and 2020 quantity of residential firewood combusted
  - 1990 to 2020 quantity of landfill gas combusted
  - 2019 and 2020 quantity of municipal solid waste combusted
  - 2015 to 2020 fuel consumption associated with marine vessel movements

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

- Abandoned oil and gas wells method (refer to Annex 3, section A3.2.2.6 for a detailed description of the method).
- New methods to estimate post-meter fugitive CO_2 and CH_4 emissions from natural gas appliances in the residential and commercial sector, natural gas-fueled vehicles, and industrial consumption of natural gas are now included in the inventory (refer to Annex 3, section A3.2.2.7 for a detailed description of the method).
- Activity data and parameters used in the Fugitive Emissions Model (FEM) to estimate emissions from pneumatics, compressor seals and fugitive equipment leaks from oil and natural gas facilities in Alberta, British Columbia, Manitoba and Saskatchewan (refer to Annex 3, section A3.2.2.1.3 for a detailed description of the method).
- Venting emissions method for oil and natural gas facilities in Alberta for the year 2020. This revision partially addresses the methodological inconsistencies introduced in 2020 as a result of changes to provincial vent gas reporting guidelines. (refer to Annex 3, section A3.2.2.1.5 for more details).
- Method to estimate volumes of biodiesel applicable to transport from the RESD (refer to Annex 3, section 3.1.4.2.1 for more details).
- Method to allocate RESD fuel between on-road vehicles and off-road vehicles/equipment (refer to Annex 3, section 3.1.4.2.1 for more details).
- Method for on-road vehicle population estimates (refer to Annex 3, section 3.1.4.2.1 for more details).
- New on-road vehicle kilometre accumulation rates (refer to Annex 3, section 3.1.4.2.1 for more details).
- Transition to an improved on-road vehicle emissions model (refer to Annex 3, section 3.1.4.2.1 for more details).
- Off-road vehicle/equipment populations (refer to Annex 3, section 3.1.4.2.1 for more details).
- New method to estimate emissions from volumes of lubricating oil combusted in off-road two-stroke engines (refer to Annex 3, section 3.1.4.2.1 and Annex 6, section 6.1 for more details).

Emission Factors: Implementation of revised emission factors (presented in Annex 6, section 6.1), based on new information, resulted in recalculations of:

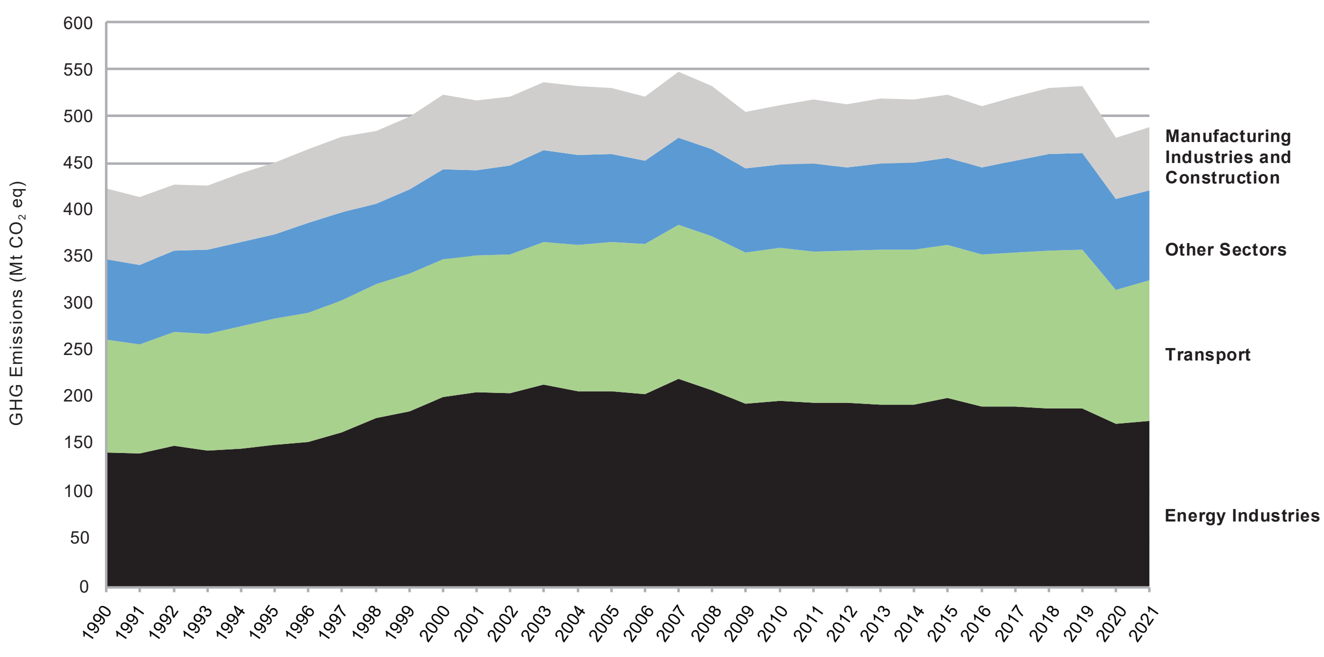
- CO_2 emission factor for petroleum coke stationary fuel combustion in New Brunswick.
- CO_2 emission factor for anthracite coal stationary fuel combustion.
- Non-marketable natural gas stationary combustion CO_2 and CH_4 emission factors for Newfoundland and Labrador offshore oil production.
- CO_2 and CH_4 emission factors for natural gas flaring at Newfoundland and Labrador offshore oil production facilities (see Annex 3 section A3.2.2.1.2).
- CO_2 emission factors for marketable natural gas in the Atlantic Provinces, and all years from 1999 to 2020.
- CH_4 and N_2O emission factors for motor gasoline combusted in off-road two-stroke engines.
- CH_4 and N_2O emission factors for on-road vehicles compliant with Tier 3 federal exhaust standards.

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 (i.e., the residential and commercial subcategories). 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 methodologies are consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines) Tier 2 and Tier 3 approach, with country-specific emission factors and parameters.

In 2021, about 488 Mt (73%) of Canada's GHG emissions were from the combustion of fossil and biomass fuels (Table 3–1). Overall, GHG emissions from Fuel Combustion Activities have increased by 15.3% since 1990. Between 1990 and 2021, emissions from the Energy Industries (1.A.1), Manufacturing Industries and Construction (1.A.2) and Other Sectors (1.A.4) categories increased by 11.3% (34.3 Mt), and emissions from the Transport (1.A.3) category increased by 25.5% (30.3 Mt) (see Figure 3–1).

Figure 3–1 **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 (Statistics Canada, 1990–) 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.

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

GHG Source Category	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
International Aviation	5 800	6 610	9 230	10 100	9 130	11 400	12 000	13 200	15 000	15 200	6 590	6 600
Domestic & Military Aviation	7 510	6 700	7 800	7 720	6 690	7 590	7 520	7 940	8 660	8 590	4 750	5 590
Total	**13 300**	**13 300**	**17 000**	**17 800**	**15 800**	**19 000**	**19 500**	**21 100**	**23 700**	**23 800**	**11 300**	**12 200**

Note: Totals may not add up due to rounding.

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 are based on the assumption 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.

3.2.2.2. 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 (Statistics Canada, 1990–) 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.

3

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	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
International Navigation	7 210	6 890	7 870	9 390	9 060	7 900	6 990	7 270	7 720	7 230	5 600	5 680
Domestic, Fishing & Military Navigation	3 100	3 350	3 630	4 020	3 700	3 100	3 280	3 460	3 470	4 310	3 840	4 400
Total	**10 300**	**10 200**	**11 500**	**13 400**	**12 800**	**11 000**	**10 300**	**10 700**	**11 200**	**11 500**	**9 440**	**10 100**

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 (for the production of 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.

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

GHG Source Category	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Energy Industries TOTAL (1.A.1)	**143 000**	**152 000**	**203 000**	**208 000**	**199 000**	**202 000**	**193 000**	**192 000**	**190 000**	**190 000**	**174 000**	**177 000**
Public Electricity and Heat Generation	94 500	98 900	132 000	125 000	102 000	87 900	81 600	79 500	71 000	69 600	61 500	60 400
Petroleum Refining	17 400	16 300	17 300	20 000	19 000	16 000	16 300	14 500	14 700	15 600	13 200	13 200
Manufacture of Solid Fuels and Other Energy Industries[a]	31 200	36 900	53 300	63 200	77 500	97 800	95 000	98 000	105 000	105 000	100 000	104 000

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.

In 2021, the Energy Industries category accounted for 177 Mt (26.4%) of Canada's total GHG emissions, with a 23.8% increase in total GHG emissions since 1990. The Public Electricity and Heat Generation subcategory accounted for 34.1% (60.4 Mt) of the GHG emissions from Energy Industries, while the Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries subcategories contributed 7.4% (13.2 Mt) and 58.5% (104 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 actually 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,[3] generally from diesel generators used as a backup power supply. In the case of nuclear facilities, uranium fuel production and processing occur at separate facilities, so any GHG emissions associated with these facilities appear under Manufacturing Industries and Construction. Emissions from the mining of uranium are reported under Mining. The GHG estimates in the Public Electricity and Heat Generation category therefore only reflect emissions from combustion-derived electricity. Steam generation and internal combustion engines are the primary systems used to generate electricity through thermal processes. Steam turbine boilers burn coal, petroleum coke, refined petroleum products (RPPs), natural gas or biomass, while gas turbines use natural gas or RPPs. Reciprocating engines can use natural gas and/or a combination of RPPs.

Petroleum Refining (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 as a by-product during the production of hydrogen in the steam reforming of natural gas, as well as other fugitive emissions from refinery operations.

3 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.

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. The synthetic (or upgraded) crude oil has a hydrocarbon composition similar to that of conventional crude oil, which can be refined to produce RPPs such as gasoline and diesel. Upgrading facilities also rely on natural gas as well as internally generated fuels such as still gas and petroleum coke for their operation, which result 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 (Statistics Canada, 1990–). 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)

Statistic Canada (StatCan) 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). StatCan does not differentiate fuel-use data in the RESD 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.[4] See Annex 3.1 for methodological details.

StatCan 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 input 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)

The calculation of emissions for this subcategory uses all fuel use attributed to the petroleum refining industry and includes all petroleum products reported as producer-consumed/own consumption as well as purchases of natural gas for fuel use by refineries. 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 A3.2.2.7, for more details.

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

Emissions for this subcategory are calculated using all fuel use 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 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.

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

Uncertainties for the Energy Industries category are dependent 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 (±109%) and N_2O (±265%) 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 31% 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.

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 2020 decreasing by 2.7 Mt CO_2 eq compared to the previous submission, due to:

- Revised RESD data, including updates to natural gas, still gas, petroleum coke, and diesel, resulted in recalculations between 1995 and 2020. The updated data caused a change in emissions ranging from -86.7 kt in 2005 to 0.25 Mt in 1996. In 2020 the revisions caused a 2.6 Mt decrease in emissions.
- Revised CO_2 emission factors for marketable natural gas caused recalculations for all source categories in the Energy Sector that consume natural gas between 1999 and 2020 across the Atlantic Provinces. Updated natural gas CO_2 emission factors incorporated new detailed information on gas composition data, and volumes as supplied by industry (see Annex 6, section A6.1.1 for more details) from domestic and imported sources.
- Revised CO_2 emission factors for petroleum coke in New Brunswick resulted in recalculations between 2010 and 2020. The updated CO_2 emission factors incorporated detailed petroleum coke composition data, resulting in recalculations ranging from -101 kt in 2020 to -39 kt in 2012, for the category Public Electricity and Heat Production category.

3.2.4.6. Planned Improvements

Environment and Climate Change Canada (ECCC), Natural Resources Canada (NRCan), and Statistics Canada (StatCan) continue to collaborate on improvements to the quality of the national energy balance and the disaggregation of fuel-use data via a Trilateral Energy Working Group. Shared quality control responsibilities across working group members (for the RESD and some feeder surveys[5]) also contributes to annual improvements in the national energy balance and, in turn, the

5 For example, the Industrial Consumption of Energy (ICE) Survey

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

1. Collection of monthly renewable fuels survey, on types of biodiesel and ethanol produced in Canada.
2. Improvement to data collection methods regarding the movement of fossil, and renewable, fuels via rail and marine vessels.

Canada is focused on developing country-specific emission factors with improvements that prioritize fuels 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 investigation 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 2021, the Manufacturing Industries and Construction category accounted for 66.1 Mt (9.9%) of Canada's total GHG emissions, with an 11.5% (8.6 Mt) decrease in overall emissions since 1990 (refer to Table 3–6 for more details). Within the Manufacturing Industries and Construction category, 37.9 Mt (57.3%) 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, 13.9%), Pulp, Paper and Print (6.86 Mt, 10.4%), Iron and Steel (5.17 Mt, 7.8%), Non-metallic Minerals (3.85 Mt, 5.8%); and Non-ferrous Metals (3.2 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	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Manufacturing Industries and Construction TOTAL (1.A.2)	**74 700**	**75 600**	**78 800**	**69 400**	**63 100**	**66 900**	**64 700**	**67 600**	**70 000**	**70 500**	**63 700**	**66 100**
Iron and Steel	4 950	5 790	6 200	5 510	4 960	5 760	5 620	6 010	6 390	6 080	4 570	5 170
Non-Ferrous Metals	3 540	3 420	3 800	3 840	3 240	3 380	3 460	3 430	2 960	3 450	3 250	3 200
Chemicals	8 260	10 300	10 600	8 260	9 870	12 100	10 800	9 800	9 400	9 600	9 500	9 200
Pulp, Paper and Print	14 500	12 800	12 500	8 600	5 920	6 000	6 010	6 400	7 090	7 190	6 500	6 860
Food Processing, Beverages and Tobacco[a]	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Non-Metallic Minerals	3 970	4 160	4 640	5 400	4 080	3 910	3 930	4 160	4 200	4 040	3 600	3 850
Other	39 500	39 200	41 000	37 800	35 000	35 800	34 900	37 900	39 900	40 100	36 300	37 900
Mining (excluding fuels) and Quarrying[b]	4 170	4 400	4 350	3 980	5 150	4 380	3 950	4 600	6 100	5 730	5 590	5 910
Construction	1 880	1 180	1 080	1 440	1 520	1 310	1 300	1 300	1 380	1 440	1 430	1 460
Off-Road Manufacturing, Mining and Construction	12 300	13 900	17 400	16 100	15 200	17 100	16 900	19 000	19 800	20 100	17 300	18 100
Other Manufacturing	21 200	19 700	18 200	16 200	13 100	12 900	12 800	13 000	12 600	12 800	12 000	12 400

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 metallurgical coke for iron ore reduction, other fuels for 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.

StatCan 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 input 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 ±2% 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.

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3.2.5.5. Recalculations

There are revised emissions estimates for all years, with estimates for 2020 increasing by 4.0 Mt CO_2 eq over the previous submission, because of the following changes:

- Revised RESD data, which affected 2010 to 2020 and resulted in a 0.6 Mt increase in emissions in 2020.
- Revised CO_2 emission factor for anthracite coal for all years (see Annex 6, section A6.1.4 for more details), and resulted in changes to emissions ranging from 0.2 Mt to 0.4 Mt between 1990 and 2019, and a 0.3 Mt increase in emissions in 2020.
- Revised CO_2 emission factors for marketable natural gas in the Atlantic Provinces, and all years from 1999 to 2020, developed using detailed gas composition data, and volumes, supplied by industry (see Annex 6, section A6.1.1 for more details).
- Several updates to methods associated with on-road vehicles and off-road vehicles/equipment, refer to section 3.2.6.5 for brief descriptions. Updates to on-road and off-road methodologies affected the entire time series and resulted in increases to off-road emissions in this category ranging from 1.4 Mt in 1995 to 7.0 Mt in 2001.

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 a bit 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 that Canada report the 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, as needed.

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

In 2021, transport-related GHG emissions total 149 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 26 Mt (104%) for LDGTs and 20 Mt (124%) 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 25% and have contributed the equivalent of 37% of the total overall growth in emissions observed in Canada.

Table 3–7 **Transport GHG Emissions**

GHG Source Category	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Transport	**119 000**	**133 000**	**145 000**	**158 000**	**161 000**	**161 000**	**160 000**	**163 000**	**167 000**	**168 000**	**141 000**	**149 000**
Domestic Aviation[a]	7 280	6 470	7 530	7 460	6 430	7 350	7 270	7 710	8 420	8 340	4 560	5 390
Road Transportation	92 000	100 000	110 000	123 000	133 000	129 000	128 000	129 000	132 000	132 000	111 000	116 000
Light-Duty Gasoline Vehicles	44 500	44 300	41 900	40 800	38 000	34 500	34 300	33 600	33 000	32 300	25 000	24 200
Light-Duty Gasoline Trucks	24 800	28 600	35 200	41 100	45 300	47 700	50 400	51 600	53 300	55 100	47 200	50 500
Heavy-Duty Gasoline Vehicles	4 790	4 170	4 270	4 620	4 590	4 310	4 370	4 430	4 470	4 540	4 200	4 310
Motorcycles	204	225	319	458	594	838	874	897	922	952	773	765
Light-Duty Diesel Vehicles	368	435	464	667	741	702	644	615	588	505	310	323
Light-Duty Diesel Trucks	889	1 240	1 100	750	516	589	576	642	720	744	600	716
Heavy-Duty Diesel Vehicles	15 700	21 300	26 300	34 400	43 700	40 100	36 900	37 100	38 500	37 500	32 600	35 200
Propane and Natural Gas Vehicles	760	218	42	23	33	67	77	114	131	170	178	191
Railways	6 920	6 260	6 530	6 580	6 460	6 930	6 350	7 250	7 410	7 460	6 930	6 840
Domestic Navigation[a, b]	2 200	2 450	2 730	3 120	2 850	2 810	2 990	3 200	3 220	4 050	3 610	4 140
Other Transportation[c]	10 400	16 900	18 500	17 700	12 200	15 600	15 700	15 600	16 300	16 400	15 300	16 500
Off-Road	3 460	4 850	7 180	7 620	6 480	7 330	7 940	8 030	7 960	7 900	7 550	7 740
Pipeline Transport	6 900	12 000	11 300	10 100	5 720	8 280	7 720	7 550	8 380	8 480	7 740	8 730

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. In order to cope with this complexity, transport emission estimates are calculated using the Motor Vehicle Emissions Simulator (MOVES) model, NONROAD and the Aviation Greenhouse Gas Emission Model (AGEM). These models incorporate a version of the IPCC-recommended methodology for vehicle modelling (IPCC, 2006) and are used to calculate all transport emissions except for those associated with marine navigation, railways, and pipelines (i.e., the energy necessary to transport liquid or gaseous products through pipelines). Refer to Annex 3.1 for a detailed description of Transport methodologies.

Domestic Aviation (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 (Statistics Canada, 1990–). The majority of aircraft fuel sales reported in the RESD represents 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 (Statistics Canada, 1990–) 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)

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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[6] 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[7] (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.

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

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

3.2.6.3. Uncertainties and Time-Series Consistency

Transport

The overall uncertainty of the 2021 estimates for the Transport category (not including pipelines) was estimated to be ±1.2% 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 ±5.8%. The Domestic Aviation subcategory only contributed approximately 3% to total Transport GHG emissions 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 ±1.2%, driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO_2 emissions. Conversely, the high uncertainties associated with CH_4 and N_2O emissions, as well as biofuel activity data, did not significantly influence the analysis because of their comparatively minor contributions to the inventory.

Emissions from Railways

The uncertainty associated with emissions from rail transport was estimated to be ±21%. 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% of the Transport category GHG inventory 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 Off-road subcategory includes equipment consuming gasoline, diesel, propane, natural gas and lubricating oil. The uncertainty associated with the off-road transport sources was estimated to be ±1.5%, 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 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 1990–2020 period as follows.

- **RESD fuel**: Notable revisions include updating preliminary 2020 RESD data for all fuels as well as updating diesel fuel volumes for the 2010–2019 period. These revisions significantly reduced the amount of diesel fuel oil allocated to on-road vehicles and off-road vehicles/equipment. Refer to Annex 3, section 3.1.4.2.1 for more details.
- **Updated method to estimating volumes of biodiesel applicable to transport from the RESD**: Volumes of biodiesel combusted are now estimated on the basis that the diesel fuel oil reported in the RESD includes biodiesel. In the previous submission volumes of biodiesel were estimated on the basis that the diesel fuel oil reported in the RESD excluded biodiesel. This update resulted in minor decreases to amounts of diesel fuel oil and biodiesel consumed nationally. Refer to Annex 3, section 3.1.4.2.1 for more details.
- **Updated method to allocate fuel reported in the RESD between on-road vehicles and off-road vehicles/equipment**: The normalization approach has been updated for motor gasoline and diesel fuel oil such that RESD categories have a more profound impact on the allocation of RESD fuel between on-road and off-road. In the previously submission this allocation was solely dependent on emission model outputs. This update resulted in a significant reallocation of those fuel volumes between on-road and off-road. Refer to Annex 3, section 3.1.4.2.1 for more details.
- **Updates to on-road vehicle population estimates**: On-road vehicle populations modelled in MOVES were updated using the latest supplier data and making adjustments such that totals are consistent with vehicle registration totals published by Statistics Canada. This update resulted in a notable reallocation of fuel consumption amongst on-road vehicle subcategories. Refer to Annex 3, section 3.1.4.2.1 for more details.
- **Updates to on-road vehicle kilometre accumulation rates**: On-road vehicle kilometre accumulation rates modelled in MOVES were updated using the latest vehicle maintenance and inspection data available. This update resulted in a notable reallocation of fuel consumption amongst on-road vehicle subcategories. Refer to Annex 3, section 3.1.4.2.1 for more details.
- **Transition to an improved on-road vehicle emissions model**: Emissions estimates from on-road vehicles are now modelled with MOVES3 as opposed to MOVES2014B, which includes updates to energy consumption rates. This update resulted in a notable reallocation of fuel consumption amongst on-road vehicle subcategories. Refer to Annex 3, section 3.1.4.2.1 for more details.
- **Updates to off-road vehicle/equipment populations**: Off-road vehicle/equipment populations modelled in NONROAD were updated using the latest supplier data. This update resulted in a notable reallocation of fuel consumption amongst subcategories applicable to off-road. Refer to Annex 3, section 3.1.4.2.1 for more details.
- **New method to estimating emissions from volumes of lubricating oil combusted in off-road two-stroke engines**: Emissions from volumes of lubricating oil combusted in off-road two-stroke engines are now estimated distinctly from motor gasoline. This update resulted in a minor increase to emissions estimated from off-road. Refer to Annex 3, section 3.1.4.2.1 and Annex 6, section 6.1 for more details.
- **CH_4 and N_2O emission factors for on-road vehicles compliant with Tier 3 federal exhaust standards**: Data from the MOVE3 model, and USEPA's engine certification data, were used to establish coherent Tier 3 emissions factors for CH_4 and N_2O, respectively.
- **Updated activity data for marine navigation**: The Marine Emission Inventory Tool (MEIT) was revised for the 2015, 2016, 2017, and 2018 calendar years and new activity data for 2019 and 2020 were incorporated into the marine fuel consumption-based model.

Revisions to the Transport category total occurred back to 1990. The updates in relation to the RESD resulted in the revisions being significant for years 2010 and later, ranging from a 3.8 Mt decrease in 2010 to an 18 Mt decrease in 2020. The revisions to RESD fuel, in addition to the updated approach to estimating biodiesel from the RESD reduced the amount of fuel associated with transport. The updated method to allocate fuel reported in the RESD between on-road vehicles and off-road vehicles/equipment resulted in the reallocation of fuel amongst the various on-road and off-road subcategories reported within the Energy sector. The remaining updates associated with on-road and off-road, excluding those related to lubricating oil and emission factors, also contributed to the reallocation of RESD fuel but to a lesser degree. Refer to sections 3.2.5.5 and 3.2.7.5 for details on how these revisions impacted CRF categories 1.A.2 and 1.A.4 respectively.

3.2.6.6. Planned Improvements

Planned improvements have been identified for the Transport category. Current high priority is to implement further updates to off-road emissions modelling inputs. Off-road emissions modelling inputs subject to update 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. These improvements will not be exclusive to off-road vehicles and equipment assigned to the Transport category. Off-road vehicles and equipment assigned to Other Sectors (CRF Category 1.A.4) and Manufacturing Industries and Construction (CRF Category 1.A.2) will also be improved upon.

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 were 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 2021, the Other Sectors category contributed 95.4 Mt (14.2%) of Canada's total GHG emissions, with an overall growth of about 10.1% (8.77 Mt) since 1990. Within the Other Sectors category, the Commercial/Institutional subcategory contributed 41.2 Mt (43.2%), followed by the Residential subcategory contributed 37.5 Mt (39.3%) and the Agriculture/Forestry/Fishing subcategory contributed 16.7 Mt (17.5%). Since 1990, GHG emissions have grown by 35.4% (10.8 Mt) in the Commercial/Institutional subcategory and 38.7% (4.7 Mt) in the Agriculture/Forestry/Fishing subcategory, while GHG emissions in the Residential subcategory have declined by about 15.1% (6.6 Mt). Refer to Table 3–8 for additional details. Chapter 2 has further discussion of trends for the Other Sectors category.

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.

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

GHG Source Category	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Other Sectors TOTAL (1.A.4)	**86 600**	**90 400**	**96 200**	**94 400**	**88 400**	**92 300**	**92 500**	**97 600**	**102 000**	**103 000**	**96 800**	**95 400**
Commercial/Institutional	30 400	33 300	37 900	36 900	33 200	35 400	37 000	39 700	41 400	43 300	41 300	41 200
Commercial and Other Institutional	26 200	29 400	33 300	32 400	28 600	30 400	31 700	34 000	35 500	37 200	35 900	35 400
Off-Road Commercial & Institutional	4 250	3 980	4 570	4 500	4 650	4 930	5 230	5 650	5 920	6 030	5 340	5 800
Residential	44 100	45 600	45 700	44 600	42 500	42 000	40 300	41 100	42 900	41 700	39 000	37 500
Stationary Combustion	43 800	44 900	44 700	43 300	41 300	40 900	39 300	40 100	41 900	40 700	38 000	36 500
Off-Road Residential	366	686	993	1 220	1 190	1 060	1 060	1 040	1 020	1 000	970	940
Agriculture/Forestry/Fishing	12 000	11 400	12 600	13 000	12 700	14 900	15 200	16 800	17 700	18 000	16 600	16 700
Agriculture and Forestry	2 410	2 770	2 570	2 180	2 660	2 960	3 180	3 080	3 190	3 490	3 030	3 090
Off-Road Agriculture/Forestry/Fishing	9 610	8 680	10 080	10 790	10 030	11 950	12 020	13 740	14 510	14 470	13 530	13 570

Note: Totals may not add up due to rounding.

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 5% 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 2020 increasing by 3.5 Mt CO_2 eq over the previous submission, because of the following changes:

- Revised RESD data, which affected 2010 to 2020 and resulted in a 0.4 Mt decrease in emissions for 2020.
- Revised residential firewood data, which resulted in a decrease in emissions ranging from -21 to -2 kt between 2018 and 2020.

- Revised municipal solid waste data, which resulted in changes in emissions ranging from -5.444 to 5.1 kt between 2019 and 2020.
- Revised landfill gas data, which affected the entire time series and resulted in a change in emissions ranging from -0.11 to 0.05 kt.
- Revised CO_2 emission factors for marketable natural gas in the Atlantic Provinces, and all years from 1999 to 2020, developed using detailed gas composition data, and volumes, supplied by industry (see Annex 6, section A6.1.1.1 for more details), which caused changes ranging from -1.3 kt in 2016 to 1.1 kt in 2012.
- Revised on-road vehicles and off-road vehicles/equipment methods. Refer to section 3.2.6.5, Recalculations, for brief descriptions of these updates. Updates to on-road and off-road methodologies affected the entire time series and resulted with combined changes to off-road emissions in this category ranging from a 2.4 Mt decrease in 1995 to a 6.0 Mt increase in 2019.

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, Planned Improvements for a bit 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, Planned Improvements 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 (Statistics Canada, 1990–). See Table 3–9 for additional data.

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

GHG Source Category	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Other (Not Specified Elsewhere) TOTAL (1.A.5)	**262**	**259**	**293**	**286**	**283**	**376**	**387**	**335**	**333**	**342**	**267**	**281**

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 sale are reported in the appropriate fuel combustion category.

The two categories reported in the inventory are fugitive releases associated with solid fuels (coal mining and handling, and abandoned coal mines) and releases from activities related to the oil and natural gas industry.

In 2021, the Fugitive Emissions from Fuels category accounted for 55 Mt (8.2%) of Canada's total GHG emissions, with a 14.6% (7.0 Mt) growth in emissions since 1990. Fugitive emissions from oil and natural gas increased by 19.2% (8.7 Mt) and those from coal decreased by 58.4% (-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	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Fugitive Emissions from Fuels (1.B)	**48 000**	**62 000**	**70 000**	**70 000**	**70 000**	**73 000**	**66 000**	**66 000**	**66 000**	**64 000**	**55 000**	**55 000**
Solid Fuels – Coal Mining (1.B.1)	**2 800**	**2 300**	**1 700**	**1 400**	**1 400**	**1 100**	**1 300**	**1 200**	**1 300**	**1 400**	**1 100**	**1 200**
a. Underground – Mining activities	1 500	700	100	90	90	30	NO	60	100	160	NO	NO
b. Abandoned Underground Mines	190	400	550	170	150	60	70	80	70	60	60	60
c. Surface – Mining activities	1 100	1 200	1 100	1 100	1 100	1 100	1 200	1 100	1 200	1 200	1 000	1 100
Oil and Natural Gas (1.B.2)	**45 000**	**60 000**	**68 000**	**69 000**	**68 000**	**72 000**	**65 000**	**65 000**	**65 000**	**63 000**	**54 000**	**54 000**
a. Oil[a]	6 500	8 100	9 600	10 700	12 600	13 400	13 000	13 200	13 400	13 400	12 000	12 200
b. Natural Gas[a]	11 000	14 000	14 000	15 000	14 000	13 000	12 000	12 000	12 000	12 000	11 000	10 000
c. Venting and Flaring[b]	27 000	38 000	45 000	43 000	41 000	46 000	39 000	40 000	40 000	38 000	32 000	31 000
i. Venting	22 000	32 000	38 000	38 000	36 000	39 000	34 000	34 000	33 000	32 000	25 000	24 000
ii. Flaring	5 050	5 910	6 380	5 450	4 970	6 860	5 680	6 020	6 230	6 010	6 550	7 070

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 producing 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 per cent of Canada's national total emissions and below 500 kt CO_2 eq in accordance with UNFCCC Conference of the Party, Decision 24/CP19, Annex 1, paragraph 37.b., as such 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
- 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

This category required no recalculations.

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

3

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

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

Accidents and Equipment Failures: Fugitive emissions can result from human error or extraordinary equipment failures in all segments of the conventional UOG industry. The major sources are emissions from 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 the 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	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Abandoned Oil and Gas Wells	**150**	**180**	**230**	**290**	**360**	**460**	**480**	**500**	**520**	**540**	**540**	**540**
Abandoned Oil Wells[a]	80	90	110	130	150	200	220	250	260	270	270	270
Abandoned Gas Wells[b]	70	90	120	160	210	250	260	250	260	270	270	270

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 the production of refined petroleum products and the distribution of natural gas to end consumers, including fugitive emissions at the final point of consumption (post-meter fugitives). Reported emissions fall into the 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 fuel gas (or 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.

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

GHG Source Category	GHG Emissions (kt CO_2 eq)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Post-Meter Fugitives[a]	**1 100**	**1 300**	**1 400**	**1 500**	**1 600**	**1 700**	**1 700**	**1 800**	**1 800**	**1 800**	**1 900**	**1 900**
Natural gas appliances in residential and commercial sectors	900	1 000	1 100	1 200	1 400	1 400	1 500	1 500	1 500	1 500	1 600	1 600
Natural gas fueled vehicles	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03
Power plants and industrial facilities consuming natural gas	200	270	290	240	250	280	280	270	290	300	290	310

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.

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 2015–2021 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: *Alberta 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 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 (Statistics Canada, 1990–). 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 were 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 2015–2021 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 Natural Resources Canada (2022) for the years 2000–2019 by province/territory. Appliance counts for 1990–1999 and 2020–2021 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 Report on Energy Supply and Demand (Statistics Canada, 1990–) 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 2021 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, 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 2021 oil sands/bitumen fugitive emissions is -19.1% to +20.0%. 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 source.

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 2003–2012 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	± 9.1	-5.6 to +8.2	-5.2 to +5.3	-3.6 to +4.6
Oil Sands Mining and Bitumen / Heavy Oil Upgrading	-23.8 to +23.9	-29.2 to +35.1	-29.4 to +30.0	-19.1 to +20.0
Gas Production / Processing	-4.5 to +4.7	-1.6 to +2.4	-8.0 to +24.8	-4.8 to +14.8
Gas Transmission, Storage and Distribution	-15.3 to +19.8	-25.4 to +26.8	-19.9 to +22.3	-18.8 to +19.9
Accidents and Equipment Failures	—	± 59.6	—	± 59.6
Well Drilling, Servicing and Testing	-19.8 to +16.7	-23.0 to +25.6	-18.0 to +35.9	-17.1 to +14.9
Abandoned Oil and Gas Wells	—	-40.9 to +60.9	—	-40.9 to +60.9
Post-meter Fugitives	—	± 29.0	—	± 29.0

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

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.

3.3.2.5. Recalculations

There are revised fugitive emissions from oil and natural gas for the 1990–2020 period because of changes to activity data and methodologies. See Table 3–2 for a summary of recalculations.

The following improvements caused recalculations in oil and natural gas fugitive emission estimates.

- **Oil**: Various changes resulted in recalculations to fugitive emissions (excluding venting and flaring) from crude oil systems. Revised fugitive emissions went downwards from 1990–2019 and upwards in 2020, with changes ranging from -1.4 Mt CO_2-eq in 1997 to +0.32 Mt CO_2-eq in 2020.
    - **Fugitive equipment leaks**: there are updates to several key parameters used in the Fugitive Emissions Model. See Annex 3, section A3.2.2.1.3 for a full description of the FEM methodology. There were refinements to existing well and facility count estimates, which also enabled regionally specific gas composition data to be included for Saskatchewan (SKMER, 2021). Model parameters that reflect leak detection and repair (LDAR) activities were updated to incorporate real world implementation of LDAR practices in Alberta (AEP, 2022). Combined, the changes to fugitive equipment leak estimates resulted in decreases in from 1990–2019, ranging from -0.36 Mt CO_2-eq in 2015 to -1.4 Mt CO_2-eq in 1997, and an increase of +0.20 Mt CO_2-eq in 2020.
    - **Abandoned oil wells**: an updated methodology for estimating CH_4 emissions from abandoned oil wells includes Canada-specific emission factors and improved annual well count estimates. The updated CH_4 emission factors come from recent studies that used data from direct measurements of abandoned oil wells in Canada (Williams et al., 2020; Bowman et al., 2022). See Annex 3, section A3.2.2.6 for a full description of the new methodology. These changes resulted in increases in emissions from abandoned oil wells in each year of the time series, ranging from +51 kt CO_2-eq in 1992 to +118 kt CO_2-eq in 2017.

- **Surface casing vents**: revisions occurred due to minor corrections and updates to reported surface casing vent data for Alberta and British Columbia. These changes resulted in downward revisions in 1990, 1991, 1995 and 1996, ranging from -0.05 kt CO_2-eq in 1991 to -1.1 kt CO_2-eq in 1990. Emissions increased in all other years, from +0.10 kt CO_2-eq in 1997 to a maximum of +15 kt CO_2-eq in 2020.
- **Petroleum refining**: minor recalculations occurred throughout the time series, as estimates were revised downward in 1990, 1992, 1995, 1998–2002, and 2004–2020 with a maximum decrease of -9.0 kt in 2020, and upward revisions in all other years with a maximum of +0.1 kt CO_2-eq in 2009.

- **Natural Gas**: the following describes recalculations to fugitive emissions (excluding venting and flaring) from natural gas systems. Overall, natural gas fugitive emissions decreased from 2002–2011, and increased from 1990–2001 and from 2012–2020. Changes range from -0.48 Mt CO_2-eq in 2006 to +1.8 Mt CO_2-eq in 2020.
  - **Fugitive equipment leaks**: there are updates to several key parameters used in the Fugitive Emissions Model. See Annex 3, section A3.2.2.1.3 for a full description of the FEM methodology. There were refinements to existing well and facility count estimates, which also enabled regionally specific gas composition data to be included for Saskatchewan (SKMER, 2021). Model parameters that reflect leak detection and repair activities were updated to reflect real world implementation of LDAR practices in Alberta (AEP, 2022). Combined, the changes to fugitive equipment leak estimates resulted in decreases from 1990–2020, ranging from -92 kt CO_2-eq in 2020 to a maximum of -2.1 Mt CO_2-eq in 2008.
  - **Post-meter fugitives**: the implementation of the new methodology for post-meter fugitive emissions resulted in upward revisions for the entire time series. See Annex 3, section A3.2.2.7 for the full description of this new methodology. Inclusion of this new emissions source resulted in upward revisions ranging from +1.1 Mt CO_2-eq in 1990 to +1.9 Mt CO_2-eq in 2020.
  - **Abandoned gas wells**: an updated methodology for estimating CH_4 emissions from abandoned gas wells includes Canada-specific emission factors and improved annual well count estimates. The updated CH_4 emission factors are taken from recent studies that used data from direct measurements of abandoned gas wells in Canada (Williams et al., 2020; El Hachem et al., 2022). See Annex 3, section A3.2.2.6 for a full description of the new methodology. These changes resulted in increases in emissions from abandoned gas wells in each year of the time series, ranging from +59 kt CO_2-eq in 1991 to +0.18 Mt CO_2-eq in 2016.
  - **Transmission, Distribution and Storage**: updated pipeline length data resulted in revisions from 2015–2020, with decreases each year ranging from -4.0 kt CO_2-eq in 2015 to -0.15 Mt CO_2-eq in 2016.
  - **Surface casing vents**: revisions occurred due to minor corrections and updates to reported surface casing vent data for Alberta and British Columbia. These changes resulted in decreased emissions from 1990–2019 with a maximum change of -67 kt CO_2-eq in 1998, and an increase of +0.2 kt CO_2-eq in 2020.
  - **Spills and pipeline ruptures**: minor updates to activity data from 2018 to 2020 resulted in revisions ranging from -0.8 kt CO_2-eq in 2019 to +0.8 kt CO_2-eq in 2018.
- **Flaring**: the following describes several changes to flaring emission estimates. Flaring emissions increased in the years 1997–2003, 2014 and 2020, and decreased from 2004–2013 and 2015–2019, with changes ranging from -89 kt CO_2-eq in 2018 to +0.20 Mt CO_2-eq in 1998.
  - **Newfoundland and Labrador**: the methodology for estimating flaring emissions from Newfoundland and Labrador now incorporates new data sources, as described in section A3.2.2.1.2 of Annex 3. This change resulted in revisions from 1997–2020, with increases in 1997–2003 ranging from +4.9 kt CO_2-eq in 2001 to a maximum of +0.20 Mt CO_2-eq in 1998, and decreases in 2004–2020, ranging from -7.2 kt CO_2-eq in 2008 to a maximum of -66 kt CO_2-eq in 2018.
  - **Alberta**: updates to reported flared gas volumes at upstream oil and gas facilities resulted in a +0.15 Mt CO_2-eq upward revision in 2020.
  - **Saskatchewan**: incorporation of a new data source resulted in updates to reported flared gas volumes, as described in Annex 3, section A3.2.2.1.2. This change resulted in revisions from 2013–2020, with increases in 2014, 2017, and 2020, and decreases in the remaining years. Changes ranged from -24 kt CO_2-eq in 2019 to +59 kt CO_2-eq in 2014.
  - **Petroleum refining**: recalculations resulted in upward revisions to emissions of +1.6 kt CO_2-eq in 2019 and +6.5 kt CO_2-eq in 2020.

- **Venting**: overall venting emissions decreased from 1990–2019 ranging from -0.51 Mt CO_2-eq in 1996 to -1.5 Mt CO_2-eq in 2008. In 2020, recalculated venting emissions increased by +3.5 Mt CO_2-eq.
  - **Reported venting**: due to the methodological inconsistency introduced to reported vent volumes as a result of changes to provincial vent gas reporting guidelines in 2020, the methodology for Alberta venting emissions for 2020 and onwards was updated to incorporate vent gas volumetric data from the OneStop reporting system. This resulted in an upward revision of +3.4 Mt in 2020. For a full description of the updated methodology, see section A3.2.2.1.5 of Annex 3. Other activity data updates also resulted in revisions including decreases from 2016–2018 and 2020, and increases from 2013–2015 and 2019, ranging from -0.16 Mt CO_2-eq in 2017 to +79 kt CO_2-eq in 2014.
  - **Pneumatics and Compressor Seals**: updates were made to several key parameters used in the Fugitive Emissions Model. See Annex 3, section A3.2.2.1.3 for a full description of the FEM methodology. Refinements were made to existing well and facility count estimates, and provincial gas composition data was incorporated for Saskatchewan. These changes impacted estimates for pneumatics and compressor seals from 1990–2020. Compressor seal emission estimates decreased in all years, with changes ranging from -78 kt CO_2-eq in 2020 to -0.56 Mt CO_2-eq in 2008. Emissions from pneumatic devices decreased from 1990–2019, with changes ranging from -0.38 Mt CO_2-eq in 1998 to -0.95 Mt CO_2-eq in 2008.
  - **Formation CO_2**: updated acid gas shrinkage volumes for natural gas processing facilities in British Columbia resulted in recalculations for 2019 and 2020. These recalculations resulted in increases to emissions estimates of +0.10 Mt CO_2-eq in 2019 and +0.16 Mt CO_2-eq in 2020.
  - **Petroleum refining**: recalculations resulted in upward revisions to emissions of +6.6 kt CO_2-eq in 2019 and +27 kt CO_2-eq in 2020.

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 including:

- Atmospheric measurements of CH_4 emissions from the oil and gas industry have identified a gap between bottom-up inventory estimates and top-down estimates based on aircraft measurements, stationary towers and vehicles. Work is underway to use measurement data from recent field campaigns in British Columbia, Alberta and Saskatchewan using low-altitude LiDAR measurement technology to improve inventory estimates.
- Analyze and incorporate raw gas composition data collected by the British Columbia Oil and Gas Commission (BCOGC) into fugitive emission estimates from oil and gas facilities in British Columbia.
- Incorporate storage tank emission estimates into the FEM previously developed to estimate emissions for pneumatics, compressor seals and equipment leaks in the oil and gas industry.
- Incorporate emission estimates for natural gas transmission, distribution and storage received from the CEPEI for the years 2016-2021, including revisions to 1990–2015 historical emissions, as required.

3.4. CO_2 Transport and Storage (CRF Category 1.C)

Carbon dioxide transport and storage involves the capture of anthropogenic CO_2 and its transport to a storage facility or enhanced oil recovery operation. Table 3–15 summarizes the two sources of CO_2 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, Shell's Scotford bitumen upgrader, in Alberta and Agrium's fertilizer plant, in Alberta. Table 3–15 also summarizes the final disposition of CO_2 imported into, or captured in, Canada: whether used for EOR or injected into long-term storage. In 2021, CO_2 emissions from the three active pipelines were approximately 0.65 kt, an increase of about 0.56 kt since 2000, as shown in Table 3–16.

Three CO_2 pipelines exist in Canada, two of which are associated with the use of carbon dioxide in an EOR process. There are no estimates for emissions from storage since the EOR process recovers all CO_2 for reuse. Any net emissions from these operations are included in Canada's inventory as part of the Energy Industries (1.A.1) and Oil and Natural Gas and Other Emissions from Energy Production (1.B.2) categories.

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

	CO_2 Quantity (kt)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
CO_2 Capture Source												
Imported	NO	NO	1800	2000	2000	2200	1600	1700	1600	1800	1600	1700
Domestic Capture	NO	NO	NO	NO	NO	800	1900	1600	1700	1700	1800	2700
CO_2 Final Disposition												
Long-Term Geologic Storage	NO	NO	NO	NO	NO	400	1200	1200	1100	1200	1000	1100
Enhanced Oil Recovery	NO	NO	1800	2000	2000	2600	2300	2200	2100	2300	2400	3300

Note:
Total quantities for capture source and fate may not be equal due to rounding.
NO = Not occurring

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

GHG Source Category	GHG Emissions (kt CO_2)											
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
CO_2 Transport and Storage (1.C)	**NO**	**NO**	**0.09**	**0.09**	**0.09**	**0.22**	**0.27**	**0.27**	**0.28**	**0.28**	**0.49**	**0.65**

Note:
NO = Not occurring

3

Captured CO_2 Usage for Enhanced Oil Recovery

In Canada, CO_2, captured during coal gasification in the United States, coal-fired power generation in Saskatchewan and fertilizer manufacture in Alberta, acts as a flooding agent in EOR operations to increase crude oil production volume at three depleting oil reservoirs. Carbon dioxide used as a flooding agent in EOR acts as a solvent while also increasing reservoir pressure, resulting in the release of trapped hydrocarbons to production wells. The high-pressure flooding process also results in CO_2 being trapped in the voids previously occupied by hydrocarbon molecules. In the future, the fully depleted reservoir will provide long-term geological storage of CO_2.

CO_2 flooding started in 2000 at the Weyburn site and in 2005 at the Midale site to extend the life of these mature reservoirs by another 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 2021, the Boundary Dam facility had captured approximately 5.0 Mt of CO_2 for shipment to the Weyburn site (SaskPower, 2023). Injections at this reservoir include this fresh supply of CO_2 and the recovered CO_2 from previous flooding cycles. Currently, the CO_2 injection rate at the Weyburn-Midale operations is about two Mt per year.[8] From 2000 to 2021, the Weyburn and Midale sites have injected over 41 Mt of new CO_2 purchased from the Dakota gasification plant and Sask Power Boundary Dam power plant.

In addition to being a CO_2 EOR operation, Weyburn is also 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. 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). Additional details on the findings of the research project are available on the PTRC website.

The IEA Weyburn-Midale research project, outlined on the PTRC website, focused on developing a best practice manual for future projects on the geological storage of CO_2. This research used technical and non-technical components such as site characterization, selection, well bore integrity, monitoring and verification, risk assessment, regulatory issues, public communication and outreach, and business environment policy.

8 *CO_2 Injected Data for Weyburn and Midale. Operational* information provided in a presentation by F. Mourits, IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project, Natural Resources Canada. January 2010.

Some of the data associated with carbon capture cannot be disaggregated and fully reported under category 1.C. These emissions, including 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 CRF table. The net impact of GHG emissions from all capture activities is included in Canada's inventory as part of the Energy Industries (1.A.1), Oil and Natural Gas (1.B.2) categories and CO_2 Transport and Storage (1.C).

3.4.1. Transport of CO_2 – Pipelines (CRF Category 1.C.1.a)

Pipelines transport carbon dioxide captured at Dakota Gasification Company's Great Plains Synfuels Plant in North Dakota and SaskPower's Boundary Dam Power Station near Estevan (which started CO_2 capture in November 2014) to the Weyburn-Midale EOR sites near Weyburn, Saskatchewan.

A pipeline, part of Shell Canada's Quest carbon capture and storage project, transports captured CO_2 north from the Scotford upgrader, near Edmonton, Alberta, to a long-term geological storage site.

The Alberta CO_2 trunk line became active in 2020 and moves CO_2 captured at the Agrium fertilizer plant to EOR sites in Southern Alberta.

3.4.1.1. Source Category Description

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

3.4.1.2. Methodological Issues

The 2006 IPCC Guidelines provide a Tier 1 methodology for emissions from pipeline transport of CO_2. Pipeline length from both the Canada/United States border to the Whitecap Resources EOR facilities at Weyburn and from Boundary Dam to Weyburn are 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 facility and the associated EOR site is approximately 80 km. Emission calculations use the IPCC default medium emission factor of 0.0014 kt CO_2/km pipeline length/year.

3.4.1.3. Uncertainties and Time-Series Consistency

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

3.4.1.4. QA/QC and Verification

Estimates underwent QC checks in a manner consistent with the 2006 IPCC Guidelines.

3.4.1.5. Recalculations

No recalculations were undertaken.

3.4.1.6. Planned Improvements

Future emissions estimates will include additional CO_2 capture facilities and pipelines, currently planned or under construction in Alberta, as they come on-line and report their data to Canada's Greenhouse Gas Reporting Program. Increased inclusion of facility-reported data will continue after assessment for compliance with quality (such as completeness, transparency, etc.) and methodology standards, as prescribed in Canada's Greenhouse Gas Quantification Requirements (ECCC, 2021).

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)[9] 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.

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

Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Ethanol Consumed (ML)	7	21	225	267	1 874	2 598	2 688	2 690	2 739	2 778	2 320	2 385

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

Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Biodiesel Consumed (ML)	NO	NO	NO	NO	290	619	705	859	904	897	800	859

Note:
NO = Not occurring

9 *Higher heating value and lower heating value* are technical terms identifying the energy content of a specific fuel and differ depending on whether the water in the combustion products is in the liquid or gaseous phase respectively. Synonyms for *higher heating value* include *gross heating value or gross calorific value* while synonyms for *lower heating value* include *net heating value* or *net calorific value*.

CHAPTER 4

INDUSTRIAL PROCESSES AND PRODUCT USE (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 52 Mt to the 2021 national GHG inventory (Table 4–1), compared with 56.5 Mt in 2005. IPPU emissions represented 7.7% of total Canadian GHG emissions in 2021. The contributing factors of the long-term and short-term trends in this sector are discussed in Chapter 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	2005	2010	2015	2016	2017	2018	2019	2020	2021
INDUSTRIAL PROCESSES AND PRODUCT USE	**57 000**	**58 400**	**56 500**	**50 600**	**53 400**	**54 200**	**52 400**	**53 900**	**52 900**	**50 400**	**51 900**
Mineral Products	**8 490**	**9 190**	**10 280**	**7 830**	**8 000**	**7 880**	**8 610**	**8 700**	**8 850**	**8 210**	**9 000**
Cement Production	5 820	6 530	7 610	6 010	6 180	6 110	6 860	6 990	7 200	6 710	7 380
Lime Production	1 800	1 900	1 750	1 410	1 410	1 380	1 420	1 390	1 340	1 190	1 310
Mineral Product Use	860	750	910	410	410	390	330	320	310	300	310
Chemical Industry	**17 530**	**18 480**	**10 370**	**5 760**	**6 730**	**6 830**	**6 340**	**6 410**	**6 230**	**5 940**	**5 750**
Ammonia Production	2 740	2 920	2 700	2 470	2 920	2 850	2 620	2 420	2 500	2 290	2 540
Nitric Acid Production	970	960	1 200	480	230	260	250	270	250	190	220
Adipic Acid Production	10 300	10 310	2 550	-	-	-	-	-	-	-	-
Petrochemical and Carbon Black Production (includes Carbide Production)	3 510	4 290	3 920	2 810	3 590	3 720	3 470	3 720	3 480	3 460	2 990
Metal Production	**23 770**	**23 490**	**20 230**	**16 030**	**14 430**	**15 350**	**14 600**	**14 540**	**13 930**	**13 120**	**13 950**
Iron and Steel Production	10 480	11 470	10 310	8 980	8 470	9 220	8 450	8 880	8 330	7 110	7 960
Aluminium Production	10 330	10 010	8 680	6 870	5 720	5 990	6 010	5 510	5 310	5 920	5 850
SF_6 Used in Magnesium Smelters and Casters	2 960	2 010	1 230	180	240	140	140	150	300	100	140
Production and Consumption of Halocarbons, SF_6 and NF_3	**980**	**500**	**5 120**	**7 740**	**11 080**	**11 350**	**11 140**	**12 190**	**12 150**	**11 970**	**11 490**
Non-Energy Products from Fuels and Solvent Use	**5 830**	**6 340**	**9 970**	**12 790**	**12 640**	**12 230**	**11 120**	**11 320**	**11 050**	**10 390**	**11 040**
Other Product Manufacture and Use	**370**	**390**	**540**	**430**	**540**	**600**	**630**	**700**	**670**	**720**	**720**

Note: Totals may not add up due to rounding.

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 4–2 **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	2016	2017	2018	2019	2020
INDUSTRIAL PROCESSES AND PRODUCT USE											
Current (2023) submission	57.0	58.4	54.0	56.5	50.6	53.4	54.2	52.4	53.9	52.9	50.4
Previous (2022) submission	57.0	58.4	54.1	56.6	50.7	53.5	54.5	52.7	53.9	53.5	50.3
Net change in emissions	+0.0	-0.0	-0.1	-0.1	-0.1	-0.1	-0.3	-0.2	-0.0	-0.6	+0.0
Mineral Products											
Current (2023) submission	8.5	9.2	10.1	10.3	7.8	8.0	7.9	8.6	8.7	8.8	8.2
Previous (2022) submission	8.5	9.2	10.1	10.3	7.8	8.0	7.9	8.6	8.6	8.8	8.1
Net change in emissions	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	+0.0	+0.1	+0.1	+0.1
Chemical Industry											
Current (2023) submission	17.5	18.5	8.7	10.4	5.8	6.7	6.8	6.3	6.4	6.2	5.9
Previous (2022) submission	17.5	18.5	8.8	10.4	5.8	6.8	7.0	6.4	6.8	6.7	6.6
Net change in emissions	-0.0	-0.0	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1	-0.4	-0.5	-0.6
Metal Production											
Current (2023) submission	23.8	23.5	23.4	20.2	16.0	14.4	15.3	14.6	14.5	13.9	13.1
Previous (2022) submission	23.8	23.5	23.4	20.2	16.0	14.4	15.3	14.6	14.5	13.9	13.0
Net change in emissions	+0.0	+0.0	+0.0	+0.0	-0.0	-0.0	+0.0	-0.0	-0.0	+0.1	+0.1
Production and Consumption of Halocarbons, SF_6 and NF_3											
Current (2023) submission	1.0	0.5	2.8	5.1	7.7	11.1	11.3	11.1	12.2	12.2	12.0
Previous (2022) submission	1.0	0.5	2.8	5.1	7.7	11.1	11.4	11.2	12.2	12.2	12.0
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
Non-Energy Products from Fuels and Solvent Use											
Current (2023) submission	5.8	6.3	8.5	10.0	12.8	12.6	12.2	11.1	11.3	11.0	10.4
Previous (2022) submission	5.8	6.3	8.5	10.0	12.8	12.7	12.3	11.3	11.0	11.3	9.9
Net change in emissions	+0.0	+0.0	+0.0	-0.0	-0.0	-0.0	-0.1	-0.2	+0.3	-0.2	+0.5
Other Product Manufacture and Use											
Current (2023) submission	0.4	0.4	0.6	0.5	0.4	0.5	0.6	0.6	0.7	0.7	0.7
Previous (2022) submission	0.4	0.4	0.6	0.5	0.4	0.5	0.6	0.6	0.7	0.7	0.7
Net change in emissions	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	-0.0

Note: Totals may not add up due to rounding.

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 7380 kt (or 1.1%) of Canada's total emissions in 2021, a 3% 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.

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 2017–2021, 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, 2022). The CO_2 emissions reported by cement production facilities to the GHGRP were calculated using Equation 4–2, a modified Tier 3 method (IPCC, 2006).

Equation 4–1

$$CO_2\ emissions = EF_{cl} \times M_{cl} \times CF_{ckd} + EF_{toc} \times M_{cl}$$

EF_{cl}	=	annual calcination emission factor based on clinker production, kt CO_2/kt clinker
M_{cl}	=	clinker production data, kt of clinker
CF_{ckd}	=	correction factor for the loss of cement kiln dust and by-pass dust, fraction
EF_{toc}	=	annual emission factor for CO_2 emissions from total organic carbon in the raw feed, kt CO_2/kt clinker

Equation 4–2

$$E_{CO_2} = \sum_m^{12}[Q_{CLI_m} \times EF_{CLI_m}] + \sum_q^4[Q_{CKD_q} \times EF_{CKD_q}] + [TOC_{RM} \times RM \times 3.664]$$

E_{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 2017–2021 (ECCC, 2022). 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

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

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]

For this submission, emission estimates for 2017-2020 were corrected to have CO_2 emissions from CKD not recycled back to the kiln be added to emission estimates instead of being subtracted. 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 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 through using the plant-specific emission factors of CKD.

Equation 4–3

$$EF_{CKDq} = [CaO_{CKDq} - fCaO_q] \times 0.785 + [MgO_{CKDq} - fMgO_q] \times 1.092$$

EF_{CKDq}	=	the plant specific emission factor of CKD not recycled back to the kiln in quarter "q" (tonnes CO_2 / tonnes CKD)
CaO_{CKDq}	=	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_{CKDq}	=	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 2017–2021. For the unknown data years (1991–1999, 2001, 2015–2016), an average is taken from the years before and after the unknown data point.

Clinker production data for 1990–1996 was obtained from the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC, 2010). Clinker production data for 1997–2016 was obtained from Statistics Canada (Statistics Canada, 1990–2004, n.d.[a]).

Provincial/territorial emission estimates are apportioned from national emission estimates 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 2017–2021, 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 2017–2021.

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

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).

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 2017–2021, 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}.

4.2.4. 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

Recalculations for this category include updated facility-reported data from the GHGRP for 2018, and the Tier 3 calculation methodology corrected to add CO_2 emissions from CKD not recycled to the kiln in the calculation of the total CO_2 emissions from Cement Production. The magnitude of the 2017–2020 recalculations ranged from 36 kt CO_2 to 88 kt CO_2.

4.2.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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 4–3 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 1310 kt (0.2%) to Canada's total emissions in 2021, a 25% 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 2017–2021, 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

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).

personal communication.[7] For 2017–2021, CO_2 emissions came directly from the CO_2 emissions reported by lime production facilities in Canada to the GHGRP (ECCC, 2022). 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]

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

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 4–3 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 2017–2021 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 2017–2021, provincial/territorial emission estimates are based on the emissions reported to the GHGRP by lime production facilities in each province/territory.

Table 4–3 **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%

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

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).

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 2017–2021. 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 2017–2021, 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 2017–2021 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 2017–2021 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 informal quality control checks throughout the emission estimation process.

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 updated production data for 2018. The magnitude of the recalculations ranged from -2 kt CO_2 to -1 kt CO_2 for 1990–2016, and +0.2 kt for 2018.

4.3.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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 2021, the aggregate category accounted for 308 kt (or 0.05%) of Canada's total GHG emissions, with a decrease of approximately 67% in total emissions since 2005. Non-metallurgical Magnesia Production accounted for 38% of Mineral Product Use emissions, whereas Other Limestone and Dolomite Use, Other Uses of Soda Ash, and Glass Production contributed 33%, 15% and 14% 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.

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

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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 2021. 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 2021, 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 2021 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 37(b) of the UNFCCC Annex I inventory reporting guidelines. 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 a number of 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 37(b) of the UNFCCC Annex I inventory reporting guidelines, 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.

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.

Import and export data have been obtained from Global Trade Information Services (GTIS, 1995–2006, 2007–2009) and Statistics Canada's Canadian International Merchandise Trade Database (Statistics Canada, 2010–2021). The trade data for the years 1990–1994 was assumed to be the average of the 1995–2000 trade data, as GTIS commenced reporting trade data in 1995. 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 (1990–2021) and its annual activity data is sourced from British Columbia's Ministry of Energy and Mines (British Columbia Geological Survey, 2022).

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

A Tier 2 method is used to estimate CO_2 emissions from limestone and dolomite separately, using respective consumption data (Table 4–4) and emission factors.

The emission factor used for Canadian limestone use is derived from the process stoichiometric ratio of 440 g of CO_2 per kilogram of pure 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 on the basis of 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 the years 1990 through 2006, data on raw stone use in iron and steel furnaces, non-ferrous smelters, glass factories, pulp and paper mills, and other chemical uses 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. Moreover, data for stone used as flux in iron and steel furnaces for all years is disaggregated into limestone and dolomite on the basis of a 70/30 split (AMEC, 2006). Table 4–4 exhibits the split between consumption of high-calcium limestone and dolomite in the iron and steel sector, glass production, and other process uses of carbonates. National CO_2 emissions are estimated by multiplying the quantities of limestone and dolomite consumed by the corresponding emission factors. The emissions are subsequently allocated to the respective reporting categories of Glass Production (CRF category 2.A.3), Iron and Steel Production (CRF category 2.C.1, refer to section 4.10), and Other Limestone and Dolomite Use (CRF category 2.A.4.d).

The source of activity data does not provide a comprehensive breakdown of "other chemical uses." Therefore, this subcategory has been assumed to be 100% emissive and 100% composed of limestone and has been duly accounted for. Dolomite is usually less appropriate than limestone for most industrial applications, and most dolomite that is mined is crushed and sieved to be utilized as aggregate in concrete or asphalt (Bliss et al., 2008). Other markets of dolomite, such as glassmaking and agricultural use, are excluded from Canada's "other chemical uses" subcategory.

According to Canadian information,[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).

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.

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

Table 4–4 **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)	High-Calcium Limestone (kt)	High-Calcium Limestone (kt)		
				Pulp and Paper Mills	Non-Ferrous Smelters	Other Chemical Uses
1990	459	197	171	214	16	846
1991	344	147	169	220	162	964
1992	393	169	154	231	167	264
1993	139	59	161	224	176	244
1994	133	57	146	234	154	587
1995	215	92	146	130	181	436
1996	208	89	146	134	164	711
1997	232	100	181	117	158	915
1998	274	118	158	89	129	857
1999	274	118	137	96	101	522
2000	476	204	51	118	39	928
2001	334	143	44	69	94	680
2002	181	77	46	57	55	927
2003	197	85	18	62	46	939
2004	146	63	18	75	51	1 109
2005	151	65	18	80	47	1 175
2006	140	60	18	173	57	1 057
2007	69	30	32	41	64	1 178
2008	223	95	12	15	65	1 182
2009	182	78	0	36	74	923
2010	219	94	0	41	65	423
2011	350	150	0	40	52	508
2012	532	228	0	31	34	521
2013	438	188	0	30	46	342
2014	709	304	0	40	32	364
2015	866	371	0	37	32	356
2016	791	339	0	36	28	350
2017	85	37	0	45	28	196
2018	0	0	0	30	28	201
2019	0	0	0	28	26	187
2020	0	0	0	25	25	184
2021	0	0	0	26	23	192

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 2021 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 37(b) of the UNFCCC Annex I inventory reporting guidelines, 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 took into account 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 took into account 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.

The same emission factors have been consistently applied over the time series. 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.

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4.4.5. Category-Specific Recalculations

For the Other Uses of Soda Ash category, updates to the activity data for 1994, 2003-2004, and 2007-2020 resulted in an increase of less than 1 kt CO_2 for each impacted year.

4.4.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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

4.5.1. Category Description

The Ammonia Production category accounted for 2500 kt (0.3%) of Canada's emissions in 2021.

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. The eight other plants use steam-methane reformers to produce ammonia, of which most recover CO_2 emissions to produce urea. Two 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 4–5). 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 4.13 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) were determined to be a significant source of emissions and are reported in CRF category 2.B.10.

16 Brown, T. Canada. 2018. [accessed 2021 Feb 24]. Available online at https://ammoniaindustry.com/tag/canada/.

The two SMR facilities that conduct CCS activities 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, 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 takes into account emissions that are recovered for use in urea production. A Tier 3 country-specific method is applied in accordance with the 2006 IPCC Guidelines (IPCC, 2006) for the years 2018 to 2021, 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 purpose) are available, emissions resulting from the energy use of natural gas are accounted for in the Energy sector.

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 for 1990 to 2017. 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 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 units each) provided ammonia-to-feed fuel factors. Two of the nine plants did not provide such factors. Also to note is that one of the two plants did not use steam methane reforming and for the remaining facility with SMR, an average of the reported ammonia-to-feed fuel conversion factors was applied. 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 to 2021, the natural gas quantity used as feedstock reported by facilities through the GHGRP was directly used in the CO_2 emission estimation.

The amount of natural gas used as feed is multiplied by a facility-specific natural gas carbon content factor (CCi) and default carbon oxidization factor (COF) (IPCC, 2006) to determine the resulting CO_2 emissions generated. 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 4–5 below summarizes these natural gas carbon contents.

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 the three facilities that shut down prior to 2018, internally developed year- and province-specific carbon contents were used. Facility-reported carbon content values obtained through the GHGRP were applied for 2018 to 2021.

Table 4–5 **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.

The amounts of CO_2 recovered for urea production and CCS are then subtracted from the process-related emissions (Equation 4–5).

Equation 4–5 **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

Over the 1990 to 2017 time series, it is assumed that the urea production process consumes a stoichiometric quantity of CO_2 of 0.733 kg CO_2/kg urea. CO_2 recovered for urea production from 2018 to 2021 was directly reported by facilities through the GHGRP and also assumes the same stoichiometric ratio of urea production to CO_2 emission. For 1990–2007, urea production was estimated on the basis of actual ammonia production and the respective average ratio of ammonia-to-urea production for each plant. Urea production data for 2008–2017 was retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

As an emission estimation improvement in the 2023 NIR submission, emissions recovered for CCS activities are estimated for the whole time series. To make sure that the recovered CO_2 emissions for CCS are accurately accounted for in the estimation process, data reported as "Other Recovered CO_2" to the 2022 GHGRP by ammonia facilities were closely examined and analysed. In addition, where needed, facilities were contacted by email to obtain confirmation on whether they were involved in CCS activities, to validate their reported values and to get further explanations on their CCS activities. As a result of the analyses and checks done, two facilities were identified as being involved in CCS activities for which CO_2 emissions need to be subtracted from the gross CO_2 emission amounts.

Table 4–6 summarizes the CCS and other carbon recovery activities for each facility using SMR.

Table 4–6 **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

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.

Further details with respect to the calculation method used are provided in Annex 3.3.

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 use of the corrected recovery factor of CO_2 consumed in the production of urea for years 1990 to 2017, following comments made by the ERT in 2022 and the inclusion of CCS for years 1990 to 2020 contributed to recalculations ranging from -173 to -4.9 kt.

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

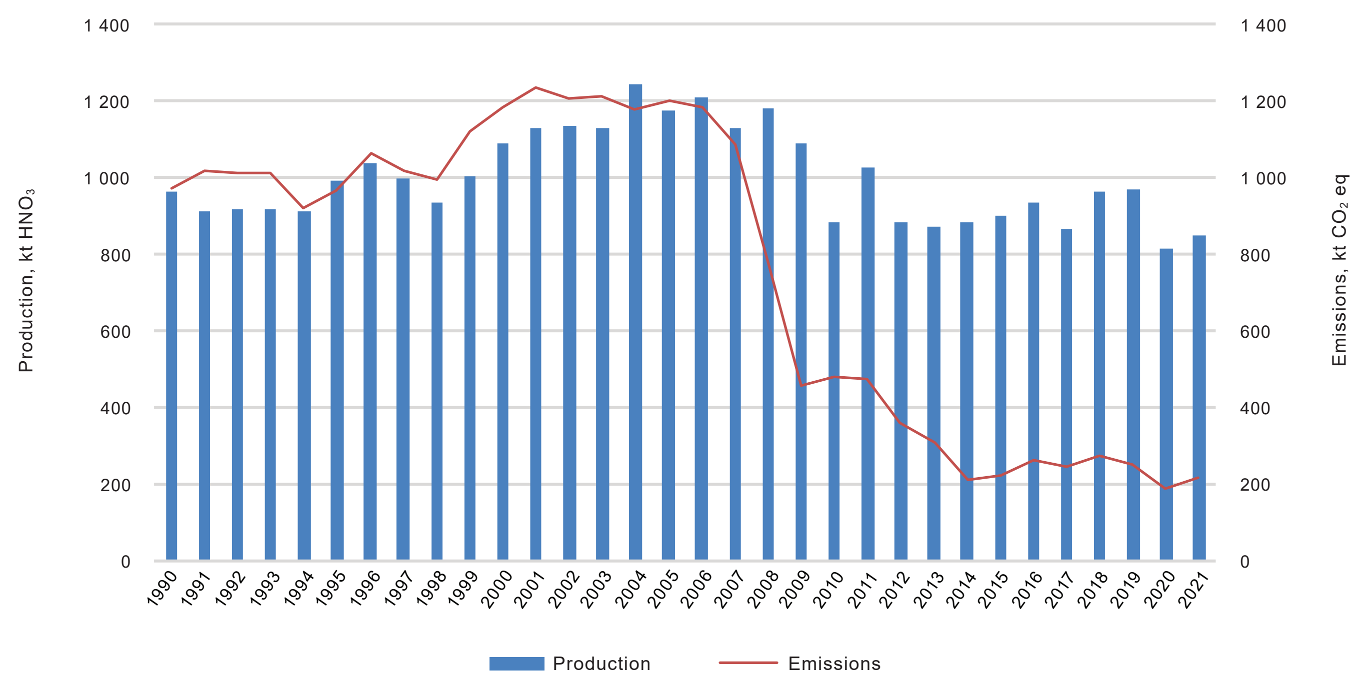
Nitric acid is a chemical intermediate that is commonly used to produce ammonium nitrate fertilizers or explosives. The Nitric Acid Production category accounted for 216 kt CO_2 eq of Canada's emissions in 2021, an 82% decrease from 2005. 14 nitric acid production lines (plants) at 9 facilities have been active over the time series (Cheminfo Services, 2006). In 2021, 8 plants were operational at 5 facilities. All operational plants 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 catalyst 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 basic types of nitric acid production process types: high pressure and dual pressure. Both technologies can be found in Canadian nitric acid plants. 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 4–7, 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 4–7 (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 natural gas is used as a reductant 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

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



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 employ NSCR systems (Cheminfo Services, 2006).

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 two operating plants in 2008[17] and 2012.[18] These installations are responsible for the majority of the emissions decrease observed between 2005 and 2021 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 pre-dominance 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 emissions 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 when plant-specific emission factors were not available; or
3. Tier 1 method: use of estimated production data and either plant-specific or technology-specific emission factors

Table 4–7 describes the nitric acid industry in Canada and the methods used in compiling the estimates on a facility-specific basis.

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

Table 4–7 **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
Agrium Inc.	Redwater, AB	1	1990–2021	HP	NSCR	1991–1999	1990, 2000–2021	2005–2021	1990–2004	T1 (1991–1999) T2 (2005–2021) T3 (1990, 2000–2004)
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: 1990–2021 Plant 2: 1994–2021 Plant 3: 1997–2021	HP	NSCR	1991–1999, 2007	1990, 2000–2006, 2008–2021	1990–2021	N/A	T1 (1991–1999, 2007) T2 (1990, 2000–2006, 2008–2021)
Orica Canada Inc.	Carseland, AB	2	Plant 1: 1990–2021 Plant 2: 1999–2021	Plant 1: DP (M/H), EA1 Plant 2: HP	Plant 1: None (1990–2008), PGCD (2008–2021) Plant 2: None (1999–2012), PGCD (2012–2021)	N/A	1990–2021	Plant 1: 1990–2008 Plant 2: 1999–2012	Plant 1: 2008–2021 Plant 2: 2012–2021	Plant 1: T2 (1990–2008), T3 (2008–2021) Plant 2: T2 (1999–2012), T3 (2012–2021)
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	1990–2021	HP	NSCR	N/A	1990–2021	2005–2021	1990–2004	T2 (2005–2021) T3 (1990–2004)
Yara Belle Plaine Inc.	Belle Plaine, SK	1	2004–2021	HP	NSCR	N/A	2004–2021	2005–2021	2004	T2 (2005–2021) 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 or summarized 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 or summarized during the Cheminfo Services (2006) study and from offset project verification reports (Orica Canada Inc., 2014; Orica Canada Inc., 2016).

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).

For 1990–2004, plant activity data were from the 2006 Cheminfo study (Cheminfo Services, 2006) where possible. To fill in missing activity data gaps, the sum of known production data was subtracted from the published national total nitric acid production data from Statistics Canada's Industrial Chemicals and Synthetic Resins (ICSR) survey. The unallocated production was distributed to the plants with missing activity data based on their share of the national production capacity.

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 facility-level data was unavailable from voluntary surveys and the ICSR, the sum of known production data was subtracted from the published national total nitric acid production data, and the remainder was allocated to the plants with missing activity data based on their share of the national production capacity.

For 2010–2021, facility-level production data was obtained from Statistics Canada's ICSR survey. One facility reported their aggregated production to the ICSR using a start and end date that did not correspond to a calendar year. Plant-specific calendar year production information was obtained through a separate company data request for these years.

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 2021 is available in Table A6.2–3.

4.6.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Nitric Acid Production. It takes into account 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 as a whole 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 3.7% from 2012–2021. 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 Carseland Works. The emission factors are the largest contributors to the uncertainty for this category.

All activity data gaps in the time series are filled in using the same methodology of production allocation based on national capacity share. The same emission factors are consistently applied over the time series unless a Tier 3 emission factor is available.

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

Emissions for 1992 and 1997 were recalculated due to the use of revised national production totals to match Statistics Canada's online data. An error in the 2007 allocation of national level production data to a facility was fixed, resulting in a recalculation in the emissions for that year. 2019 emissions were recalculated using plant-specific production and CEMS data for a facility instead of an aggregated production and emissions total. These recalculations range from -27 kt CO_2 eq (-2.6%) in 1992 to +0.16 kt CO_2 eq (0.02%) in 1997 compared to the previous submission.

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 (IPCC, 2006).

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.

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 4–7) separately from emissions that occur when the abator is not operating (Equation 4–8) due to maintenance or technical problems. The total emissions for the category are the sum of both operational modes, as shown in Equation 4–6.

Equation 4–6

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

N_2O Emissions with Abator:

Equation 4–7

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

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 4–8

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

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 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 2021, 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).

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19 Weidenhammer, Erich. *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

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

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. In 1990, there were three plants operating in Canada. One small plant closed in 1993, and two began operation in 1994 and 2000, for a total of four operational plants (owned by three companies) in 2021. CO_2 emissions are a by-product of the direct oxidation of ethylene feedstock and are dependent on the selectivity of the process. CH_4 is used to carry all reaction gases through the process. It can be emitted through the ethylene oxide process vent, the purification process exhaust gas stream, and as fugitive.

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

Four facilities produced carbon black in Canada between 1990 and 2021, 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 2021, 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 971 kt, 1,057 kt and 830 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 was used to estimate total CH_4 emissions from carbide production:

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Equation 4–9

$$\text{Total } CH_4 \text{ emissions (t)} = \sum^{y}[(\boldsymbol{SiC\ capacity} \times \boldsymbol{capacity\ utilization} \times \boldsymbol{Emission\ Factor\_SiC}) + (\boldsymbol{CaC_2\ capacity} \times \boldsymbol{Emission\ Factor\_CaC_2})]$$

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

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

The facilities producing titanium slag and TiO_2 using the chloride process report their primary process inputs (anthracite coal and petroleum coke, respectively) to the RESD as energy inputs rather than process inputs. Thus, titanium slag emissions are reported as part of the Energy sector's Non-Ferrous Metals emissions, and TiO_2 chloride process emissions are reported as part of the Energy sector's Chemicals emissions. To reflect the activity data and emission estimate situation, CO_2 emissions from the Titanium Dioxide Production category are reported as "Included Elsewhere" (notation key "IE") in the CRF reporter.

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 2012–2021, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

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 2008–2021, 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 production quantities by default emission factors. The appropriate 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).

Because all Ethylene Oxide plants in Canada use pure oxygen as a reactant, the CO_2 emission factors were selected from the oxygen process configuration emission factors list. Within the set of emission factors for this process configuration, emission factors were selected based on plant-specific catalyst selectivities. When there was no emission factor matching the exact plant-specific catalyst selectivity, an emission factor was generated by interpolating between the two closest catalyst selectivity-specific emission factors. Because no information on the catalyst selectivity for two plants was obtained during the consulting study, the default lowest catalyst selectivity percentage was selected, yielding the highest emission factor. Also, due to a lack of information, CH_4 emissions were estimated for all plants using the “No Thermal Treatment” process configuration default emission factor. The sector-wide average CO_2 emission factor and the default CH_4 emission factor are displayed in Table A6.2–4.

National production data for years 1990 to 2009 were obtained through the Canadian C2+ Petrochemical Report, as part of the 2010 Cheminfo Study. National production data was distributed to plants and used for calculating plant-specific emissions based on their share of the national production capacity. For years 2016 onwards, the activity data source was plant- or company-specific production data reported to Statistics Canada’s Industrial Chemicals and Synthetic Resins (ICSR) Survey. In 2016, all plants reported their production independently to the ICSR. In 2017 and 2018, one company reported the total combined ethylene oxide production for their two plants. The combined production was distributed based on the 2016 contributions of the respective plants to the company production total. From 2019 to 2021, the same company did not report ethylene oxide production to the ICSR survey and explained that they had stopped tracking production data on ethylene oxide since it is an intermediate product. To fill in the missing production data, Statistics Canada imputed production data by deflating the company’s 2019 to 2021 shipment data (monetary) provided to their Annual Survey of Manufacturing and Logging (ASML) or Monthly Survey of Manufacturing surveys to calculate real growth from 2018. The growth rates were then applied to the 2018 reported production data to calculate 2019 to 2021 production data, which was then distributed to the two plants based on the 2016 (latest available) contributions of the respective plants to the company total.

No production data is available from 2010 to 2015. Therefore, data for each facility was linearly interpolated between 2009 and 2016 to complete the time series.

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.

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 2010–2021 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).

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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 2012–2021, 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 4–8 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]

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.

Table 4–8 **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

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 4–10) was derived from that described in the U.S. National GHG Inventory.[22]

Equation 4–10

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

National total urea production data for 2008–2017 was retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. National total urea production data for 2018–2021 was retrieved by summing the facility-reported production to the Greenhouse Gas Reporting Program (ECCC, 2022). For 1990–2007, urea production was estimated on the basis of actual ammonia production and the respective average ratio of ammonia to urea production for each plant. The plant production totals were summed to determine the national total urea production.

Nationally complete import and export data for urea and urea-ammonium-nitrate from 1990–2021 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 4.14 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 gets emitted upon use.

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.

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.

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).

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 ±7% to ±20% for CH_4 emissions, from ±11% to ±30% 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, the interpolation period 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 2021, the uncertainties are ±7.3% and ±30.6% 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 method used for the missing data gap (2010 to 2015) is 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 took into account 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 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, 2022) 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

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

Ethylene Production emissions were recalculated for 2016 to 2020 due to changes in the type of feedstock used at two facilities and thus, the emission factors were updated. The emissions decreased by a range of 31 kt CO_2 eq (1.7 %) to 432 kt CO_2 eq (18.9 %).

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 all years, with a maximum change of -71 kt (-14%) in 2014. These recalculations were caused by upward revisions to Statistic Canada's export data for urea and urea-ammonium-nitrate fertilizer mixes for all years, as well as revised estimates for urea used as diesel exhaust fluid in selective catalytic reduction (SCR) vehicles for 2008 to 2020 due to Energy (Transport) methodological updates.

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 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 Greenhouse Gas Reporting Program (GHGRP) from 2017 to 2019, emissions from the category are estimated to be potentially significant (more than 500 kt CO_2 eq).

As noted in section 4.9.2 of this inventory submission, due to inaccurate facility reporting to the RESD, industrial process emissions from the main process inputs (anthracite coal and petroleum coke) are currently reported as part of the Energy sector's CO_2 emissions from Manufacturing Industries and Construction (CRF Category 1.A.2). Therefore, Titanium Dioxide Production is currently reported in the CRF using the "Included Elsewhere" ("IE") notation key.

Given the potential significance of this category, the inventory team is exploring data sources for estimating industrial process emissions in the correct category. For example, the inventory team is attempting to co-ordinate a data sharing agreement with the Quebec provincial government and the two facilities. This data sharing agreement could allow the inventory team to use 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 industrial process emissions.

Due to the different and non-competitive nature of the products manufactured between the two facilities (titanium slag input for chloride/sulphate TiO_2 processes versus finished TiO_2 product), the inventory team aims to get approval from the facilities to publish production and emissions totals for this category in the NIR and CRF despite the potential ability for each facility to calculate the other's data. The inventory team will also work internally to ensure that Titanium Dioxide Production emissions are reconciled with the Energy sector emissions 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 7962 kt (1.2%) to Canada's total emissions in 2021, a 23% 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. 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)

4.10.2. 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.

CO_2 emissions from pig iron production were estimated using the following equation:

Equation 4–11

$$E_{CO2\_PI} = (EF_{met\_coke} \times M_{met\_coke}) - (P_{PI} \times CC_{PI}) \times (44/12)$$

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). The GHG emissions associated with the use of reductants other than metallurgical coke are estimated under the appropriate industrial category in the Energy sector.

The data source for the use of metallurgical coke was the *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada, 1990–2021). Data on total pig iron production in Canada came from Statistics Canada for 1990–2003 and 2004–2012 (Cat. No. 41-001 and 41-019, respectively), from the Canadian Steel Producers Association (CSPA) for 2013–2016, and the Greenhouse Gas Reporting Program (GHGRP) for 2017–2021 (ECCC, 2022). The Pig Iron CRF category (2.C.1.b) includes iron production from both the blast furnace and the direct reduction process and at this time, cannot be disaggregated due to confidentiality concerns.

The emission factors for coke use (EF_{met_coke}) from 1990–2009 are year-specific and come from the Cheminfo Services (2010) study. In that study, Cheminfo Services surveyed four integrated steel mills in Canada for their coke consumption and emission estimates for the years 1990 to 2009. The emission factors were calculated as ratios of CO_2 emissions to coke consumption. The Canada-specific coke (EF_{met_coke}) emission factors for 2010–2016 was estimated as an average of the 2009 value from Cheminfo Services (2010), and the yearly national average of GHGRP data for the years 2017–2019 (ECCC, 2022). The emissions factor of coke for 2017–2021 was the year-specific national average of facility provided data, as reported to the GHGRP (ECCC, 2022). The coke carbon content was then applied to the coke use data provided by Statistics Canada. With respect to the carbon content of pig iron, CSPA[24] provided an industry-average content value that was used for 1990–2016. The national annual weighted average of facility reported carbon content of pig iron was used for 2017–2021, as per GHGRP (ECCC, 2022).

CO_2 emissions from steel production were estimated using the following equation:

Equation 4–12

$$E_{CO2\_steel} = [CC_{iron} \times M_{iron} + CC_{scrap\ steel} \times M_{scrap\ steel} - CC_{BOF} \times M_{BOF} - CC_{EAF} \times M_{EAF}] \times 44/12 + EF_{EAF} \times P_{EAF} + EF_{BOF} \times P_{BOF}$$

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 4–12, 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

24 Chan K. 2009. Personal communication (email from Chan K to Pagé M, Environment Canada, dated July 21, 2009). Canadian Steel Producers Association.

of pig iron fed to steel furnaces (used in Equation 4–12) is not equal to the amount of total pig iron production (used in Equation 4–11). 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.

Data on the total pig iron and scrap steel charged to steel furnaces, and on the amount of steel produced in EAFs and BOFs was obtained from Statistics Canada for 1990–2003 and 2004–2012 (Cat. No. 41-001 and 41-019, respectively), from CSPA for 2013–2017 and from GHGRP for 2018–2021. 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, based in part, on the CSPA,[25] and in part on the annual averages for all facilities in Canada as reported to the GHGRP from 2017–2021 (ECCC, 2022).

The methodology used to estimate CO_2 emissions from limestone used as a flux in iron and steel furnaces is described in section 4.4.2.

CH_4 emissions were estimated on the basis of the mass of metallurgical coke used (Statistics Canada 1990–2021) 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.

Data on provincial-level metallurgical coke use from RESD (Statistics Canada, 1990–2021) was used to distribute national-level emissions to the applicable provinces.

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.

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 RESD and GHGRP data revisions. The magnitude of the recalculations ranged from +0.03 to +120 kt CO_2 eq and impacted the time series from 2017–2020.

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 coal used in pulverized coal injection (PCI) and natural gas in blast furnaces 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).

25 Chan K. 2009. Personal communication (email from Chan K to Pagé M, Environment Canada, dated July 21, 2009). Canadian Steel Producers Association.

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.

Moreover, during the integration of GHGRP data into the Iron and Steel model, the activity data for iron production from 2013–2016 was identified as missing direct reduction production, and as such, the implied emissions factor for these years is impacted. Communication has been on-going with the data provider to correct the activity data of those years.

4.11. Aluminium Production (CRF Category 2.C.3)

4.11.1. Category Description

The Aluminium Production category accounted for 5847 kt (0.9%) of Canada's emissions in 2021, representing an overall decrease in emissions of 33% 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.[26] 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.

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,[27] and the 10 plants currently in operation have focused on modernizing their facilities and improving production efficiency.

4.11.2. 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 2022), 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 which is summarized in Table 4–9. 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 4–9 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).

26 Chaput P. 2007. Personal communication (email from Chaput P to Au A, Environment Canada, dated Oct 12, 2007). Aluminium Association of Canada.

27 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.

Table 4–9 **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	N/A	1990–2000	N/A	T3	PS
Usine de Bauhamois	1990–2009	1990–2009	N/A	1990–2009	N/A	N/A	N/A
Usine Grande-Baie	1990–2021	1990–2007	2008–2021*	1990–1995	1996–2021	T3	PS
Jonquière	1990–2004	1990–2004	N/A	1990–2004	N/A	N/A	N/A
Usine Arvida	1990–2021	1990–2007	N/A	1990–2006	2007–2021	T3	PS
AP-60	2013–2021	N/A	2013–2021	2013–2015	2016–2021	T3	PS
Usine Laterrière	1990–2021	1990–2007	2008–2021	1990–2013	2014–2021	T3	PS
Usine Shawinigan	1990–2013	1990–2007	2008–2013	1990–2013	N/A	N/A	N/A
Usine Alma	2000–2021	2000–2007	2008–2021*	2000–2007	2008–2021	T3	PS
Kitimat	1990–2021	1990–2007	2008–2021*	1990–2006	2007–2021	T3	PS
Alcoa							
Usine Becancour	1990–2021	1990–2016	2017–2021*	1990–2004	2005–2021	T3	PS
Usine de Baie-Comeau	1990–2021	1990–2016	2017–2021	1990–2003	2004–2021	T3	PS
Deschambault	1993–2021	1993–2016	2017–2021*	1990–2004	2005–2021	T3	PS
Alouette							
Sept-Iles	1992–2021	1992–1994	1995–2021*	1990–2004	2005–2021	T3	PS

Note: *Method uses facility specific variables, with the exception of hydrogen content of pitch from anode and cathode baking, which is obtained from IAI (2006).

4.11.3. 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.

4.11.4. 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*.

4.11.5. Category-Specific Recalculations

Emissions of CF_4 and C_2F_6 were recalculated due to updated facility reported data to the GHGRP. The recalculations increased emissions by +14 kt CO_2 eq for both 2019 and 2020.

4.11.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

4.12. Magnesium Production (CRF Category 2.C.4)

4.12.1. 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.[28] 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 139kt CO_2 eq in 2021 (< 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.

4.12.2. 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,[29] 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.[30] 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 1990-2021 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.

28 Laperrière J. 2004. Personal communication (email from Laperrière J to Au A, Environment and Climate Change Canada, dated October 27, 2004). Norsk Hydro.

29 Laperrière J. 2006. Personal communication (email from Laperrière J to Au A, Environment and Climate Change Canada, dated October 4, 2006). Norsk Hydro.

30 Katan R. 2006. Personal communication (emails from Katan R to Au A, Environment and Climate Change Canada, dated March 16–22, 2006). Timminco.

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 2021, 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 2021, 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 2010–2021 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 2010–2021 for facilities that provided SF_6 data directly, the emission estimation method is of Tier 3 type.

4.12.3. 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 2021.

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.

4.12.4. 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.

4.12.5. Category-Specific Recalculations

Emission estimates for 2010 to 2020 were recalculated for Magnesium Casting due to updates in gross output data and inclusion of updated SF_6 use data provided by the operating magnesium casting facilities.

The changes were between -2.2 kt to +0.3 kt.

4.12.6. Category-Specific Planned Improvements

There are no planned improvements for magnesium production.

4.13. Lead and Zinc Production (CRF Category 2.C.5 and 2.C.6)

4.13.1. 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 the vast majority 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. Currently, work is ongoing to identify a method to disaggregate the quantity of reductants throughout the time series.

4.14. Non-Energy Products from Fuels and Solvent Use and Use of Urea in Selective Catalytic Reduction Vehicles (CRF Category 2.D.3)

4.14.1. 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 11039 kt (1.6%) to Canada’s total emissions in 2021, a 10.7% 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.

4.14.2. 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 4–10.

Fuel quantity data for non-energy fuel usage was reported by the RESD (Statistics Canada, 1990–2021). 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 4–10 **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.[31]

4.14.3. 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 took into account the uncertainties associated with the activity data and emission factors (ICF Consulting, 2004). The uncertainty for the category as a whole 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%.

4.14.4. 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.

4.14.5. Category-Specific Recalculations

For the Non-Energy Products from Fuels and Solvent Use category, CO_2 emissions were recalculated for the entire time series (1990–2020) due to updates to the RESD and the implementation of three methodological changes: the update to the emission factor for anthracite, the update to the emissions factors and types of feedstock used for two ethylene producing facilities and the subtraction of lubricating oils and greases used in off-road two stroke engines. The overall impact of all the revisions ranges from a maximum of +481 kt in 2020 to a minimum -241 kt in 2019.

Revised activity data from 2008 to 2020 caused recalculations ranging from -5.2 kt in 2016 to 3.4 kt in 2019, for the category of use of urea in SCR vehicles.

4.14.6. 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. There is a plan to evaluate whether these emission factors are still valid and to update them if 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), 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.

4.15. Electronics Industry (CRF Categories 2.E.1 and 2.E.5)

4.15.1. 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 46 kt CO_2 eq in 2021, a 437% increase from 2005.

31 Rideout G. 2014. Personal communication (email to McKibbon S. November 4, 2014). Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

4.15.2. 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 4.17). 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 in the absence of a 2021 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 4–13, was used to estimate PFC emissions from the semiconductor manufacturing industry:

Equation 4–13

$$E_{SC,PFC} = E_{FC} + E_{CF_4} + E_{C_2F_6}$$

$E_{SC,PFC}$	=	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 the purchased canister after use, 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, emission control use rates and destruction efficiencies were held constant at 2020 levels for 2021, resulting in a constant emissions trend.

NF_3 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

In 2013, Environment Canada 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 Environment Canada using the Domestic Substances List (Environment Canada, 1986) indicated that between 33 and 199 kg of NF_3 were used in 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 4–14, was used to estimate NF_3 and by-product CF_4 emissions from the semiconductor manufacturing industry:

Equation 4–14

$$E_{SC,NF_3} = E_{NF_3} + E_{CF_4}$$

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 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 emission factors 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 emission factors 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 emission factors (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 data collection, NF_3 use data and the emission control use rate were held constant at 2020 levels for 2021, 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. 2014–2021 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 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 2012–2021 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.[32] 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 4–15 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 in absence of a data collection. Equation 4–15 is an expanded country-specific version of IPCC 2006 Volume 3, Equation 6.2:

Equation 4–15

$$E_{SC,SF_6} = (1 - \mathrm{h}) \times [\mathrm{FC} \times (1 - U) \times \left(1 - \sum_{f=1}^{n} (s_f \times a_f \times d_f)\right)]$$

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

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 4.17. 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.

32 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.

4.15.3. 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 2021. The uncertainty of holding the 2020 data constant for 2021 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 semiconductors, 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)

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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%.

4.15.4. 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.

4.15.5. Category-Specific Recalculations

SF_6 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

Emissions were recalculated for years 2012–2020 due to the revision of gross output data for the Computer and Electronic Products Manufacturing NAICS (334), which are used to extrapolate 2012 to 2020 SF_6 imports from 2011 levels. The effects of these recalculations range from -0.31 kt CO_2 eq (-0.88%) in 2020 to +0.01 kt (+0.04%) in 2016.

4.15.6. **Category-Specific Planned Improvements**

Voluntary data surveys for 2021 were not collected, and 2021 use levels and emissions were held constant at 2020 levels. A voluntary data collection of 2021 data is planned in 2023 to obtain updated PFC use data. Additional Canadian electronics manufacturers will be contacted to verify gas distributor purchase data, to provide annual use quantities (if available), to facilitate more accurate and process-specific activity data and to obtain information on implemented emission control technologies. The data obtained from facilities will be assessed for quality for eventual implementation in future inventory submissions.

4.16. Product Uses as Substitutes for Ozone-Depleting Substances (CRF Category 2.F, HFCs)

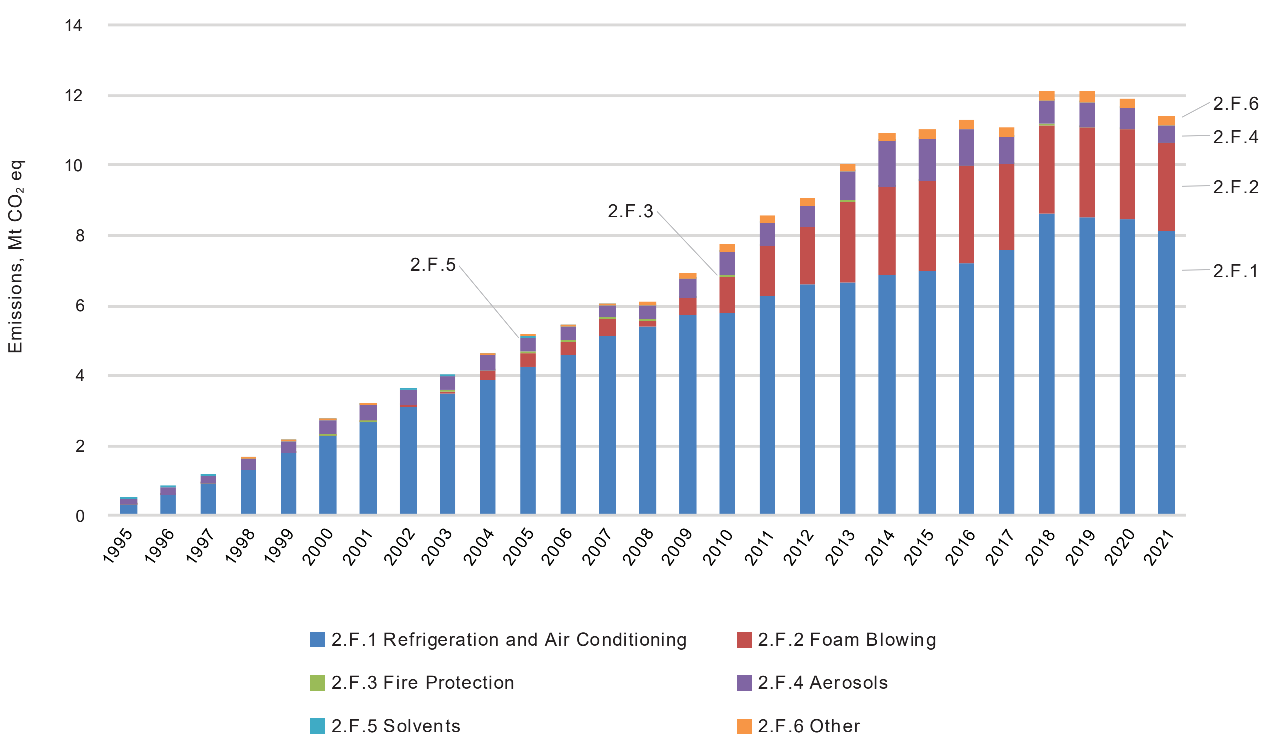
4.16.1. Category Description

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 4.16 and 4.17, 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 agents. All HFCs consumed in Canada are imported in bulk or in manufactured items and products (e.g., refrigerators).

HFC releases contributed approximately 11 Mt CO_2 eq (1.7%) to Canada's total emissions in 2021, a 124% increase from 2005. 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 12 Mt, HFC emissions have begun to decline, in part due to reduced imports of bulk HFCs.

Figure 4–2 **Emissions from HFCs used as Substitutes for Ozone-Depleting Substances, by Application**



4.16.2. 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 was gathered via periodic, mandatory surveys for the data years 1995 through 2004; additional mandatory activity data collection took place in 2014 and 2016, covering activity data of years 2008 through 2015. Activity data for 2017, 2018, 2019, 2020 and 2021 was collected in 2018, 2019, 2020, 2021 and 2022, respectively, from 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 data by market segment were collected from 2006 to 2011 covering activity data of years 2005 through 2010. The surveys were collected by Environment and Climate Change Canada and others (additional information is provided in Annex 3.3.4) and had varying response rates and application aggregation levels.

The 2014, 2016, and 2018–2022 mandatory surveys of HFC bulk imports, exports and sales by HFC type and market segment forms the foundation for the 2008 through 2015 and 2017 through 2021 portion of the HFC inventory. When there were overlaps between the voluntary and the mandatory surveys, the mandatory surveys took precedence. Some additional imports and exports of MIs activity data was reported to the 2014 and 2016 surveys and are included in the inventory. Reporting of HFCs to the 2014 and 2016 mandatory surveys were done on the basis of applications and sub-applications so that the quantities for manufacture and servicing could be broken out.

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 (IPCC, 2006). More information on the received data, the disaggregation methodology and the sub-applications are available in Annex 3.3.4.

The full list of HFCs and the activity data years in which they appeared are shown in Table 4–11. No data was collected for 2016.

Table 4–12 shows the breakdown of 2021 bulk HFC import data by type per application, as reported mandatorily to the *Ozone-depleting Substances and Halocarbon Alternatives Regulations* program in 2022.

4

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.[33] However, no data is publically 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 application to support the development of country-specific emission factors that are representative of Canada's circumstances (Environmental Health Strategies Inc. [EHS], 2013; Environment Canada, 2015). Additional information on survey results and quality control procedures can be found in Annex 3.3.4.3. The country-specific emission factors were applied for the entire time period.

Table 4–11 **HFCs Used in Canada and Years of Appearance in Activity Data**

HFC Type	Years	HFC Type	Years
HFC-125	1995–2015, 2017–2021	HFC-23	1995–2004, 2008–2015, 2017–2021
HFC-134	2008–2009, 2015, 2017–2021	HFC-236fa	1996–1998, 2000–2004, 2008, 2010, 2012–2013 and 2020
HFC-134a	1995–2015, 2017–2021	HFC-245fa	2001–2015, 2017–2021
HFC-143	2013	HFC-32	1995–2015, 2017–2021
HFC-143a	1995–2015, 2017–2021	HFC-365mfc	2008–2015, 2017–2020
HFC-152a	1995–2015, 2017–2021	HFC-41	1999–2000 and 2010
HFC-227ea	1995–2015, 2017–2021	HFC-4310mee	1998–2015, 2018–2020

33 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.

Table 4–12 **2021 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	16.2%	-	0.0%	-	100.0%	99.2%	10.5%
HFC-125	27.1%	-	100.0%	-	-	-	17.8%
HFC-134	-	3.1%	-	-	-	-	0.7%
HFC-134a	41.0%	19.7%	-	7.9%	-	0.2%	31.6%
HFC-143a	9.4%	-	-	-	-	-	6.0%
HFC-152a	-	57.1%	-	92.1%	-	-	25.0%
HFC-227ea	0.0%	-	-	-	-	-	0.0%
HFC-245fa	6.3%	20.1%	-	-	-	-	8.5%
Application share of total bulk imports	63.5%	22.6%	0.5%	13.1%	0.0%	0.2%	

Notes:
2021 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.

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 a HFC in a specific sub-application, Equation 7.1 from Volume 3, Chapter 7 (IPCC, 2006) has been adapted to the Canadian context and used. Refer to Annex 3.3.4 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 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 3.3.4.

4.16.3. 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 residential/commercial refrigeration, stationary/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%.

4.16.4. 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.*

4.16.5. Category-Specific Recalculations

There are downward recalculations for this category for 2011–2020 from the use of updated proxy variables in extrapolating manufactured item imports and exports from 2010 onwards for all sub-applications. The maximum impact of these recalculations is -26 kt (-0.2%) in 2020.

4.16.6. Category-Specific Planned Improvements

Research into the commercial and industrial refrigeration emission factors, market share and other characteristics in Canada will be examined for application in future inventories. A data gap exists with the manufactured item import and export data that is available up to 2010. To fill this gap, sources of statistics and import/export data will be searched and examined. A voluntary survey will also be developed and sent out.

Another planned improvement is to obtain more information on reclamation and destruction activities in Canada to further improve end-of-life emission factors. This will be explored through communications with the HRAI Refrigerant Management Canada program, or directly through the reclamation and former destruction facilities.

4.17. Product Uses as Substitutes for Ozone-Depleting Substances (CRF Category 2.F, PFCs)

4.17.1. 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 9.2 kt CO_2 eq in 2021, a 324% increase from 2005.

4

4.17.2. 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 2021. 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 on the basis of 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 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 2017–2021 HFC/PFC blend activity data was collected through mandatory HFC surveys in 2018, 2019, 2020, 2021 and 2022. 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.

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 6.3 kt CO_2 eq in 2021.

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 2021, emissions from the uses of CF_4 and C_2F_6 in solvent applications contributed 2.9 kt CO_2 eq.

4.17.3. 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.

4.17.4. 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.

4.17.5. Category-Specific Recalculations

Following planned improvements outlined in the 2022 NIR publication, emission estimates for Foam Blowing Agents were updated to an IPCC Tier 2a methodology from an IPCC Tier 1a methodology, resulting in recalculations for 1995-2017. The updated methodology uses sub-application specific emission factors, found in Volume 3, Chapter 7, Table 7.7 of the 2006 IPCC Guidelines. These revisions included a shorter product lifetime, greater first-year losses, and less annual losses compared to the application-specific emission factors that were previously applied. The recalculations resulted in changes ranging from -0.016 kt each year from 2012–2015 (-100%) to +0.13 kt in 2010 (829%).

4.17.6. Category-Specific Planned Improvements

Voluntary data surveys for 2021 were not collected, and 2021 use levels were held constant at 2020 levels for most applications. A voluntary data collection of 2021 data is planned for 2023 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).

4.18. Other Product Manufacture and Use (CRF Category 2.G)

4.18.1. 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 721 kt (<0.1%) to Canada's total emissions in 2021, a 33% increase from 2005.

4.18.2. 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., 2006–2021) 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 2006–2021 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 2006–2021 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)

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 2006–2021 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 on the basis of 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 4.17). 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.

4.18.3. 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 4.17.2 (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 took into account 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.

4.18.4. 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.

4.18.5. Category-Specific Recalculations

Sulphur Hexafluoride Emissions from Electrical Equipment (CRF Category 2.G.1)

There were recalculations for SF_6 emissions from electrical equipment of 8.3 kt CO_2 eq in 2019 and -10 kt CO_2 eq in 2020 due to updates in activity data.

4.18.6. 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. The UNFCCC ERT has recommended that the inventory team perform a significance assessment on this category. Previously, preliminary research was conducted and found that the activities mentioned in the 2006 IPCC Guidelines (vol. 3 section 8.3) seemed to not take place at a detectable level, and the category is currently reported as "Not Estimated" using notation key "NE" in the CRF reporter.

To assess the category, a voluntary data reporting survey will be sent to gas distributors to obtain a time-series estimate of SF_6 and PFCs sold within Canada for Other Product Use activities. In addition, during the collection of 2014–2020 SF_6 and PFC sales data from major Canadian gas distributors, purchasers were identified who may be involved in Other Product Use activities. Large potential end-users from the dataset have been or will be sent surveys to obtain activity data for recent years. As well, relevant national agencies for certain applications (such as those knowledgeable on particle accelerators and ophthalmology uses) have been or will be contacted. Once a comprehensive set of 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 an 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)

The coverage of this category may overlap with other existing categories. Activity data contributing to this category are under review. Legacy data sources are being investigated in order to ensure that emissions estimates are re-attributed to the correct category(ies) to improve inventory comparability.

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 2021. Emissions in the sector increased by 32% between 1990 and 2021. 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 77% 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 90% 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 2021, while dairy cattle populations have decreased until recently, with some fluctuations, stabilizing at just under 1 million head in 2021.

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, corn production increased from 7 Mt to 14 Mt, and soybean production from 1.3 Mt to 6.3 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. With the changes in crop production, inorganic nitrogen (N) fertilizer consumption has more than doubled, from 1.2 Mt in 1990 to 3.0 Mt in 2021, while land under conservation tillage has increased by 18 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 total GHG emissions from the Agriculture sector rose from 41 Mt CO_2 eq in 1990 to 54 Mt CO_2 eq in 2021 (Table 5–1). This 32% increase is mainly due to emissions associated with the greater use of inorganic N fertilizers (148% increase in N shipments), recent declines in the proportion of perennial cropland, larger swine populations (38% 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 25 Mt CO_2 eq in 1990 and 28 Mt CO_2 eq in 2021, with an uncertainty range of -6% to +20% for the mean estimates. Over the 1990 to 2021 time series, mean CH_4 emissions are estimated to have increased by 3.6 Mt CO_2 eq, a 14% increase, which is associated with an uncertainty range of 10% to 17%. Emissions of N_2O from agricultural soils and livestock represented 15 Mt CO_2 eq in 1990 and 23 Mt CO_2 eq in 2021, with an uncertainty range of approximately -27% to +29% of the mean estimates. Over the time series, mean N_2O emissions increased by 7.8 Mt CO_2 eq, an increase of 52%.

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	2000	2005	2015	2016	2017	2018	2019	2020	2021
Agriculture TOTAL[a]		**41 000**	**51 000**	**54 000**	**52 000**	**53 000**	**52 000**	**53 000**	**54 000**	**55 000**	**54 000**
Enteric Fermentation (CH_4)		**22 000**	**28 000**	**31 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**
Dairy Cattle		4 000	3 400	3 200	3 200	3 200	3 300	3 400	3 500	3 500	3 500
Beef Cattle[b]		18 000	23 000	26 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000
Others[c]		730	1 100	1 300	1 000	1 100	1 100	1 100	1 100	1 100	1 100
Manure Management		**6 100**	**7 900**	**8 700**	**7 700**	**7 800**	**7 800**	**7 800**	**7 800**	**7 800**	**7 800**
Dairy Cattle	CH_4	430	560	680	870	880	890	920	940	950	960
	N_2O	520	460	350	260	260	260	270	270	270	270
Beef Cattle[b]	CH_4	810	1 100	1 200	1 000	1 000	1 000	1 000	1 000	1 000	1 000
	N_2O	1 900	2 700	3 000	2 300	2 300	2 300	2 300	2 300	2 300	2 300
Swine	CH_4	1 000	1 500	1 800	1 600	1 700	1 700	1 700	1 700	1 700	1 700
	N_2O	100	70	70	50	50	50	50	50	50	50
Poultry	CH_4	160	190	190	200	200	200	200	200	190	190
	N_2O	430	530	540	600	610	610	600	590	580	580
Others[d]	CH_4	40	50	60	50	40	40	40	40	40	30
	N_2O	90	140	170	130	120	120	120	110	110	110
Indirect Source of	N_2O	600	680	720	610	610	610	610	600	600	600
Agricultural Soils (N_2O)		**11 000**	**13 000**	**13 000**	**18 000**	**18 000**	**17 000**	**19 000**	**19 000**	**20 000**	**19 000**
Direct Sources		8 700	10 000	10 000	14 000	14 000	14 000	15 000	15 000	16 000	15 000
Synthetic nitrogen fertilizers		4 400	5 800	5 300	8 900	9 000	8 400	9 400	9 500	11 000	10 000
Organic nitrogen fertilizers		1 200	1 400	1 500	1 500	1 500	1 500	1 500	1 500	1 400	1 400
Crop residue decomposition		2 500	2 800	3 100	4 000	4 400	4 400	4 300	4 300	4 500	3 400
Cultivation of organic soils		60	60	60	60	60	60	60	60	60	60
Mineralization of soil organic carbon		210	230	270	690	390	320	350	430	550	470
Conservation tillage[e]		-410	-990	-1 200	-2 300	-2 300	-2 200	-2 400	-2 400	-2 600	-2 400
Irrigation		560	720	780	1 100	1 200	1 100	1 200	1 200	1 300	1 200
Manure on pasture, range and paddock		220	240	260	210	200	200	200	200	200	190
Indirect Sources		2 600	3 100	3 100	3 800	3 900	3 800	3 900	3 900	4 200	4 000
Field Burning of Agricultural Residues (CH_4 & N_2O)		**220**	**130**	**40**	**60**	**50**	**50**	**50**	**50**	**50**	**30**
Liming and Urea Application (CO_2)		**1 200**	**1 600**	**1 400**	**2 600**	**2 500**	**2 400**	**2 600**	**2 700**	**3 000**	**3 100**

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.

Emissions from the Agriculture sector peaked in 2005, and decreased to 49 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 55 Mt CO_2 eq in 2020; though in 2021, emissions decreased again to 54 Mt CO_2 as a result of a severe drought that lead to a decrease in crop production on the prairies.

In this submission, 1990 emissions were revised downward by 43 kt CO_2 eq; 2005 emissions by 29 kt CO_2 eq lower; and 2020 emissions, were revised upward by 332 kt CO_2 eq compared to the previous submission, representing recalculations of -0.1%, -0.05%, and +0.6%, respectively (Table 5–2).

The recalculations were primarily the result of the integration of activity data from the 2021 *Census of Agriculture*. To a lesser extent, changes resulted from (i) a refresh of time series activity data in order to ensure consistency with updates or revisions to data sources; (ii) the implementation of the Tier 1 methodology for estimating nitric oxide emissions from manure management based on the 2019 EMEP/EEA Guidebook (EEA, 2019); (iii) minor 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 2023 National Inventory Report**

		Recalculations (kt CO_2 eq)								
		1990	2000	2005	2015	2016	2017	2018	2019	2020
Previous submission (2022 NIR)		41 000	51 000	54 000	52 000	53 000	52 000	53 000	53 000	55 000
Current submission (2023 NIR)		41 000	51 000	54 000	52 000	53 000	52 000	53 000	54 000	55 000
Change due to continuous improvement or refinement:										
Activity data updates (2021 census of agriculture, annual survey products)										
Enteric Fermentation	kt CO_2 eq	0	0	0	-8.4	-5.7	74	330	410	690
	%	0	0	0	-0.0002	-0.0001	0.0014	0.0062	0.0077	0.013
Manure Management	kt CO_2 eq	0	0	0	-35	-23	-20	19	4	33
	%	0	0	0	-0.0007	-0.0004	-0.0004	0.0004	0.00008	0.0006
Agricultural Soils	kt CO_2 eq	-23	-29	-2	-31	-32	14	-5	-39	-330
	%	-0.0006	-0.0006	0	-0.0006	-0.0006	0.0003	-0.0001	-0.0007	-0.006
Implementation of Tier 1 Nitric Oxide Method from EMEP/EEA Guidelines										
Manure Management	kt CO_2 eq	2	1	1	-2	-1	-3	-4	-7	-11
	%	0	0	0	0	0	-0.0001	-0.0001	-0.0001	-0.0002
Error Correction										
Agricultural Soils	kt CO_2 eq	-22	-25	-28	-22	-45	-21	-29	-35	-54
	%	-0.0005	-0.0005	-0.0005	-0.0004	-0.0008	-0.0004	-0.0005	-0.0007	-0.001
Field Burning of Agricultural Residues	kt CO_2 eq	0	0	0	0	0	0	0	1	0
	%	0	0	0	0	0	0	0	0.00002	0

Table 5–3 **Qualitative Summary of the Revisions to Methodologies, Corrections and Improvements Carried out for Canada's 2023 Submission**

Correction or Improvement	Recalculation Categories Affected	Years Affected
Activity data updates (2021 census of agriculture, annual survey products)	CH_4 emissions from enteric fermentation and manure management N_2O emissions from manure management, direct and indirect N_2O emissions from agricultural soils, direct and indirect	Complete time series
Implementation of Tier 1 Nitric Oxide Method from EMEP/EEA Guidelines	Indirect N_2O emissions from manure management	Complete time series
Miscellaneous Error Corrections	Direct and indirect N_2O emissions from agricultural soils CH_4 and N_2O from field burning of agricultural residues	Complete time series

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 2020, and mean estimates in 2020 lie within a range of -14% to +17% (Table 5–4). Over the time series of 1990 to 2020, mean emissions are estimated to have increased by 1.3 Mt CO_2 eq, a 6% 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 (1990–2021), 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% Prob.	97.5% Prob.
Dairy Cattle	Population (1000 head)		974	923 (-5.2%)	1 025 (+5.2%)
	Tier 2 emission factor (kg/head/year)		143	122 (-15%)	171 (+19%)
	Emissions (Mt CO_2 eq)		3.5	2.9 (-16%)	4.2 (+20%)
Non-Dairy Cattle	Population (1000 head)		11 083	10 871 (-1.9%)	11 309 (+2.0%)
	Tier 2 emission factor (kg/head/year)		72	61 (-15%)	84 (+18%)
	Emissions (Mt CO_2 eq)		20	17 (-16%)	24 (+21%)
Other Livestock	Emissions (Mt CO_2 eq)		1.1	0.87 (-18%)	1.2 (+18%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	22	19 (-16%)	27 (+21%)
		2021	24	21 (-14%)	29 (+17%)
	Trend	1990–2021	2.1 (+9.4%)	0.99 (+4.4%)	2.8 (+13%)

Notes:

a. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2021.

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 2021.

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 2023 NIR submission as a result of the integration of activity data from the 2021 *Census of Agriculture*, and general activity data updates to historical populations in the survey products (Table 5–5). These changes had no impact in 1990 or 2005, but increased emissions by 690 kt CO_2 eq in 2020. This resulted in an increase in the short-term trend from -23% to -21% and the long-term trend from +6% to +9%.

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	2022	22 347	0	0	Long term (1990–2020)	
		2023	22 347			6	9
	2005	2022	30 821	0	0		
		2023	30 821			Short term (2005–2020)	
	2020	2022	23 677	693	2.9	-23	-21
		2023	24 370				
Manure Management CH_4	1990	2022	2 461	0.01	0	Long term (1990–2020)	
		2023	2 461			58	57
	2005	2022	3 908	0.001	0		
		2023	3 908			Short term (2005–2020)	
	2020	2022	3 891	-16	-0.42	0	-1
		2023	3 875				
Manure Management – Direct N_2O	1990	2022	3 042	0.08	0	Long term (1990–2020)	
		2023	3 042			8	10
	2005	2022	4 088	-0.001	0		
		2023	4 088			Short term (2005–2020)	
	2020	2022	3 290	50	1.5	-20	-18
		2023	3 339				
Manure Management – Indirect N_2O	1990	2022	584	1.9	0.33	Long term (1990–2020)	
		2023	586			5	2
	2005	2022	720	1.0	0.13		
		2023	721			Short term (2005–2020)	
	2020	2022	611	-11	-1.9	-15	-17
		2023	600				

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. 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 category, and over time. Dairy, swine and poultry production occurs in modern high-density production facilities. 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. Volatile solids for swine were corrected for animal mass as described in Annex 3.4. For sheep and poultry categories, different parameters were used for animal subcategories 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 1990–2021 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,

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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 3.9 Mt CO_2 eq from the management of livestock manure in Canada in 2021 lies within an uncertainty range of -28% to +23% (Table 5–6). The emission estimate for 1990, 2.5 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 59% increase in mean emissions between 1990 and 2021 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.

Table 5–6 **Uncertainty in the Estimates of CH_4 Emissions from Manure Management**

Livestock Category	Uncertainty Source		Mean Value[a]	2.5% Prob.[b]	97.5% Prob.
Dairy Cattle	Population (1000 head)		974	923 (-5.2%)	1 025 (+5.2%)
	Tier 2 emission factor (kg/head/year)		39	21 (-45%)	53 (+37%)
	Emissions (Mt CO_2 eq)		0.95	0.52 (-45%)	1.30 (+37%)
Non-Dairy Cattle	Population (1000 head)		11 083	10 871 (-1.9%)	11 309 (+2.0%)
	Tier 2 emission factor (kg/head/year)		3.6	2.7 (-25%)	5.3 (+45%)
	Emissions (Mt CO_2 eq)		1	0.7 (-27%)	1.51 (+51%)
Swine	Population (1000 head)		14 043	13 710 (-2.4%)	14 382 (+2.4%)
	Tier 2 emission factor (kg/head/year)		4.8	2.2 (-54%)	7.0 (+45%)
	Emissions (Mt CO_2 eq)		1.7	0.9 (-49%)	2.41 (+42%)
Other Livestock	Emissions (Mt CO_2 eq)		0.23	0.16 (-31%)	0.26 (+14%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	2.5	1.4 (-44%)	3.3 (+36%)
		2021	3.9	2.8 (-28%)	4.8 (+23%)
	Trend	1990–2021	1.4 (+59%)	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 2021.

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 2021.

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2021), 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.

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

Minor recalculations were made to manure management CH_4 emissions in all years due to activity data updated including the 2021 *Census of Agriculture*. These changes resulted in an upward revision to emission estimates of 0.01 kt CO_2 eq in 1990, 0.001 kt CO_2 eq in 2005, and a downward revision to emission estimates of 16 kt CO_2 eq in 2020. The recalculations caused a 1% reduction in the short-term and long-term emission trends (0% to -1%, and 58% to 57%, respectively; 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).

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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 3.3 Mt CO_2 eq from Manure Management in 2020 lies within an uncertainty range of 1.9 Mt CO_2 eq (-43%) to 5.0 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 new dairy and swine models has not yet been performed.

The same methodology, emission factors and data sources are used for the entire time series (1990–2021).

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 integration of the 2021 *Census of Agriculture* and other activity data updates. The net impact of these changes was a slight increase in emissions of 0.08 kt CO_2 eq in 1990, a decrease of 0.001 kt CO_2 eq 2005, and an increase in emissions of 50 kt CO_2 eq in 2020. The recalculations caused a slight increase in the short and long-term emission trends (-20% to -18%, and 8% to 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 (1990–2021).

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 mainly due to the integration of activity data from the 2021 *Census of Agriculture*. Minor recalculations occurred from the implementation of an approach for estimating the contribution of nitric oxide to volatilization losses from dairy and swine manure. The net impact of these changes was an increase in emissions of 1.9 kt CO_2 eq in 1990 and 1.0 kt CO_2 eq in 2005 and a reduction in emissions of 11 kt CO_2 eq in 2020. The recalculations caused a slight reduction in the short-term and long-term emission trends (-15% to -17%, and 5% to 2%, respectively; 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 have been implemented for dairy and swine, and similar emission factors have been developed for beef cattle. Non-Dairy Cattle Tier 2 parameters may be revised as necessary, based on more 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 emission 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 10 Mt CO_2 eq from the application of inorganic fertilizers on agricultural soils in 2021 lies within a range of 6.8 Mt CO_2 eq (-35%) to 15 Mt CO_2 eq (+43%) (Table 5–7).

The same methodology and emission factors were used for the entire time series (1990–2021).

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% Prob.[b]	97.5% Prob.
		Mt CO_2 eq		
Manure Management				
Direct emissions		3.3	1.9 (-43%)	5.0 (+51%)
Indirect emissions		0.6	0.24 (-60%)	1.0 (+70%)
Agricultural Soils (N_2O)		**19**	**12 (-36%)**	**29 (+52%)**
Direct N_2O emissions from managed soils		15	11 (-28%)	20 (+34%)
	Inorganic N fertilizers	10	6.8 (-35%)	15 (+43%)
	Organic N fertilizers	1.4	0.97 (-33%)	2.0 (+41%)
	Crop residues	3.4	2.2 (-35%)	5.0 (+45%)
	Cultivation of organic soils	0.061	0.013 (-79%)	0.12 (+96%)
	Mineralization associated with loss of soil organic matter	0.47	0.31 (-35%)	0.68 (+45%)
	Urine and dung deposited by grazing animals	0.19	0.078 (-60%)	0.34 (+75%)
	Soil N mineralization/immobilization	-1.2	-0.67 (-44%)	-1.9 (+55%)
Indirect N_2O emissions from managed soils		4	1.6 (-60%)	6.7 (+70%)
	Atmospheric Deposition	0.99	0.25 (-75%)	2.1 (+110%)
	Leaching and runoff	3	0.59 (-80%)	5.9 (+100%)

Notes:

a. Mean value reported from database.

b. Values in parentheses represent the uncertain percentage of the mean.

5.4.1.1.4. 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 the 2021 *Census of Agriculture*, and to a lesser extent, minor activity data updates and error corrections.

Emissions were revised downward by 23 kt CO_2 eq in 1990 and 29 kt CO_2 eq in 2005 and revised upward by 62 kt CO_2 eq in 2020 (Table 5–8). The recalculations caused a slight increase in the short-term and long-term emission trends (96% to 99%, and 136% to 139%, 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	2022	4 447	-23	-1	Long term (1990–2020)	
		2023	4 423			136	139
	2005	2022	5 351	-29	-1		
		2023	5 322			Short term (2005–2020)	
	2020	2022	10 505	62	1	96	99
		2023	10 568				
Organic N fertilizers	1990	2022	1 158	1	0.07	Long term (1990–2020)	
		2023	1 158			34	24
	2005	2022	1 486	1	0.04		
		2023	1 487			Short term (2005–2020)	
	2020	2022	1 546	-107	-7	4	-3
		2023	1 439				
Crop residue decomposition	1990	2022	2 507	-0.5	-0.02	Long term (1990–2020)	
		2023	2 507			78	79
	2005	2022	3 077	-0.4	-0.01		
		2023	3 077			Short term (2005–2020)	
	2020	2022	4 455	35	1	45	46
		2023	4 490				
Urine and dung deposited by grazing animals	1990	2022	224	0.03	0.01	Long term (1990–2020)	
		2023	224			-10	-12
	2005	2022	258	0	0		
		2023	258			Short term (2005–2020)	
	2020	2022	201	-4.67	-2.33	-22	-24
		2023	196				

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 2021 lies within an uncertainty range of 0.97 Mt CO_2 eq (-33%) to 2.0 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 (1990–2021).

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 activity data from the 2021 *Census of Agriculture*. Minor changes resulted from other activity data updates and error correction.

Emissions were revised slightly upward by 1.0 kt CO_2 eq in 1990 and 2005 and downward by 107 kt CO_2 eq in 2020 (Table 5–8). The short-term trend decreased from +4% to -3%, and the long-term trend, from +34% to +24%.

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 3.4 Mt CO_2 eq from crop residue decomposition in 2021 is associated with an uncertainty range of -35% to +45%, or 2.2 Mt CO_2 eq to 5.0 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 (1990–2021).

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 activity data updates following the implementation of the 2021 *Census of Agriculture*. Minor recalculations occurred from other activity data updates and error corrections.

Emissions were revised downward by 0.5 kt CO_2 eq in 1990 and 0.4 kt CO_2 eq in 2005 and upward by 35 kt CO_2 eq in 2020, respectively (Table 5–8). As a result of these changes, the long-term emission trend increased slightly from +78% to +79% and the short-term trend, from 45% to 46%.

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 0.19 Mt CO_2 eq from pasturing Canadian livestock in 2021 lies within an uncertainty range of -60% to +75%, or 0.078 Mt CO_2 eq to 0.34 Mt CO_2 eq, respectively (Table 5–7).

The same methodology and emission factors are used for the entire time series (1990–2021).

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 increased by 0.03 kt CO_2 eq in 1990, stayed constant in 2005 and reduced by 4.67 kt CO_2 eq in 2020 (Table 5–8). As a result of these changes, the short-term emission trend decreased slightly from -10% to -12% and the long-term trend, from -22% to -24%.

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 2021 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 carbon 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 0.47 Mt CO_2 eq from mineralization associated with the loss of soil organic matter in 2021 lies within an uncertainty range of -35% to +45%, or 0.31 Mt CO_2 eq to 0.68 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 2020 due to revisions to activity data including adjustments to crop yields. Emissions decreased by 20 kt CO_2 eq in 1990, increased by 0.4 kt CO_2 eq in 2005, and decreased by 277 kt CO_2 eq in 2020. The long-term trend decreased from 265% to 166%, and the short-term trend decreased from 202% to 100%.

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 enhance 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 1990–2021 (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 0.061 Mt CO_2 eq from organic soils in 2021 lies within an uncertainty range of -79% to +96%, or 0.01 Mt CO_2 eq to 0.12 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 (1990–2021).

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

There were no recalculations in this source of emission estimates.

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 the 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 -2.4 Mt CO_2 eq from conservation tillage practices in 2021 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 (1990–2021).

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 tillage practices from the 2021 *Census of Agriculture*, and as well as activity data updates and error corrections that resulted in spatial reallocation of N between ecodistricts.

These changes increased the impact of tillage adoption on N_2O emissions by 0.34 kt CO_2 eq in 1990, 0.76 kt CO_2 eq in 2005 and reduced N_2O emissions by 58 kt CO_2 eq in 2020. These recalculations increased the impact of tillage adoption on the trend from 523% to 538% in the long term, and from 112% to 117% 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	2022	-406	0.34	-0.08	Long term (1990–2020)	
		2023	-405			523	538
	2005	2022	-1193	0.76	-0.06		
		2023	-1193			Short term (2005–2020)	
	2020	2022	-2530	-58	2.3	112	117
		2023	-2588				
Irrigation	1990	2022	558	-1.9	-0.35	Long term (1990–2020)	
		2023	556			140	137
	2005	2022	784	-2.3	-0.30		
		2023	782			Short term (2005–2020)	
	2020	2022	1341	-20	-1.5	71	69
		2023	1321				

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 biological activity, reducing soil aeration (Jambert et al., 1997) and thus enhancing denitrification.

5.4.1.8.2. Methodological Issues

The methodology used is country-specific and is based on the assumptions that (i) irrigation water stimulates N_2O production in a way similar to rainfall; and (ii) irrigation is applied at rates such that the combined amounts of precipitation and irrigation water are equal to potential evapotranspiration under local conditions. Consequently, the effect of irrigation on N_2O emissions from agricultural soils was estimated using an EF_BASE estimated at P=PE (precipitation equivalent to potential evapotranspiration) for the irrigated areas of a given ecodistrict (Liang et al., 2020). To improve transparency, the effect of irrigation on soil N_2O emissions is also reported separately from other source categories.

5.4.1.8.3. 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 1.3 Mt CO_2 eq from irrigated land in 2021 has an uncertainty range of -44% to +55%, based on the uncertainty range of the combined emissions from tillage, irrigation and summerfallow 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 (1990–2021).

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 the 2021 *Census of Agriculture*, general activity data updates and error correction impacting soil emissions.

These changes decreased emissions by 1.9 kt CO_2 eq in 1990, 2.3 kt CO_2 eq in 2005 and 20 kt CO_2 eq in 2020. These recalculations decreased the short-term trend slightly from 71% to 69%, and the long-term trend from 140% to 137% (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 volatilization in the form of NH_3 and NO_x and subsequent re-deposition or leaching and runoff. The nitrogen that is transported from agricultural fields in this manner provides additional nitrogen for subsequent nitrification and 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 0.99 Mt CO_2 eq from volatilization and redeposition in 2021 has an uncertainty range of -75% to +110, or 0.25 Mt CO_2 eq to 2.1 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

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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 (1990–2021).

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 as a result of the implementation of activity data from the 2021 *Census of Agriculture*, and to a lesser extend from other activity data updates and error correction. These recalculations decreased emissions by 0.07 kt CO_2 eq in 1990, by 0.17 kt CO_2 eq in 2005 and by 6.1 kt CO_2 eq in 2020 (Table 5–10). The short-term trend stayed the same at 14%, and the long-term trend decreased slightly from +38% to +37%.

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	2022	725	-0.07	-0.01	Long term (1990–2020)	
		2023	724			38	37
	2005	2022	874	-0.17	-0.02		
		2023	874			Short term (2005–2020)	
	2020	2022	1 000	-6.1	-0.61	14	14
		2023	994				
Nitrogen leaching and runoff	1990	2022	1 836	-0.12	-0.01	Long term (1990–2020)	
		2023	1 836			74	74
	2005	2022	2 203	-0.07	-0.003		
		2023	2 203			Short term (2005–2020)	
	2020	2022	3 194	-7.9	-0.25	45	45
		2023	3 186				

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 (IPCC, 2006), such as in the Prairies. 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 3.0 Mt CO_2 eq from nitrogen leaching and runoff in 2021 lies within an uncertainty range of -80% to +100%, or 0.59 Mt CO_2 eq to 5.9 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 (1990–2021).

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 as a result of the implementation of activity data from the 2021 *Census of Agriculture*, and to a lesser extend from other activity data updates and error correction throughout the time series. These changes decreased emissions by 0.12 kt CO_2 eq in 1990, 0.07 kt CO_2 eq in 2005, and 7.9 kt CO_2 eq in 2020. 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).

2 https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5044

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

There were no recalculations in this category for the years 1990, 2005, or 2020. The long-term and short-term trends remained at -78% and +15%, respectively.

5.5.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

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 0.21 ± 0.14 Mt CO_2 eq for the level uncertainty.

The same methodology is used for the entire time series of emission estimates (1990–2021).

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

There is no immediate plan in place to improve emission estimates for this source.

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 2021 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 2020. The long-term and short-term trends remain unchanged at +155% and +115%.

5.7.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

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 removals of 65 Mt in 1990, 5.5 Mt in 2005 and 17 Mt in 2021.[3] When applied to the national totals, the net flux estimates result in a decrease of 11% in 1990, 0.8% in 2005 and 2.6% in 2021 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. Negative net fluxes (i.e. C removals) were reported in the LULUCF sector during all years of the time series, except for a small source of 24 kt observed in 2015.[4] Carbon removals declined between 1990 and 2005, due to the downward trend in net removals in the Forest Land category, which was partially attenuated by increasing removals in the Cropland category.

Emissions and removals from the forest sector in Canada consist of the net fluxes from commercially mature forest stands that are of harvest origin or have recovered from natural disturbances, and the corresponding emissions from HWP extracted from Canadian forests that have either reached their end of life or have been combusted for bioenergy. Forest management resulted in a decrease in net removals from 200 Mt to 130 Mt during the 1990–2007 period in the Forest Land category. This decline in removals reflects the combined influence of forest harvesting and increased insect-related mortality, which together have resulted in a net reduction in C removals from the atmosphere by commercially mature stands. Net removals

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/.

by forest land have fluctuated since 2007, peaking at 140 Mt in 2009 when harvest rates reached the lowest point in the 32-year time series and declining again to 130 Mt in 2021, due to recent wildfires that resulted in the loss of significant areas of mature managed forest.

Emissions in 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 1990–2021 period. In 2019, harvesting rates fell sharply and emissions decreased since then close to the minimum observed in 2009 (Table 6–1), reaching a low of 130 Mt in 2021. Emissions are influenced primarily by the trend in forest harvesting 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 harvesting from non-forest lands since 1990—amounted to net removals of 77 Mt in 1990 and 9.1 Mt in 2021, and peak net emissions of 8.2 Mt in 2005. These estimates represent the combined total of net removals from forest land and net emissions from 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 inventoried and tracked in forest management practices to serve the public interest. Natural disturbances can result in substantial emissions and subsequent removals of GHGs within the managed forest and display large interannual variability that masks in 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 47 Mt in 1992 to peak emissions of 310 Mt in 2021 (peak wildfire year since 1990). Emissions and removals have tended to be higher since the mid-2000s than in the early part of the inventory reporting period (Table 6–1) due to the increased frequency of wildfires and the tracking of insect disturbances.

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	2016	2017	2018	2019	2020	2021
Land Use, Land-Use Change and Forestry TOTAL[a]		**-65 000**	**-5 500**	**-11 000**	**-16 000**	**-11 000**	**-19 000**	**-13 000**	**-17 000**
a.	**Forest Land**	**-200 000**	**-140 000**	**-140 000**	**-140 000**	**-130 000**	**-140 000**	**-130 000**	**-130 000**
	Forest Land Remaining Forest Land	-200 000	-140 000	-140 000	-130 000	-130 000	-140 000	-130 000	-130 000
	Land Converted to Forest Land	-1 100	-950	-440	-390	-340	-300	-240	-170
b.	**Cropland**	**1 000**	**-22 000**	**-17 000**	**-23 000**	**-22 000**	**-18 000**	**-16 000**	**-18 000**
	Cropland Remaining Cropland	-8 500	-26 000	-21 000	-26 000	-25 000	-21 000	-20 000	-21 000
	Land Converted to Cropland	9 500	3 900	3 300	3 400	3 300	3 300	3 500	3 400
c.	**Grassland**	**0.6**	**0.9**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
	Grassland Remaining Grassland	0.6	0.9	1.2	1.2	1.2	1.2	1.2	1.2
	Land Converted to Grassland	NO	NO	NO	NO	NO	NO	NO	NO
d.	**Wetlands**	**5 400**	**3 100**	**3 100**	**3 100**	**2 800**	**3 100**	**3 500**	**3 300**
	Wetlands Remaining Wetlands	1 500	2 600	2 700	2 700	2 500	2 700	2 900	2 900
	Land Converted to Wetlands	3 900	500	470	420	250	420	550	440
e.	**Settlements**	**1 900**	**1 500**	**2 300**	**2 200**	**2 100**	**1 900**	**2 100**	**2 000**
	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	5 900	6 700	6 600	6 500	6 400	6 500	6 500
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**	**140 000**	**130 000**	**130 000**	**130 000**
	Forest conversion[c]	*21 000*	*16 000*	*16 000*	*16 000*	*16 000*	*16 000*	*16 000*	*16 000*
	Indirect CO_2[d]	*690*	*770*	*660*	*670*	*610*	*510*	*470*	*490*
	Natural disturbances[e]	*-27 000*	*70 000*	*120 000*	*240 000*	*270 000*	*170 000*	*21 000*	*310 000*

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.

Changes in agricultural land management practices in Western Canada, such as the extensive adoption of conservation tillage practices combined with the reduced use of summerfallow 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 peaks in yield due to weather increase interannual variability in soil C inputs and, therefore, in emissions and removals. Examples include the peak emissions associated with the drought in Western Canada in the years 2002 and 2003 (reaching 7.8 Mt in 2003) and the peak removals in 2009 (36 Mt) and 2014 (43 Mt) associated with high crop yields. As a result, short-term trends must be interpreted with care.

Over the 1990–2021 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 37% of all emissions in the Wetlands category in 2021, compared to 82% in 1990. Emissions in the Land Converted to Wetlands category decreased from 3.9 Mt to 0.4 Mt over the reporting period.

Net emissions reported in the Settlements category fluctuated between 1.2 Mt (1998) and 2.3 Mt (2015), driven mainly by rates of conversion of forested land, which accounted for 6.4 Mt of emissions in 2021. Relatively steady removals of around 4.4 Mt per year from the growth of urban trees offset these emissions on average by 72% 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 category 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 2021, including the emissions from HWP resulting from forest conversion activities since 1990. This decline in emissions consists of decreases of 4.3 Mt and 1.7 Mt in immediate and residual emissions from the conversion of forest to cropland and to wetlands, respectively; an increase of 0.4 Mt in these emissions from the conversion of forest to settlements; and an increase of 0.6 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 recalculations in the reported estimates for Forest Land and Cropland categories. The most notable recalculations were due to the alignment of Cropland activity data to the 2021 Census of Agriculture that resulted in significant recalculations for 2018 through to 2020; corrections to 2020 insect activity data; correction to slashburning activity levels in British Columbia that impacted years 1990 to 2005 and implementation of a regeneration delay for a fraction of naturally disturbed forest stands.

Other smaller recalculations occurred in Forest Land, Wetlands and Harvested Wood Products categories mainly due to updated assumptions of pre-disturbance forest type proportions for deforestation events, addition of forest-cleared and flooded areas associated to a hydro-related large event in Quebec, updated 2020 activity data for peat extraction, and updated activity data related to bioenergy and conventional forest harvest.

The combined impact of these and other minor recalculations in the LULUCF sector (Table 6–2) resulted in upward recalculations of the estimated net removals by 1.0 Mt (+1.5%) for 1990, 1.3 Mt (+31%) for 2005 and 6.6 Mt (+98%) in 2020.

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 6–2 **Summary of Recalculations in Reported Estimates for the Land Use, Land-Use Change and Forestry Sector**

Sectoral Category			1990	2005	2016	2017	2018	2019	2020
Land Use, Land-Use Change and Forestry TOTAL[a]		**kt**	**- 970**	**-1 300**	**- 350**	**790**	**-2 800**	**-2 900**	**-6 600**
		%	**1.5%**	**31%**	**3.3%**	**-4.7%**	**33%**	**18%**	**98%**
a.	**Forest Land**	**kt**	**-1 600**	**-1 200**	**680**	**1 300**	**1 100**	**1 400**	**- 840**
		%	**0.8%**	**0.9%**	**-0.5%**	**-0.9%**	**-0.8%**	**-1.0%**	**0.6%**
	Forest Land Remaining Forest Land	kt	-1 600	-1 200	680	1 300	1 100	1 400	- 840
		%	0.8%	0.9%	-0.5%	-0.9%	-0.8%	-1.0%	0.6%
	Land Converted to Forest Land	kt	-	-	-	-	-	-	-
		%	-	-	-	-	-	-	-
b.	**Cropland**	**kt**	**620**	**81**	**- 430**	**660**	**-3 100**	**-3 700**	**-6 700**
		%	165%	-0.4%	2.5%	-2.8%	16%	27%	70%
	Cropland Remaining Cropland	kt	440	- 33	- 310	600	-3 000	-3 600	-6 700
		%	-4.9%	0.1%	1.5%	-2.2%	13%	21%	51%
	Land Converted to Cropland	kt	180	110	- 120	62	- 160	- 140	- 34
		%	1.9%	3.0%	-3.6%	1.9%	-4.6%	-4.0%	-1.0%
c.	**Grassland**	**kt**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		%	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Grassland Remaining Grassland	kt	-	-	-	-	-	-	-
		%	-	-	-	-	-	-	-
d.	**Wetlands**	**kt**	**-**	**19**	**11**	**- 0.3**	**2.3**	**180**	**560**
		%	-	0.6%	0.3%	0.0%	0.1%	6.0%	19%
	Wetlands Remaining Wetlands	kt	-	- 0.1	1.2	0.5	0.0	- 0.2	260
		%	-	0.0%	0.0%	0.0%	0.0%	0.0%	9.7%
	Land Converted to Wetlands	kt	-	19.0	9.3	- 0.8	2.4	180	310
		%	-	3.9%	2.0%	-0.2%	1.0%	72%	123%
e.	**Settlements**	**kt**	**- 4.1**	**-150**	**- 260**	**- 230**	**- 82**	**- 310**	**- 110**
		%	**-0.2%**	**-8.8%**	**-10%**	**-9.5%**	**-3.8%**	**-14%**	**-4.9%**
	Settlements Remaining Settlements	kt	-	-	-	-	-	-	-
		%	-	-	-	-	-	-	-
	Land Converted to Settlements	kt	- 4.1	-150	- 260	- 230	- 82	- 310	- 110
		%	-0.1%	-2.4%	-3.8%	-3.4%	-1.2%	-4.7%	-1.6%
g.	**Harvested Wood Products**	**kt**	**-13**	**-54**	**- 350**	**-920**	**- 760**	**-440**	**450**
		%	0.0%	0.0%	-0.3%	-0.7%	-0.5%	-0.3%	0.4%
	Forest conversion[b]	*kt*	*-23*	*-83*	*- 630*	*- 400*	*- 500*	*- 580*	*- 140*
		%	*-0.1%*	*-0.5%*	*-3.7%*	*-2.4%*	*-3.1%*	*-3.5%*	*-0.9%*

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.

Planned improvements include continued refinements to the isolation of anthropogenic emissions and removals resulting from forest management, 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.

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		
Industrial forestry activity data updated from the National Forestry Database (NFD)	Activity data updates	2015–2021
Implementation of a regeneration delay for a fraction of naturally disturbed forest stands	Continuous improvement	Complete time series
Corrections to 2020 insect activity data	Continuous improvement	2020–2021
Corrections to British Columbia estimates related to slash burning targets and firewood harvest spatial locations	Continuous improvement	1990–2005
Incorporated pre-planting carbon (C) stocks into the estimation of the initial C content for recent afforestation sites	Continuous improvement	2021
Refined the temporal resolution of deforestation pre-disturbance forest type assumptions	Continuous improvement	2005–2021
Addition of forest-cleared and flooded areas associated to a hydro-related large event in Quebec	Activity data updates	2019–2021
Minor retroactive updates to the area burned statistics in several ecozones	Activity data updates	Complete time series
Cropland		
Alignment of activity data with the 2021 Census of Agriculture	Activity data updates	2018–2021
Recompilation of pre-1971 census data	Activity data updates	Early 1990s
Addressed gaps in the reporting of fababean activity over time	Continuous improvement	Complete time series
Addressed gap in the reporting of buckwheat area for 2011	Continuous improvement	Around 2011
Improved time series of activity data associated to woody biomass originating from trees and shrubs in agricultural land	Continuous improvement	1995–2005
Refined the temporal resolution of deforestation pre-disturbance forest type assumptions	Continuous improvement	2005–2021
Grassland		
No recalculations		
Wetlands		
Updates of 2020 activity data on peat extraction from NRCan	Activity data updates	2020–2021
Addition of flooded areas associated to a hydro-related large event in Quebec	Activity data updates	2019–2021
Refined the temporal resolution of deforestation pre-disturbance forest type assumptions	Continuous improvement	2005–2021
Settlements		
Addition of forest-cleared and flooded areas associated to a hydro-related large event in Quebec	Activity data updates	2019–2021
Refined the temporal resolution of deforestation pre-disturbance forest type assumptions	Continuous improvement	2005–2021
Harvested Wood Products		
Industrial forestry activity data updated from the NFD	Activity data updates	2015–2021
Updated HWP model parameters based on latest Food and Agriculture Organization (FAO) statistics on forest products	Activity data updates	2019–2021
Updated waste Incineration activity data	Activity data updates	Complete time series
Updated residential and industrial bioenergy consumption	Activity data updates	2019–2021
Improved time series of activity data associated to woody biomass originating from trees and shrubs in agricultural land	Continuous improvement	1995–2005

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, summerfallow 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 2021. 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

Table 6–4 **Land Use and Land-Use Change Matrix for the 2021 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]	171 100	*54 399*	22	NO	0.0	27	NO
Anthropogenic component	*171 400*	*449*	*22*	*NO*	*0.0*	*27*	*NO*
Natural disturbance component	*- 300*	*53 950*	*NO*	*NO*	*NO*	*NO*	*NO*
Cropland	1.4	*NO*	46 246	NO	NE	11	NO
Grassland	NO	*NO*	NO	7 207	NE	0.9	NO
Wetlands[c]	NO	*NO*	NE	NO	492	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.

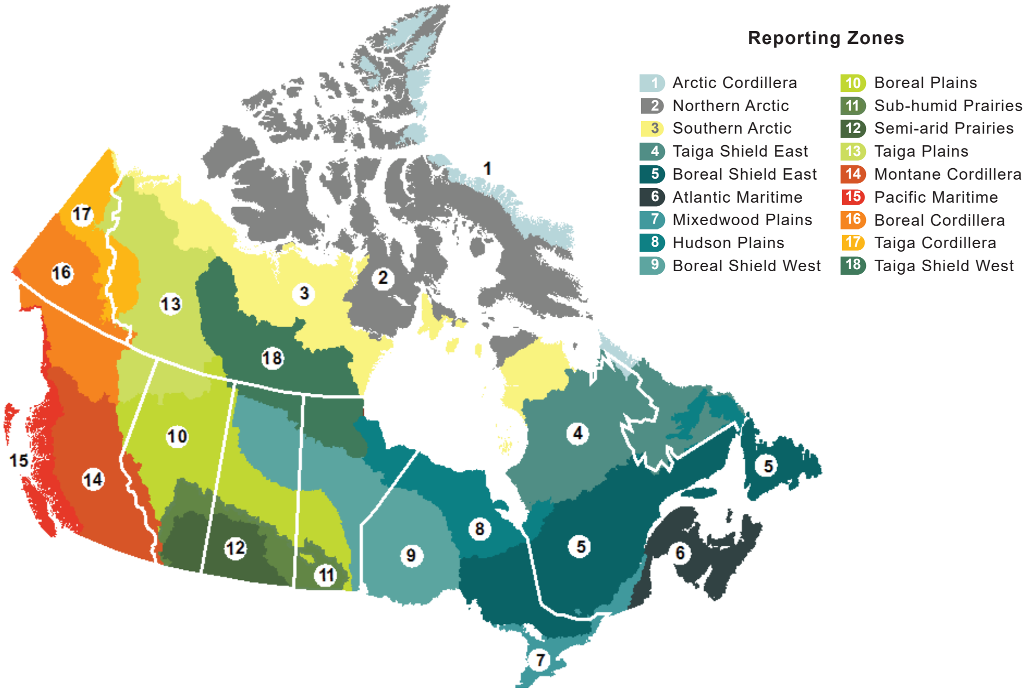
Areas presented in this table are not rounded to keep consistency within the table between numbers with different orders of magnitude, and with areas reported in the CRF Tables. However, caution is advised when interpreting these estimated areas due to the uncertainty associated with these values.

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**



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).

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 2021, the net GHG balance reported for the anthropogenic component of the managed Forest Land (see section 6.3.1.2) amounted to removals of 130 Mt (Table 6–1 and CRF Table 4), while emissions from wood products originating from Canada's managed forests amounted to 120 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 130 Mt in 2021) and Land Converted to Forest Land (0.03 Mha, net removals of 0.2 Mt in 2021) 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 between managed forests and the atmosphere (Figure 6–2).

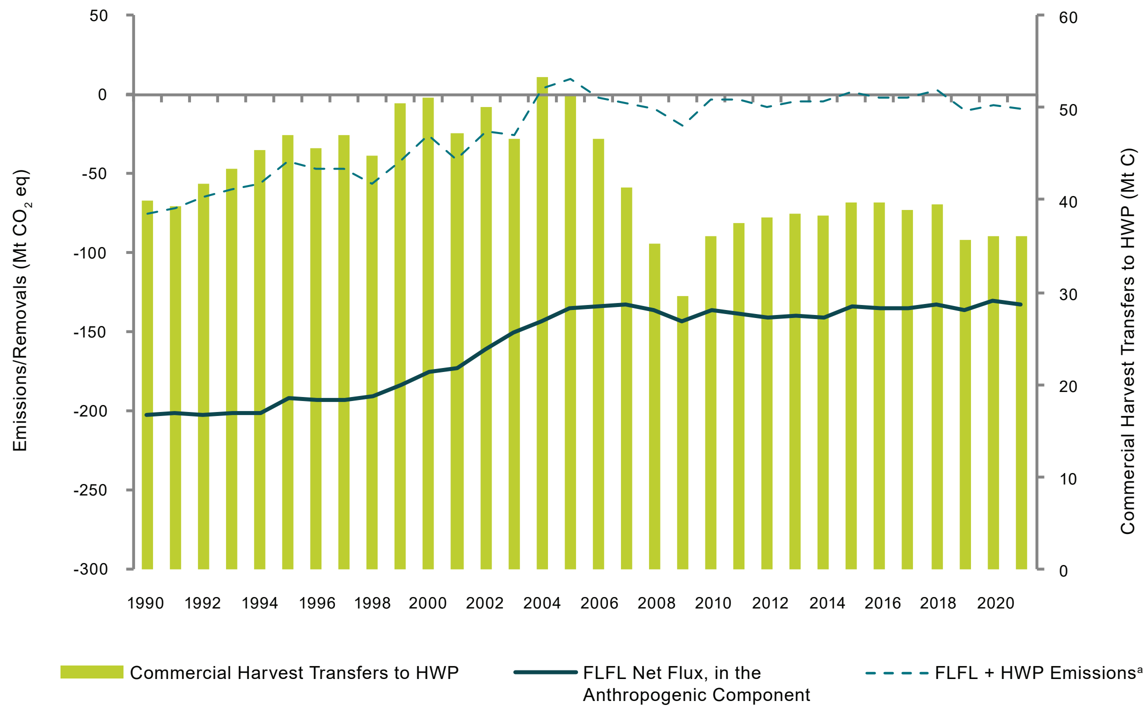
Estimated net removals reported in the Forest Land category from the management of forests include net fluxes from commercially mature forest stands that are either of harvest origin or have recovered from natural disturbances. The impact of non-anthropogenic disturbances (i.e. natural disturbances such 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 200 Mt in 1990 to 130 Mt in 2007 and have remained relatively constant since then. The decrease in removals that occurred between 2000 and 2007 (Figure 6–2) is mainly due to trends in the Montane Cordillera and Boreal Plains reporting zones. In the Montane Cordillera zone, insect infestations and salvage harvesting of infested stands resulted in a shift in the average age of the forests of this region to younger age classes and an overall decrease in the rate of C accumulation in biomass[8] in the reporting zone. 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, 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 will likely continue over the next few decades.

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.

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

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 230 Mt in 1990 and 65 Mt in 2005 and net emissions of 180 Mt in 2021. Variations in net fluxes largely depend on the occurrence of natural disturbances in a given year. Figure 6–2 provides an overview of emissions and removals reported in the forest sector, showing the short- and long-term impacts of human management and harvesting on forest carbon storage and on the emissions from HWP extracted from Canadian forests, which are reported in the Harvested Wood Products category.

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 the issue of reporting emissions from natural disturbances in some countries and has 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

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.

Table 6–5 **Area of, and Greenhouse Gas Fluxes and Carbon Transfers from, Forest Land Remaining Forest Land, Selected Years**

Subcategories	GHG	1990	2005	2016	2017	2018	2019	2020	2021
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		170 000	170 000	170 000	170 000	170 000	170 000	170 000	170 000
Areas with natural disturbance impacts		56 000	56 000	53 000	54 000	54 000	54 000	54 000	54 000
Net flux – reported and not reported (kt CO_2 eq)[a, b]		**-230 000**	**-65 000**	**-15 000**	**110 000**	**130 000**	**35 000**	**-110 000**	**180 000**
Reported estimates[c]		**-200 000**	**-140 000**	**-140 000**	**-130 000**	**-130 000**	**-140 000**	**-130 000**	**-130 000**
Anthropogenic Component, Past Forest Management Activities		-64 000	-25 000	-46 000	-47 000	-47 000	-52 000	-50 000	-53 000
	CO_2	-65 000	-26 000	-47 000	-48 000	-48 000	-53 000	-50 000	-54 000
	CH_4	300	570	450	490	430	310	250	280
	N_2O	160	320	260	270	250	200	170	180
	CO[d]	270	530	410	420	390	280	220	250
Anthropogenic Component, Mature Stands of Natural Disturbance Origin	CO_2	-140 000	-110 000	-89 000	-88 000	-86 000	-84 000	-81 000	-79 000
Emissions/removals from lands impacted by natural disturbances		**-27 000**	**70 000**	**120 000**	**240 000**	**270 000**	**170 000**	**21 000**	**310 000**
Wildfires – direct immediate emissions[e]		30 000	63 000	100 000	220 000	230 000	150 000	14 000	270 000
	CO_2	26 000	55 000	91 000	190 000	200 000	130 000	12 000	230 000
	CH_4	2 600	5 600	9 200	19 000	20 000	13 000	1 200	24 000
	N_2O	1 300	2 800	4 600	9 500	10 000	6 400	620	12 000
Wildfires – indirect immediate CO_2 emissions[e]	CO	2 600	5 500	9 100	19 000	20 000	13 000	1 200	23 000
Post-wildfire CO_2 emissions and removals[e]	CO_2	-60 000	-41 000	-21 000	-15 000	-7 900	-7 000	-13 000	- 540
Insects – emissions and removals[f]	CO_2	310	42 000	27 000	23 000	21 000	20 000	18 000	17 000
Other natural disturbances – emissions and removals[g]	CO_2	NO	26	6.2	5.5	2.3	2.1	2.0	1.8
Carbon transferred to HWP (kt C)[h]		**44 000**	**54 000**	**43 000**	**43 000**	**43 000**	**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.

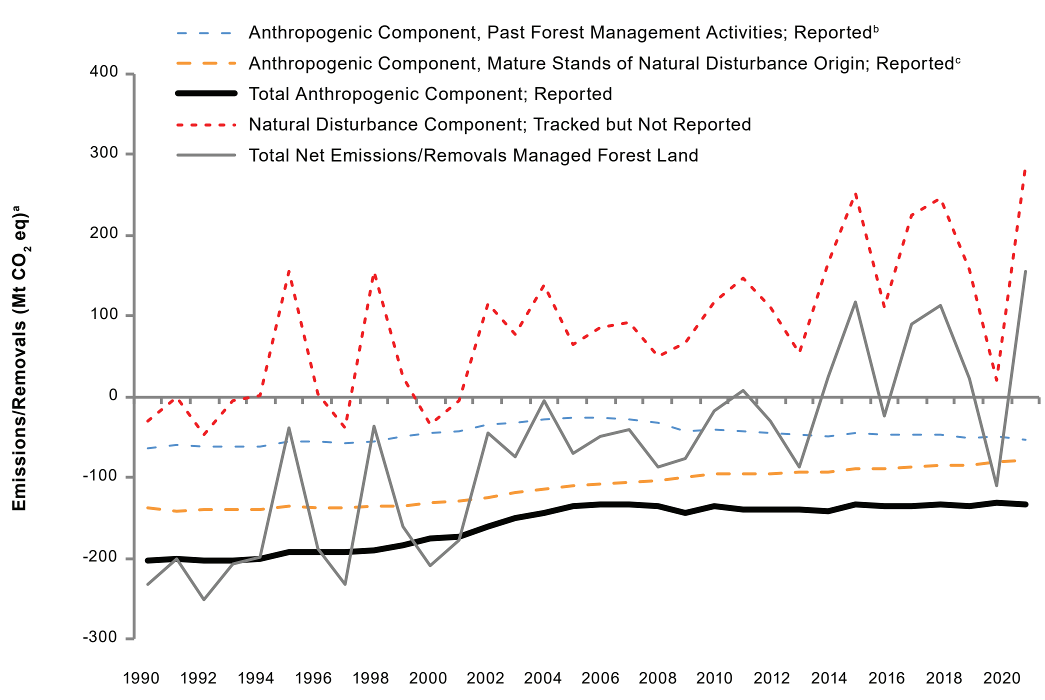
of approaches that countries (including Canada) have used to resolve this issue. Since the 2017 submission, Canada has implemented a Tier 3 approach to isolate the effects of anthropogenic activities on managed forests. This approach involves the separate monitoring and compilation of emissions and removals from forest stands impacted by anthropogenic and natural drivers (referred to as the anthropogenic and natural disturbance components respectively). The anthropogenic component includes emissions and removals associated with (i) stands that have been directly affected by past forest management activities (e.g. clear-cutting and partial harvesting, commercial and pre-commercial thinning, and salvage logging); (ii) mature stands affected by natural disturbances causing biomass mortality of 20% or less (i.e. insect defoliation) or having greater than 20% mortality and that have recovered to their pre-disturbance biomass; 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 large, uncontrollable 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 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).

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.

On the basis of calculations of direct and indirect soil N_2O emissions from net 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. Confidence intervals are obtained for each inventory year by randomly sampling 10 000 combinations of all the project runs for that year. Separate uncertainty estimates are produced for each GHG. In years when no substantial changes occur, such as in this submission, a Monte Carlo simulation is not performed (the most recent one was for the 2021 submission and covered the entire 1990–2019 time series). Instead, confidence intervals for each category in the current submission year are extrapolated.

Throughout the time series, the uncertainties associated with the annual estimates are expressed as a 95% confidence interval, bounded by the 2.5th and 97.5th percentiles of the Monte Carlo run outputs. The uncertainty range for the CO_2 estimates was 77 Mt in 1990, 81 Mt in 2005 and 75 Mt in 2021 (Table 6–6). On average, the uncertainty range was ±39 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.

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.

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	-203	-270	33	-193	-5.2
	2005	-136	-189	39	-108	-21
	2021	-133	-182	36	-107	-20
CH_4	1990	0.3	0.2	-37	0.4	31
	2005	0.5	0.4	-30	1.0	78
	2021	0.3	0.1	-49	0.6	158
N_2O	1990	0.1	0.1	-43	0.2	29
	2005	0.3	0.2	-34	0.5	80
	2021	0.1	0.1	-55	0.3	155

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 2021.

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

The more significant recalculations that occurred in this reporting category were due to (i) corrections to 2020 insect activity data; (ii) corrections to British Columbia estimates related to slash burning targets and firewood harvest spatial locations; and iii) revisions to forest harvest activity data based on provincial data supplied to the NFD and bioenergy updates.

Other less significant recalculations were made in the Forest Land category to reflect (i) the implementation of a regeneration delay for a fraction of naturally disturbed forest stands based on satellite observations; (ii) incorporation of pre-planting C stocks into the estimation of the initial C content for recent afforestation sites; (iii) addition of forest-cleared and flooded areas associated to a hydro-related large event in Quebec; (iv) refinement of temporal resolution of deforestation pre-disturbance forest type assumptions; and (v) minor retroactive updates to the burned area statistics in several ecozones.

The combined effect of these changes on reported estimates resulted in upward recalculations of net removals of 1.6 Mt (+0.8 %) in 1990, 1.2 Mt (+0.9 %) in 2005 and 0.8 Mt (+0.6%) in 2020 (see Figure 6–4).

Activity Data Updates

Industrial forestry activity data for the 2015–2020 period were updated with data from the NFD, while forestry activity targets for 2021 were assumed to be identical to those for 2020. Additional changes include correction to slashburning targets in British Columbia for the entire time-series and updates to prescribed burning targets in Ontario in 2016 and 2017.

Updates to insect activity data include a correction to the area disturbed in 2020 by spruce budworm (SBW) in Alberta and other minor updates in Quebec and the Northwest Territories with a combined impact of -1.5 Mt on Forest Land estimates in 2020.

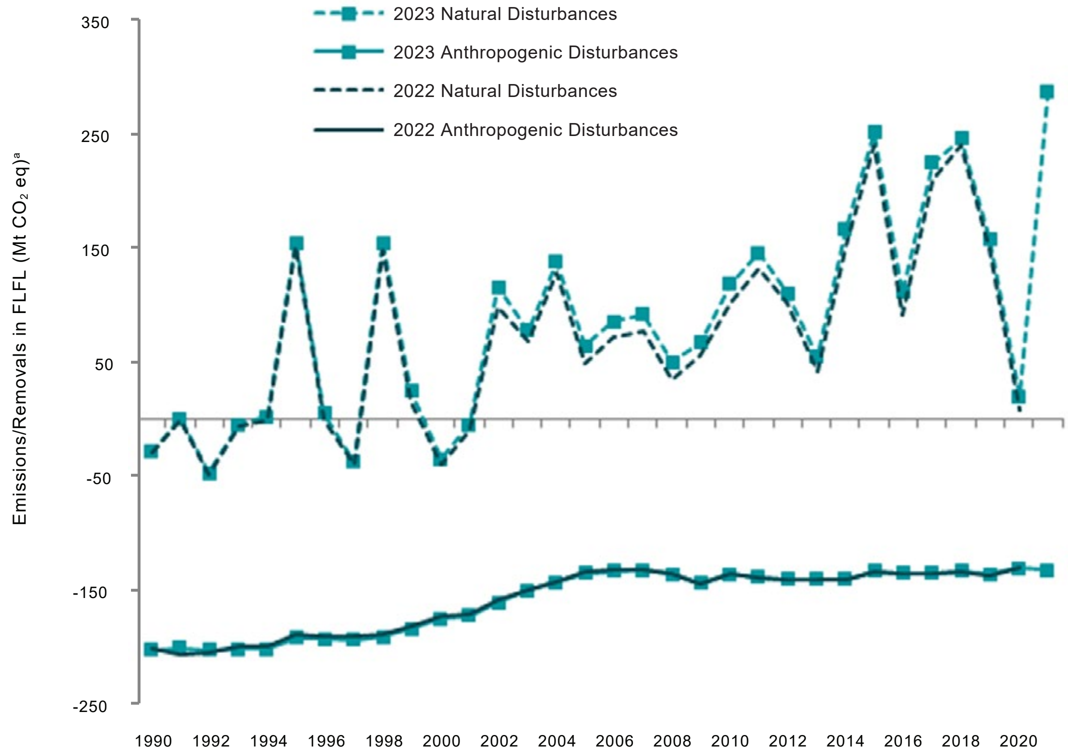
Residential bioenergy consumption data for 2019–2020 were revised based on the extrapolation applied since the latest 2019 data point from the Statistics Canada's Households and the Environment Survey. An improvement applied to the time-series of woody biomass activity data impacted the 1995–2016 period (see more details in sections 6.4.5 and 6.5.1.3). Activity data associated to industrial bioenergy consumption of spent pulp liquor and solid wood waste include retroactive changes in 2019 and the addition of new activity data for 2020 (see more details in sections 6.4.5).

Updates to deforestation activity data include the addition of forest-cleared and flooded areas for a hydro-related large event in Quebec, Boreal Shield East reporting zone, associated with the Romaine-4 project (see more details in section 6.9.5).

Continuous Improvement

The regrowth of forests on naturally disturbed sites has been assumed to start from age 0 on the pre-disturbance yield curve and maintain growth rates according to that yield curve until achieving complete regeneration or until undergoing further disturbance. For this submission, a first approximation of regional (RU-level) average regeneration delay values have been developed through remote sensing analysis (White et al., 2017; White et al., 2022) and applied to 25% of the area burned by

Figure 6–4 **Recalculations in Forest Land Remaining Forest Land**



Note:
a. Not including indirect CO_2.

wildfires in each year. These new national scale remote-sensing products provide an initial estimate of regeneration delays but it is anticipated that refinements to the default post-fire regeneration assumptions will be made in future submissions as methods and data improve (see more details in Annex 3.5.2.2 and in Hafer et al., 2022).

The deforestation estimates underwent revisions as a result of a review of assumptions related to the pre-deforestation forest type. Previously, areas deforested annually were placed in one of several forest ‘pre-type’ categories (young, old hardwood, old mixedwood and old softwood). These regionally specific forest pre-type proportions modelled by the CBM-CFS3 were considered static. The improvement implemented in this submission makes use of additional temporal detail by allowing the pre-type proportions to vary with time based on actual annual observations.

For the year 2021, initial estimates associated with very recent reforestation activities in Canada were prepared using a simplifying assumption that all reforestation events happen on previously burned forest experiencing regeneration delay (see more details in Annex 3.5.2.3 and Hafer et al., 2022).

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 2024 inventory submission, details on the most significant change and the expected impacts are provided below.

Additional planned improvements for Forest Land are outlined in Chapter 8, section 8.3.1 and Table 8–5.

Overview of Anticipated Improvement for the Next 2024 Submission

Significant changes are being applied to the data that underlie NFCMARS.[10] Specifically, a review of the harvested landbase, initiated in 2018, is near completion. As a result, new and updated data on historical harvest areas in Canada (1890 to 1989) are being finalized for implementation in the next 2024 submission after completion and publication of a peer-reviewed manuscript.

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 category. These revisions to historical harvest areas were compiled for five provinces (British Columbia, Alberta, Saskatchewan, Ontario and Quebec). For the remaining provinces and territories, current assumptions are either (i) considered appropriate (New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador), (ii) had very little harvest prior to 1990 (Yukon and Northwest Territories) or (iii) no alternate data have been found (Manitoba).

The implementation of this change is expected to reduce the area of the managed forest that is included in the anthropogenic component. The reduction in area in the anthropogenic component of the managed forest would be matched by a corresponding increase in the area of the natural disturbance component representative of land that has undergone more recent natural disturbances and has been left to naturally regenerate. These reductions in the area of the historically harvested land are expected to translate into a corresponding shift of the removals that occur in the anthropogenic component of the managed forest to the natural disturbance component.

The Forest Land and Harvested Wood Products categories combined include both GHG fluxes between the atmosphere and Canada's managed forests, and emissions from HWP originating from domestic harvest. The proposed update will result in important reductions in the reported carbon removals that occur in Canada's managed forest and as a result when the gross emissions from HWP are added, the reported anthropogenic net balance for the whole of the Forest Sector is anticipated to become a net source in all years of the time-series.

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 26 kha in 2021. Given that activity data after 2008 are only for Ontario and for recent afforestation activities 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 76% of all conversion 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 only 13% in the Prairie provinces (Boreal Shield West, Boreal Plains and Sub-humid Prairies reporting zones) and the remaining 11% 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 0.2 Mt in 2021. Net C accumulation largely occurred in living biomass (34 Gg C in 2021, 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 2007–2016 obtained through a data sharing agreement with Forests Ontario providing access to its database of tree planting activities.

10 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

For the year 2021, initial estimates associated with very recent afforestation activities in Canada were prepared based on a methodology developed for incorporating pre-planting C stocks into the estimation of the initial 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.

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 802 hectares afforested by Forests Ontario in 2017 that have now passed their 5-year survival survey assessment. This change caused a downward recalculation in net removals of 0.2 kt (-0.1%) in 2020.

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 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 from it 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 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 consumed either in Canada or abroad. Products disposed of at the end of their useful life are assumed to be immediately oxidized.

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 2021, the Harvested Wood Products category was responsible for total emissions of 130 Mt, 3.2 Mt below the 1990 value and 20 Mt below the 2005 value (Table 6–7).

Harvested Wood Products emissions 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	2016	2017	2018	2019	2020	2021
Carbon stocks (kt C)[a]									
Inputs		**46 000**	**56 000**	**45 000**	**44 000**	**45 000**	**40 000**	**40 000**	**40 000**
Conventional harvest[b]	Forest Land	40 000	51 000	40 000	39 000	40 000	36 000	36 000	36 000
Forest conversion[b]	Cropland	1 200	430	500	540	520	510	530	570
	Wetlands	1.8	5.8	35	18	0.3	3.2	3.4	3.6
	Settlements	620	680	750	750	660	670	680	660
Residential firewood[c]	Forest Land	4 200	3 100	3 700	3 700	3 500	3 200	2 900	2 800
	Cropland	230	130	160	210	190	150	140	140
	Settlements	82	83	84	84	84	84	84	84
Exports		**19 000**	**31 000**	**23 000**	**22 000**	**21 000**	**20 000**	**20 000**	**20 000**
Net stocks[d]		**330 000**	**520 000**	**590 000**	**600 000**	**600 000**	**610 000**	**610 000**	**620 000**
Emissions (kt CO_2)[a]		**130 000**	**150 000**	**140 000**	**140 000**	**140 000**	**130 000**	**130 000**	**130 000**
Domestic harvest		**88 000**	**75 000**	**72 000**	**72 000**	**76 000**	**68 000**	**66 000**	**66 000**
Solid wood – sawnwood		5 500	7 800	9 500	9 600	9 800	9 900	10 000	10 000
Solid wood – wood panels		2 700	3 300	4 100	4 100	4 200	4 300	4 400	4 500
Other solid wood products		920	1 900	2 200	2 200	2 200	2 200	2 200	2 200
Pulp and paper market		8 300	740	3 200	3 400	3 300	3 000	2 800	2 700
Residential firewood and industrial fuelwood		52 000	59 000	50 000	50 000	54 000	47 000	45 000	45 000
Mill residue[e]		19 000	1 700	2 800	2 600	1 800	1 200	1 700	1 700
Worldwide from Canadian harvest		**42 000**	**73 000**	**65 000**	**64 000**	**64 000**	**63 000**	**62 000**	**62 000**
Solid wood – sawnwood		9 900	16 000	19 000	19 000	19 000	19 000	20 000	20 000
Solid wood – wood panels		780	4 300	5 700	5 800	6 000	6 100	6 200	6 300
Other solid wood products		52	51	60	62	64	65	66	67
Pulp and paper market		31 000	51 000	38 000	37 000	36 000	35 000	34 000	34 000
Mill residue[e]		460	2 100	2 600	2 400	2 100	1 900	1 900	1 900

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 resulting 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.

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.

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 2.7% of all inputs in any year) transferred from the CBM-CFS3 model (see section 6.3.1.2); and (ii) an additional annual quantity of C from woody biomass harvested from cropland and from urban trees on land in the Settlements category and used for residential bioenergy (Table 6–7). 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.

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:

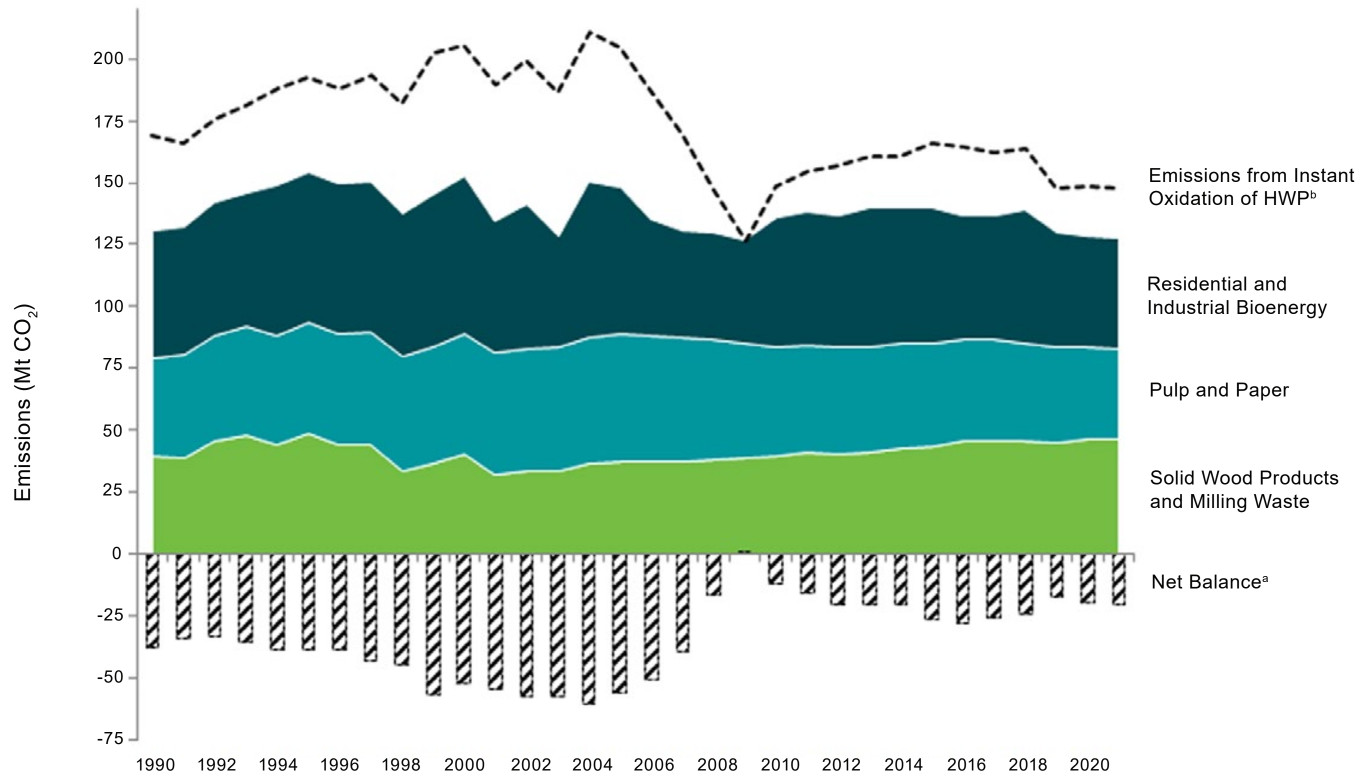
- **column B (Gains)**: corresponds to C inputs associated with C transferred from any wood-producing land category (e.g. Forest Land) to the HWP pools used domestically and exported; these C inputs would represent C losses in CRF tables 4.A–4.F if using a reporting approach other than the Simple Decay 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

For the 1990–2007 period, emissions resulting from the inclusion of the HWP pool (stacked areas in Figure 6–5) are considerably lower than those that would result from using the instant oxidation approach (dotted line in Figure 6–5), which was the case for submissions prior to 2015, with the differences (bars in Figure 6–5) ranging between -34 Mt in 1992 and -61 Mt in 2004 (highest harvest year). These large differences occur because the C in wood removed from forests in the reporting year was much higher than the C transferred to the HWP pool in past years with lower harvest rates, and occurred in the form of long-lived wood products that were disposed of in the reporting year. After 2007, although harvest rates were lower—notably in 2009—HWP emissions remained higher than the estimates obtained using the instant oxidation approach due to the higher harvest rates in previous years that continued to contribute to estimated emissions in the reporting year.

12 Contemporary harvesting refers to harvest activities that occurred since 1990.

13 National Forestry Database, available online at http://nfdp.ccfm.org/en/data/harvest.php.

Figure 6–5 **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 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.

6.4.3. Uncertainties and Time-Series Consistency

In the assessment of the uncertainty associated with the Harvested Wood Products category, model parameters were varied for Monte Carlo simulations while carrying out two additional runs using the minimum and maximum HWP inputs 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. In years with no substantial changes such as this year, Monte Carlo simulations are 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.

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	Conventional harvest – since 1990	59	42	-28	70	19
	Forest conversion – since 1990	2.6	1.7	-34	3.2	21
	Residential firewood collection	16	16	-3.4	17	3.6
	Historical harvest – before 1990	53	41	-24	67	25
2005	Conventional harvest – since 1990	118	101	-14	129	10
	Forest conversion – since 1990	2.8	2.0	-28	3.3	17
	Residential firewood collection	12	11	-3.8	12	4.2
	Historical harvest – before 1990	15	12	-24	20	33
2021	Conventional harvest – since 1990	103	95	-7.2	108	5.0
	Forest conversion – since 1990	3.3	2.4	-25	3.6	10
	Residential firewood collection	11	10	-5.1	11	5.0
	Historical harvest – before 1990	11	8.1	-23	12	14

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.

6.4.5. Recalculations

Recalculations occurred in the Harvested Wood Products category, due to (i) updated industrial forestry activity data from the NFD;[14] (ii) updated HWP model parameters based on the latest Food and Agriculture Organization (FAO) statistics on Canadian forest products;[15] (iii) updated residential and industrial bioenergy consumption data for 2019–2021; (iv) updated waste incineration activity data; (v) improved time series of activity data associated to woody biomass originating from agricultural land and used for residential bioenergy (see section 6.5.1.3); and (v) 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 recalculations of 0.5 Mt (+0.4%) in 2020.

6.4.6. Planned Improvements

Improvements are planned to enhance the uncertainty analysis of the estimates in the Harvested Wood Products category by considering the uncertainty inherent in the C inputs.

In addition, research is underway to include country-specific half-lives for a significant portion of Canada's HWP production, which reflect much longer HWP residence times in housing than the IPCC default values, to develop more accurate residential biomass burning emission factors, and to improve our knowledge of the industrial bioenergy chain (origin of the wood) and improve the characterization of the wood 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.

14 National Forestry Database: http://nfdp.ccfm.org/en/data/harvest.php

15 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.

6.5. Cropland (CRF Category 4.B)

Cropland covers approximately 46 Mha of Canada's territory. In 2021, the net GHG balance in the Cropland category amounted to net removals of 18 Mt (Table 6–1). For UNFCCC reporting purposes, the Cropland category is divided into Cropland Remaining Cropland (net removals of 21 Mt in 2021) and Land (i.e. either forest or grassland) Converted to Cropland (net emissions of 3.4 Mt and 0.01 Mt, respectively, in 2021). 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 from and removals by mineral soils, which are affected 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 also used to estimate soil C storage which is impacted by changes in crop productivity and subsequent crop residue C inputs to soils based on yield estimates. 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 removals of CO_2 associated with increases in C inputs to soils from reductions in the area of summerfallow are based exclusively on changes in yield to avoid double counting, since regional estimates of yield 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 8.5 Mt (Table 6–9). CO_2 removals by soil increased to 26 Mt in 2005 and then decreased to 21 Mt in 2021. Since 1990, on average, the yields of major field crops increased by 23% for barley, 82% for canola, 41% for corn, 72% for spring rye and 36% for spring wheat. This increase in crop yields, which was reflected in C inputs to soils from crop residues, resulted in net removals of CO_2 by soils of 8.4 Mt in 1990, 16 Mt in 2005, and 19 Mt in 2021. Interannual variability was high throughout the time series, reflecting weather-related impacts to crop production (Figure 6–6).

Conservation tillage increased significantly, from 11 Mha in 1990 to 28 Mha in 2021, and this increasing trend results in CO_2 removals by soil of 1.3 Mt in 1990, 5.6 Mt in 2005 and 4.9 Mt in 2021 (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 3.7 Mt in 1990 and net removals of 4.0 Mt in 2005.

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 7.6 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.

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	2016	2017	2018	2019	2020	2021
Total Cropland Remaining Cropland		**-8 500**	**-26 000**	**-21 000**	**-26 000**	**-25 000**	**-21 000**	**-20 000**	**-21 000**
Cultivation of histosols		**300**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Perennial woody crops		**-1000**	**38**	**-5.8**	**- 260**	**- 160**	**-29**	**-10**	**10**
Total mineral soils		**-7 800**	**-26 000**	**-21 000**	**-26 000**	**-26 000**	**-21 000**	**-20 000**	**-21 000**
Crop mixture changes	Increase in perennial crops	-3 600	-13 000	-11 000	-11 000	-11 000	-11 000	-10 000	-10 000
	Increase in annual crops	7 300	8 600	14 000	13 000	13 000	13 000	13 000	13 000
Tillage changes	Conventional to reduced	- 870	-1 000	-720	-700	-670	-650	-620	-600
	Conventional to no-till	-420	-3 700	-3 700	-3 600	-3 600	-3 500	-3 500	-3 500
	Other[b]	-0.4	-850	- 990	- 960	- 940	-910	-890	-860
Crop residue C input		-8 400	-16 000	-17 000	-23 000	-23 000	-18 000	-17 000	-19 000
Manure application		-2 100	-2 500	-2 200	-2 100	-2 100	-2 100	-2 100	-2 100
Land conversion—residual emissions[c]		200	1 700	1 800	1 700	1 700	1 700	1 700	1 700

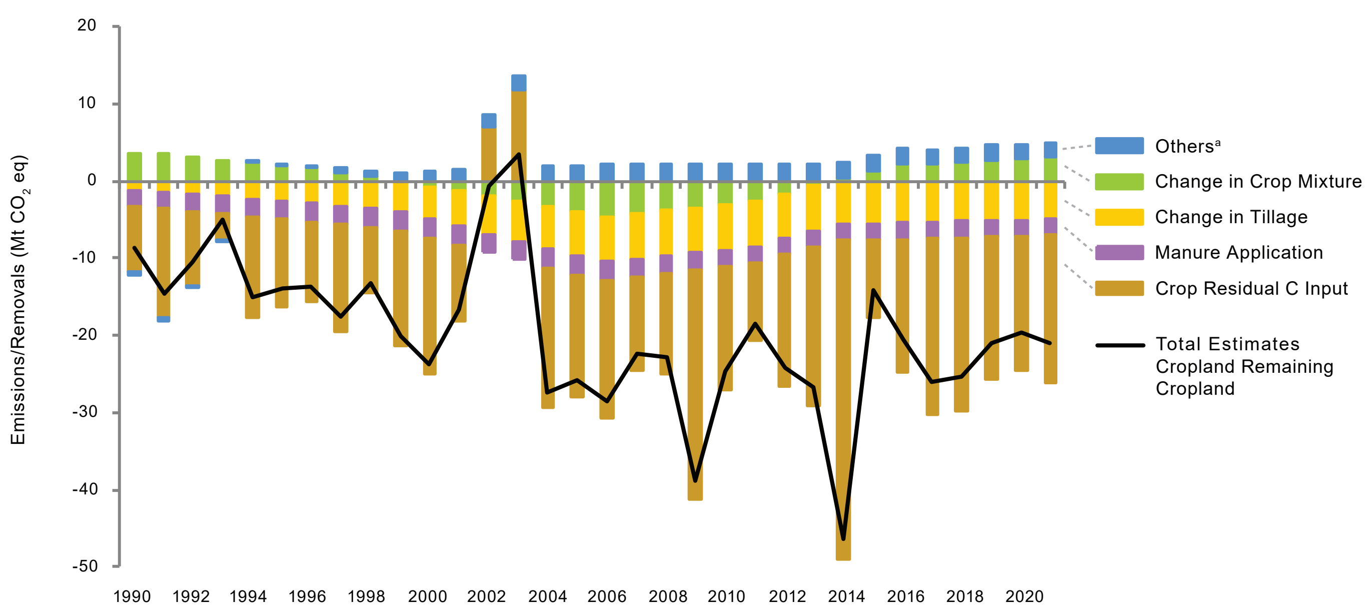
Notes:

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.

Figure 6–6 **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.

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). As a result, the area-based factor used for summerfallow underestimated the change in SOC associated with the change in carbon input to soils. 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, significant recalculations occurred due to the alignment of activity data to the 2021 Census of Agriculture. This change caused significant recalculations for the years 2018–2020 and a downward adjustment of 0.9 Mha in the total area of cultivated mineral soils.

Other less significant recalculations were due to other activity data updates to address gaps in the reporting of fababean activity over time that caused minor recalculations in all reported years, and to address gaps in the reporting of buckwheat area for 2011.

The combined effect of these changes resulted in an upward adjustment in emissions of 0.4 Mt in 1990, very minor impact in 2005 and a significant upward recalculation of 6.7 Mt in net CO_2 removals in 2020.

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 2021. 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 2021, 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 byvineyards, 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 the implementation of an improved time series of activity data associated to woody biomass originating from trees and shrubs in agricultural land by applying an interpolation method to the transition between the two 1990–2000 and 2000–2010 activity data sampling periods of digital air photos. Additional recalculations occurred due to the alignment of activity data to the 2021 Census of Agriculture. The combined effect of these changes on the estimates reported in the Cropland Remaining Cropland category resulted in a downward recalculation of net emissions in 2005 by 0.1 Mt (-66%) in 2005 and a very small downward recalculation of net removals in 2020 by 0.03 Mt.

The improved time series had a small indirect impact on the annual emissions associated with woody biomass transferred to the HWP pool to be used for residential bioenergy that are reported in the Harvested Wood Products category that resulted in an upward adjustment of 0.01 Mt in 2020.

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 9.5 Mt in 1990 to 3.4 Mt in 2021. 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 380 kha during the 20 years prior to 2021. 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 2021, immediate emissions from the conversion of forest to cropland totalled 1.4 Mt, while residual emissions from events that occurred in the last 20 years totalled 2.0 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.

6

Table 6–10 **Uncertainty Associated with the Components of CO_2 and Non-CO_2 Emissions from Forest Land Converted to Cropland for the 2021 Inventory Year**

Emission Components	Emissions (kt CO_2 eq)	Uncertainty (kt CO_2 eq)
Immediate CO_2 emissions	1 238	±395
Residual CO_2 emissions from the DOM pool[a]	1 734	±387
Residual CO_2 emissions from the soil pool	259	±160
CH_4 emissions	127	±41
N_2O emissions	70	±18

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 alignment of activity data to the 2021 Census of Agriculture. Overall, this update resulted in upward adjustments to the emission estimates of 0.02 Mt in 1990 and 0.1 Mt in 2005, and a downward adjustment of 0.01 Mt in 2020.

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 2021 amounted to 12 kt, down from 300 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 the alignment of activity data to the 2021 Census of Agriculture. To a lesser extent there were recalculations due to a recompilation of pre-1971 census data.

These modifications resulted in an upward recalculation in emissions by 0.2 Mt in 1990 and almost no impact in 2005, and a downward recalculation of 0.03 Mt in 2020.

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 37 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 19 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 2.1 Mt in 2021 (Figure 6–7). 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.

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.

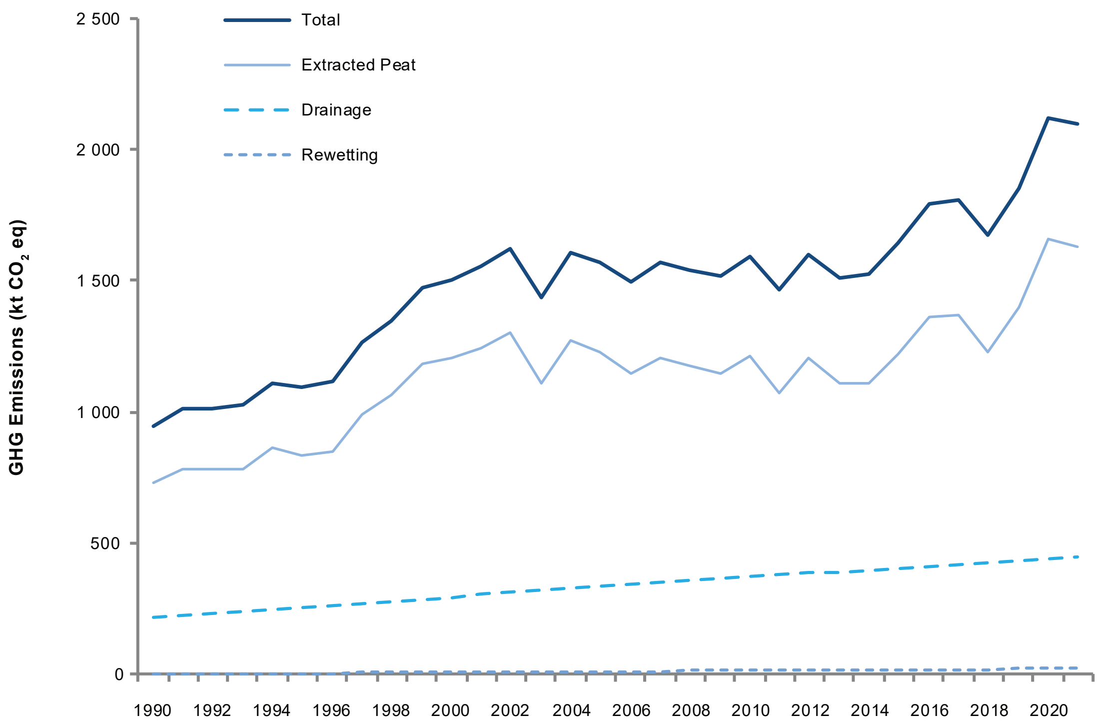
6.7.1.5. Recalculations

Recalculations in this category were due to updated peat production statistics in 2020, resulting in an upward recalculation of emissions of 0.3 Mt for that year.

6.7.1.6. Planned Improvements

Planned improvements include updates to activity data under a new data agreement with Statistics Canada and the addition of a new mapping sampling point for 2020 for high-resolution satellite imagery to update the area of peat extraction sites undergoing exploitation, restoration and abandonment.

Figure 6–7 **Emissions from Peatlands Converted and Managed for Peat Extraction**



6

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 2021, 45% 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 1.2 Mt in 2021.

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 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), whichhas not been verified.

6.7.2.5. Recalculations

Recalculations occurred due to the addition of the Romaine-4 project in Quebec and the updates applied to deforestation pre-type proportion assumptions (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 0.02 Mt in 2005 and of 0.3 Mt in 2020.

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 2021, the 0.59 Mha of land in the Land Converted to Settlements subcategory accounted for emissions of 6.5 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 2021 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. (2021). 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 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 2021, emissions in the Land Converted to Settlements subcategory totalled 6.5 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 1990–2021 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.[16] Over 200 points were used to verify land cover / land-use change for each time period, using visual interpretation. The points were defined using stratified random sampling, with 50% of points in areas with a change from cropland to settlements and 50% in areas with no changes, separated by a minimum distance of 1 km, to avoid statistical bias.

6.8.2.1.5. Recalculations

No recalculations occurred 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 2021, 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).

16 Landsat Time Enabled Imagery – Canada: https://hub.arcgis.com/maps/9a239fbe2952436a80d3cff95cab34bc/about.

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 data 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 2021, 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 1.7-Mt decrease in emissions from forest conversion to wetlands (reservoirs). There was also an increase of 0.4 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 2021, up from 2.7 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 2021) 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 2021, 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 30%, 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—

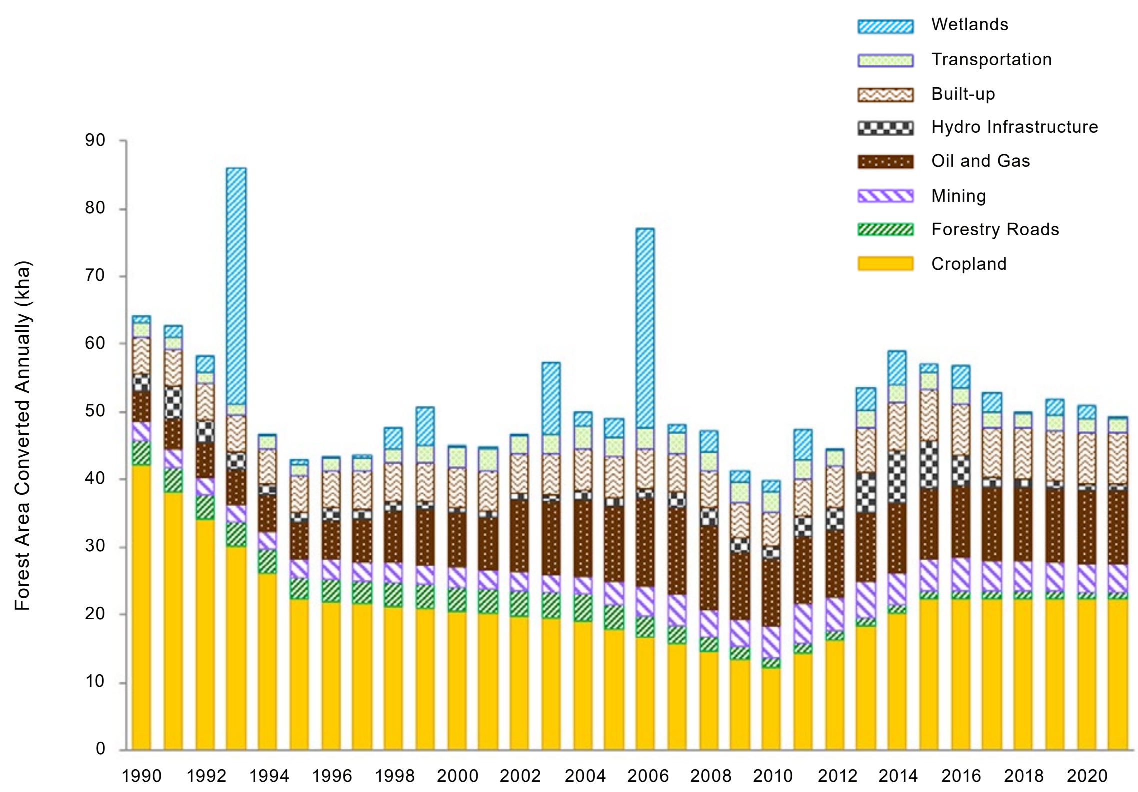
reaching the levels observed in mid-1990s—due to a recent agricultural expansion, mostly in the Boreal Plains, Sub-humid Prairies and Mixedwood Plains zones (Figure 6–8). While this trend has been maintained constant since 2016, completion of the next mapping period will identify if this trend is continuing.

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 2021 (Figure 6–8). Since 2000, the conversion of land to settlements has become the main driver of forest conversion, accounting on average for 57% of the total area converted annually, except for the years 2003 and 2006, when large areas of forest were cleared for major hydroelectric development projects (Figure 6–8). 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 28% of the total forest area lost nationally in 2021.

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 6–8). 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 6–8 **Annual Area of Forest Converted by End Land Use**



6.9.2. Methodological Issues

The conversion of forest to other land categories has occurred at high rates in the past, and is still a prevalent practice in Canada. It is driven by a variety of circumstances across the country, including policy and regulatory frameworks, market forces and resource endowment. The economic activities causing forest losses are diverse and result in heterogeneous spatial and temporal patterns of forest conversion, which have been systematically documented in recent decades. The challenge has been to develop an approach that incorporates a variety of information sources to capture the various forest conversion patterns across the Canadian landscape, while maintaining a consistent approach 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. 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 across the 1975–1990, 1990–2000, 2000–2008, 2008–2013 and 2013–2018 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.

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

Changes were made to the deforestation pre-type proportion assumptions, as a result of the update to regional temporal details, to allow the pre-type proportions to vary with time. Other changes were applied due to the addition of forest-cleared and flooded area for the major hydro-related event Romaine-4, in Quebec. These changes resulted in very small recalculations to forest conversion estimates in 1990 and 2005, and an upward adjustment of 0.1 Mt (+0.5%) in 2020, 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 (-1.9%) in 2005, and 0.2 Mt (-5.7%) in 2020.

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 medium term, improvements include the revision of the 1970 to 2010 deforestation activity data, which will lead to improved estimates for earlier time periods.

More details are provided in Chapter 8, section 8.3.1 and Table 8–5.

WASTE (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 2021, greenhouse gas (GHG) emissions from the Waste sector accounted for 21.1 Mt of total national emissions, compared with 18.9 Mt for 1990—an increase of 2.1 Mt or 11% (Table 7–1). The emissions from this sector represented 3.22% and 3.14% of total Canadian GHG emissions in 1990 and 2021, respectively.

The chief contributor to the Waste sector emissions was Solid Waste Disposal (Landfills) which, in 2021, accounted for 17.2 Mt CO_2 eq or 81% 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.

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 7–1 **Waste Sector GHG Emissions Summary, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)						
	1990	2005	2017	2018	2019	2020	2021
Waste	**18.9**	**21.7**	**21.3**	**21.3**	**21.1**	**21.0**	**21.1**
Solid Waste Disposal (Landfills)	16.1	18.2	17.3	17.3	17.2	17.1	17.2
Industrial Wood Waste Landfills	0.9	1.0	0.8	0.7	0.7	0.7	0.7
Biological Treatment of Solid Waste	0.1	0.2	0.3	0.4	0.4	0.4	0.4
Incineration and Open Burning of Waste	0.3	0.3	0.2	0.2	0.2	0.2	0.2
Wastewater Treatment and Discharge	1.6	1.9	2.7	2.8	2.7	2.7	2.6

Note: Totals may not add up due to rounding.

Table 7–2 **Summary of Recalculations in the Waste Sector for Selected Years (Mt CO_2 eq)**

Sector	1990	2000	2005	2016	2017	2018	2019	2020
Solid Waste Disposal (Landfills)								
Previous (2022) inventory submission	19.59	22.46	22.97	20.86	21.39	21.68	21.91	22.14
Current (2023) inventory submission	16.14	17.92	18.21	17.02	17.29	17.27	17.16	17.14
Net change in emissions	3.45	4.53	4.76	3.84	4.10	4.41	4.74	4.99
Industrial Wood Waste Landfills								
Previous (2022) inventory submission	2.87	3.38	3.26	2.43	2.36	2.30	2.24	2.18
Current (2023) inventory submission	0.89	1.00	0.97	0.78	0.76	0.75	0.73	0.71
Net change in emissions	1.98	2.38	2.29	1.65	1.60	1.55	1.51	1.46
Biological Treatment of Solid Waste								
Previous (2022) inventory submission	0.07	0.20	0.24	0.32	0.33	0.36	0.36	0.36
Current (2023) inventory submission	0.07	0.20	0.24	0.32	0.33	0.36	0.36	0.36
Net change in emissions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Incineration and Open Burning of Waste								
Previous (2022) inventory submission	0.27	0.37	0.35	0.20	0.19	0.18	0.18	0.16
Current (2023) inventory submission	0.26	0.33	0.35	0.20	0.19	0.18	0.18	0.16
Net change in emissions	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Wastewater Treatment and Discharge								
Previous (2022) inventory submission	1.61	1.88	1.90	2.44	2.45	2.47	2.47	2.51
Current (2023) inventory submission	1.57	1.87	1.91	2.79	2.70	2.77	2.68	2.67
Net change in emissions	0.04	0.01	-0.02	-0.35	-0.25	-0.29	-0.22	-0.17

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).

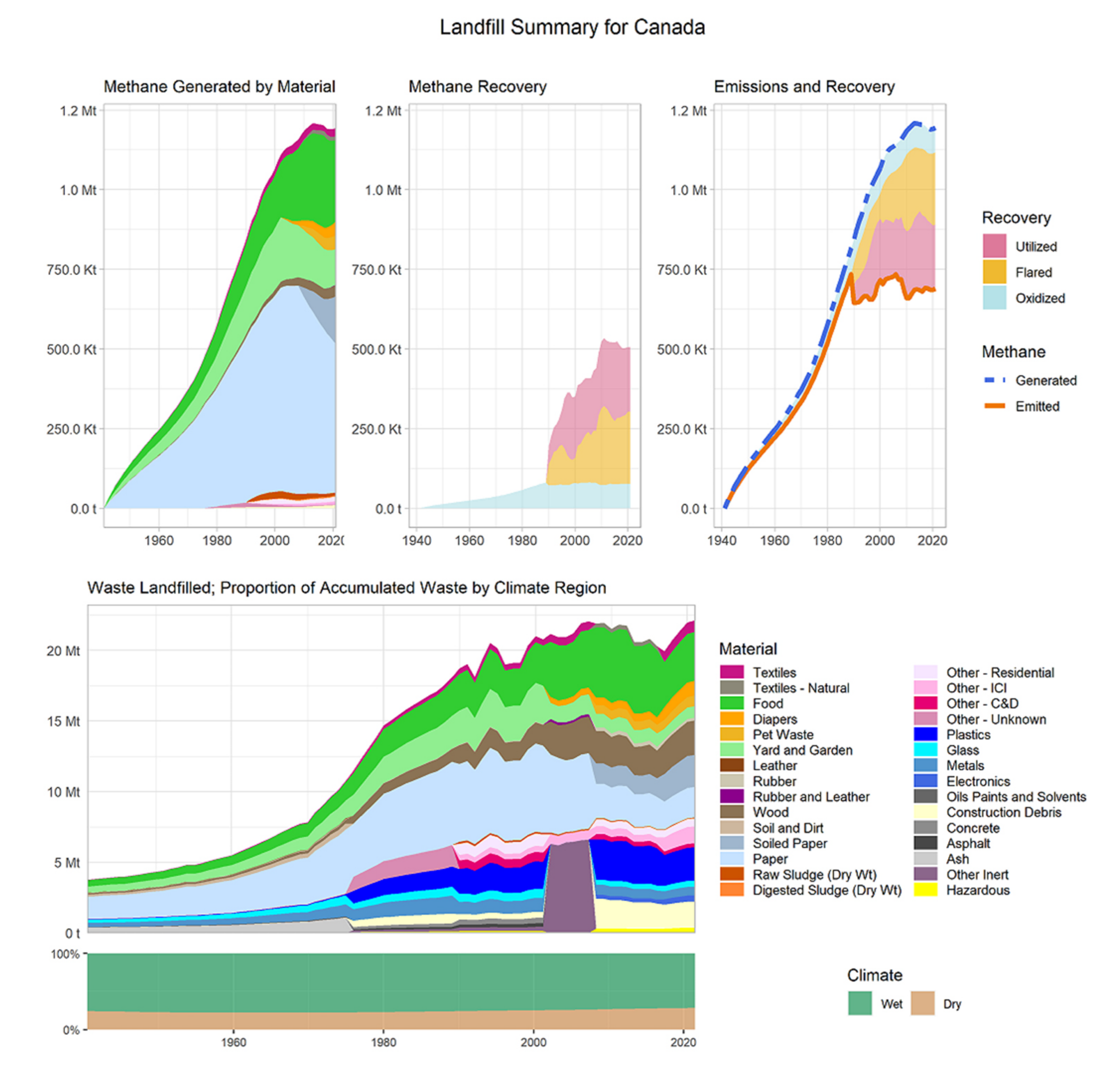
In Canada, most waste disposal occurs in managed municipal landfills. Few, if any, unmanaged waste disposal sites exist in Canada. The disposal of MSW is regulated by provinces and territories, but is typically managed by municipal or regional authorities. While regulations vary across the country, common 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 81% of the Waste sector emissions (Table 7–1).

The primary factors influencing emissions from MSW landfills over time include population growth and waste management practices (Figure 7–1). As the population increases, more waste is generated. CH_4 production is closely tied to the composition of the material that was landfilled. Waste diversion practices and landfill gas capture have been increasing over time and offset emissions associated with increased population.

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.

A number of 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 a number of 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

Material parameters – degradable organic carbon content (DOC), the fraction of DOC that does decay in landfill (DOCf) and decay rate (k) – were updated for several material categories, bringing more model parameters in-line with the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019). A notable change was for the “Other” waste category, which has been updated and parameterized by waste-source category. An investigation of materials typically lumped into “Other” in the source waste characterization studies was used to inform the updated DOC values. The typical materials in “Other” waste are fines, personal-hygiene, furniture and bulky items; in the case of waste from Construction and Demolition (C&D) “Other” tends to only include inert materials. The new DOC values are 0.1 for Residential waste, 0.05 for Industrial-Commercial-Institutional (ICI) waste and 0.0 for Construction and Demolition (C&D) waste.

The recalculation resulted in a decrease in emissions for all years, to varying degrees between regions and over time – the actual change depends on the material composition and history of waste deposition. Overall, emission estimates from municipal solid waste landfills have decreased by 3.5 Mt (18 %) in 1990, 4.7 Mt (21 %) in 2005 and 5.0 Mt (23 %) in 2020.

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 (CRF Category 5.A.2)

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 waste water 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% (0.9 Mt CO_2 eq) of the emissions from waste in 1990, 4.5% (1.0 Mt) in 2005, and 3.3% (0.7 Mt) in 2021.

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

Emissions from wood waste landfills are comprised of emissions from two industries: the solid wood industry and the pulp and paper industry. Recalculations were completed for the pulp and paper component of the industrial wood waste emissions calculation. Based on new data that provided an improved understanding of the amount and composition of pulp and paper residuals four categories were used to represent the activity data: wood waste, ash, water treatment residuals and other waste. Survey data were used to quantify the amount of waste disposed in each category from 2005 to the current year with linear interpolation applied to represent missing values. For the time period prior to 2005, a correlation between the amount of residual wood waste landfilled and pulp and paper industry-specific gross domestic product (GDP) data was used to back interpolate activity data to the year 1981 (the total amount of residual waste was assumed to be constant prior to 1981). The GDP data were also used for establishing ratios used to attribute emissions on a provincial basis. Activity data from the Province of Quebec pulp and paper industry were used to proportion the national activity data into the four waste types (wood waste, ash, water treatment residuals and other) from 1970 to 2004. Appropriate input parameters for the first order decay model (oxidation factor, methane correction factor, methane fraction, decay rate, and degradable organic carbon content) were selected to represent each of these residual types based on a literature review. In order to capture the additional decay time from historical waste disposal, the model start time was extended to 1941 (from 1970).

The recalculation of total estimated emissions from the industrial wood waste industry decreased by approximately 67-70%, with a peak CO_2 eq reduction from 3.4 Mt to 1.0 Mt.

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 up to 190% 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, a number of 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 the moisture content and composition of the waste and the ability to maintain aerobic decomposition conditions. 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 2021, the Biological Treatment of Solid Waste category contributed 358 kt of CO_2 eq or 1.7% of total emissions to the Waste sector and 0.05% to Canada's total. Emissions were 285 kt (388%) above the 1990 levels of 73 kt.

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 is available for both anaerobic digestion and composting facilities in Canada. This data has been collected with industry associations, online literature searches and annual reports as well as other in-house 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 in-house literature review that compiled information from primary literature sources (ECCC, 2020a).

Under the Biological Treatment of Solid Waste category, anaerobic digestion emissions are only calculated for industrial or 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 an in-house 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. In order to fill the data gaps throughout the time series, the earliest available data point is carried back to 1990 for facilities that were known to be open 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/municipal sector that were in operation in 1990. Therefore, the earliest data point available for the facility is carried back to its opening year and is also carried forward until the next data point for the facility becomes available. 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.

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 33 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, 2022c), 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 three 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 are currently two major centralized clinical waste incinerators in Canada, one in Ontario and the other in Alberta. They accounted for nearly 80% of the GHG emissions from clinical waste incineration. The remaining 20% of GHG emissions are from a number of small hospital-based incinerators and incinerators operated by the Government of Canada.

The Incineration and Open Burning of Waste category contributed 152kt CO_2 eq (0.72%) of total emissions to the Waste sector or 0.02% of Canada's total emissions in 2021. Emissions from this category are 43% below the 1990 level of 265 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 ±34%, ±98%, and ±86%, 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

A survey was conducted this year resulting in some updates to the amounts of waste incinerated at each facility.

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. However, 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. 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. The treatment process results in emissions of CO_2, CH_4 and N_2O.

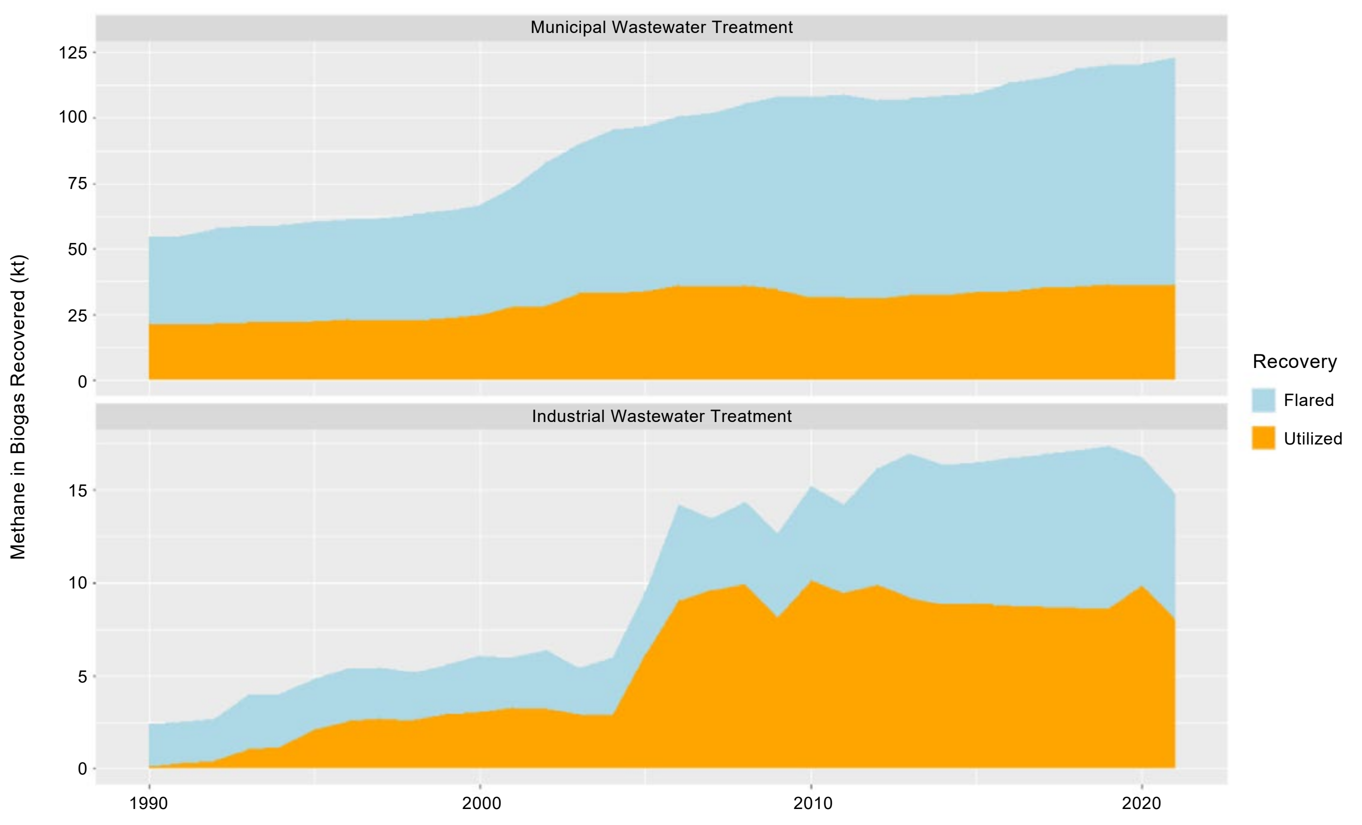
Centralized treatment systems can encompass a number of technologies, often classified by the degree of solids removal, the reduction in organic matter content (measured as BOD_5) and nutrient removal. The treatment level is classified as primary (solids removal only), secondary (solids removal, biological treatment and sometimes nutrient removal) and tertiary (advanced biological treatment and nutrient removal with additional disinfection).

The most common types of treatment systems in Canada are primary and secondary centralized treatment systems, 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. Wetland treatment systems, sequence batch reactors, anaerobic lagoons and some other treatment types are also in use in Canada. Many of the largest systems in Canada have tertiary level treatment.

Wastewater treatment produces varying amounts of CH_4, depending on the organic load (BOD_5)—determined by the population—and treatment type. CH_4 is produced from certain treatment processes, steps, or areas in 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 wastewater treatment plants with secondary or tertiary levels of treatment often include 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. The quantity of biogas recovered is shown in 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 2021 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 increased by 125% from 1990 (54.7 kt) to 2021 (123.1 kt), of which flaring increased from 33.2 kt to 86.6 kt and utilized increased from 21.5 kt to 36.5 kt. Methane recovery from wastewater treatment includes recovery of biogas generated from anaerobic digestion of sludge.

Figure 7–2 **Methane Recovered from Wastewater Treatment**



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. However, as detailed in section 7.1, CO_2 emissions originating from the decomposition of organic matter are not included with the national total estimates in the Waste sector.

The Wastewater Treatment and Discharge category accounted for 2613 kt CO_2 eq, or 12.4%, of the total emissions of the Waste sector and 0.39% of Canada's total in 2021. Wastewater Treatment and Discharge emissions in 2021 were 1046 kt CO_2 eq (66.8%) above the 1990 level of 1567 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. On the whole, 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. A methodological challenge is determining the number of people serviced by each wastewater treatment system type (e.g., septic, lagoon, untreated). The population served by septic systems 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 appropriate 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 for Municipal and Industrial Wastewater are largely based on survey results for the latest wastewater survey.

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 enhance the completeness, consistency and accuracy of the reported information. 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 major 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

8.1.1. Estimated Impacts on Emission Levels and Trends

In this year's GHG inventory, total emissions were revised downward for all years, as shown in Figure 8–1. Overall, recalculations of previously reported 1990–2015 estimates have resulted in a decrease in emissions of between 0.9 to 1.3 percent (6 to 9 Mt) and a slightly larger decrease of 1.4 to two percent (10 to 14 Mt) for the 2016–2020 period.

The trend between 1990 and 2020 is now reported as an 11.9% increase in total GHG emissions since 1990, compared with a 13.1% increase reported in last year's National Inventory Report (NIR). There is a net downward recalculation of 9 Mt for the base year 2005 (Table 8–1).

Figure 8–1 **Comparison of Emission Trends (2022 NIR vs 2023 NIR)**

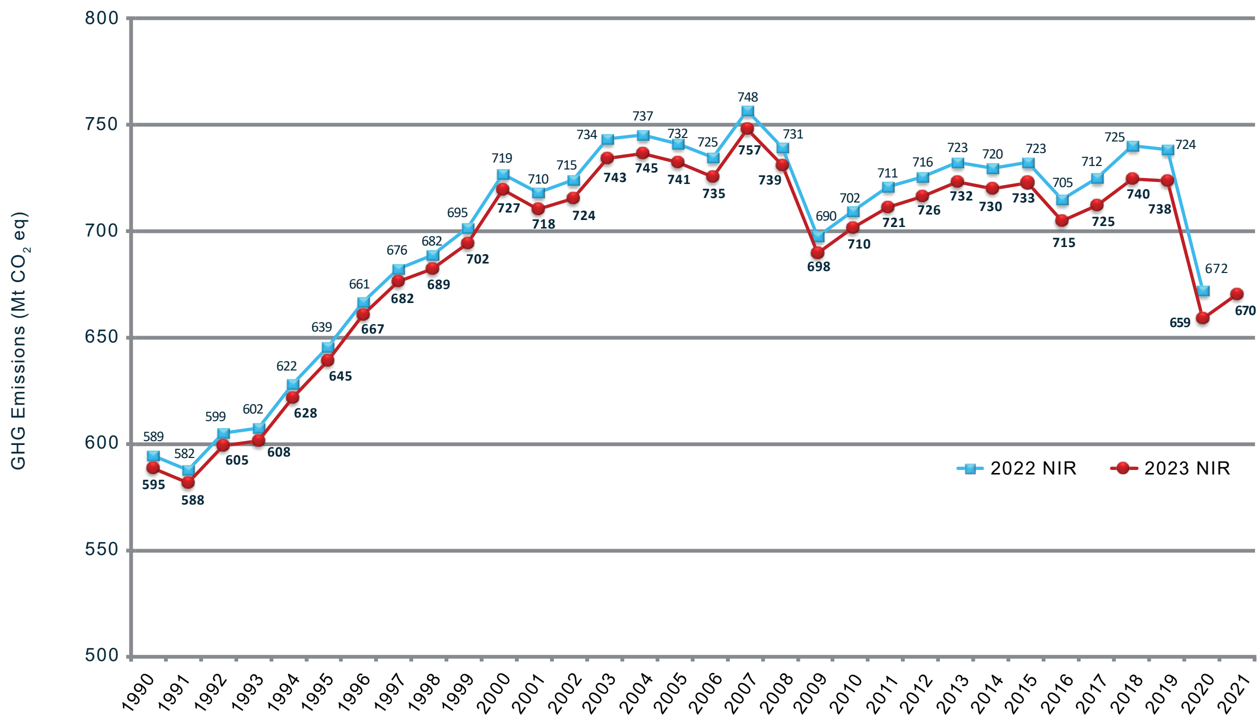


Table 8–1 **Summary of Recalculations in the 2023 National Inventory (Excluding Land Use, Land-Use Change and Forestry)**

National Total	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2016	2017	2018	2019	2020	(1990–2020)	(2005–2020)
Previous Submission (2022 NIR)	594 722	726 987	741 182	715 094	725 014	740 005	738 283	672 354	13.1%	-0.4%
Current Submission (2023 NIR)	588 603	719 464	732 219	704 926	712 232	724 615	723 679	658 788	11.9%	-1.2%
Change in Total Emissions	**-6 119**	**-7 524**	**-8 963**	**-10 168**	**-12 782**	**-15 390**	**-14 604**	**-13 566**	-	-
	-1.03%	**-1.03%**	**-1.21%**	**-1.42%**	**-1.76%**	**-2.08%**	**-1.98%**	**-2.02%**	-	-

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 Intergovernmental Panel on Climate Change (IPCC) sectors (Energy; Industrial Processes and Product Use [IPPU]; Agriculture; Land Use, Land-Use Change and Forestry [LULUCF]; and Waste) and Energy subsectors (Stationary Combustion, Transport and Fugitive Sources) and for all applicable years in the time series (1990–2020).

These revisions are largely due to improved estimation methodologies as well as updated energy data. As reflected in Table 8–2, for 2020, the revisions made resulted in the most significant changes in Transport (-11.2 Mt), Waste (-6.3 Mt) and Fugitive (+5.7 Mt). The sum of the revisions made for the IPPU and Agriculture sectors is almost zero. Revisions for selected years of the time series are presented in Table 8–3.

Table 8–2 **Changes in Canada's GHG Emissions from 672 Mt (for 2020, Previous Submission) to 670 Mt (for 2021, Current Submission)**

Sector	2020 to 2021 Change ($Mt\ CO_2\ eq$)	2020 Change Due to Recalculations ($Mt\ CO_2\ eq$)
Energy (Stationary Combustion)	2.6	-2.1
Energy (Transport)	9.0	-11.2
Energy (Fugitive)	-0.2	5.7
Industrial Processes and Product Use	1.6	0.0
Agriculture	-1.2	0.3
Waste	0.0	-6.3
Total Change	**11.6**	**-13.6**

Note: Totals may not add up due to rounding.

Energy (Stationary Combustion)

With respect to Stationary Combustion emissions, most of the recalculations for 2020 occurred in Petroleum Refining Industries (-1.2 Mt), Oil and Gas Extraction (-0.8 Mt), Public Electricity and Heat Production (-0.6 Mt), Commercial/Institutional (-0.3 Mt), and Manufacturing Industries (+0.9 Mt). Recalculations also occurred throughout the time series, with the major source being updates to the natural gas, anthracite coal, and petroleum coke EFs. See section 3.1 for further recalculation details.

Recalculations to Petroleum Refining Industries are a result of updated EFs and revisions to the RESD, specifically decreased volumes for natural gas, petroleum coke, and still gas.

Recalculations to the Oil and Gas Extraction category occurred from 1996–2020. Revisions to producer consumed natural gas EFs in Newfoundland and Labrador caused downward revisions from 1996–2020 ranging from -0.3 kt in 2016 to -0.2 Mt in 2018. Updates to natural gas volumes caused an upward revision in 2018 and downward revisions from 2019–2020.

Recalculations in the Public Electricity and Heat Production sector occurred between 1995 and 2020. Recalculations between 2010–2020 are a result of a method change that revised petroleum coke EFs, ranging from -0.04 Mt to -0.1 Mt. Revisions to natural gas volumes between 1995–2020 caused a change in emissions ranging from -0.5 Mt to +0.3 Mt.

Recalculations in the Commercial/Institutional category occurred for the entire time series, with significant revisions from 2016 to 2020. These significant revisions are caused by decreased volumes of natural gas, partially offset by increased volumes of propane. Prior to 2016, the recalculations are a result of revised quantities of landfill gas used for energy purposes.

Recalculations for Manufacturing Industries occurred for the entire time series due to updated anthracite EFs and revisions to the RESD.

Recalculations in the Residential category occurred between 1999 and 2020, with significant revisions in 2010 and from 2016 to 2018. These significant revisions are due to changes to natural gas volumes. Other recalculations are due to corrections in natural gas EFs.

Energy (Transport)

Recalculations for the Transport sector occurred for the entire time series. At the sectoral level, changes to emissions were most impacted by corrections to diesel fuel oil determined from the RESD for years 2010 and later, as well as corrections to motor gasoline determined from the RESD for years 2018 and later. These corrections were least impactful for 2010 and most impactful for 2020, where emissions for 2010 were revised by -1.1 Mt (-0.6%) and emissions for 2020 were revised by -11.2 Mt (-5.9%). Methodological updates applicable to Transport had minimal impact on emissions at the sectoral level.

At the subsector level, changes to emissions were most significant for Road Transportation and Off-Road Transportation due to the reallocation of RESD fuel. The Marine Emission Inventory Tool (MEIT) was revised for the 2015, 2016, 2017, and 2018 calendar years and new activity data for 2019 and 2020 were incorporated into the marine fuel consumption-based model. While the RESD determines amounts of fuel consumed for the Transport sector, the following methodological updates resulted in the reallocation of fuel consumed amongst the various types of vehicles and equipment associated with Road Transportation and Off-Road Transportation:

1. Updated method to allocate fuel reported in the RESD between on-road vehicles and off-road vehicles/equipment
2. Updates to on-road vehicle population estimates
3. Updates to on-road vehicle kilometre accumulation rates
4. Transition to an improved on-road vehicle emissions model
5. Updates to off-road vehicle/equipment populations

Other methodological updates implemented that also affected Road Transportation and Off-Road Transportation estimates, but to a lesser degree include:

1. Expanded CH_4 and N_2O emission factors for on-road vehicles
2. Estimation of CO_2, CH_4 and N_2O emissions from lubricating oil combusted in two-stroke engines distinctly from motor gasoline

The implementation of these methodological updates, in addition to the RESD correction, resulted in significant shifts of emissions amongst subcategories within Road Transportation and Off-Road Transportation throughout the entire time series. At the subsector level, significant decreases to Off-Road Transportation occurred, ranging from -0.7 Mt (-1.8%) to -12.4 Mt (-28%) between 1990 and 1999, offset by increases to Road Transportation ranging from +1.4 Mt (1.3%) to +13.8 Mt (16%) over the same timeframe. For years 2000 and later, significant increases to Off-Road Transportation occurred, ranging from +1.4 Mt (4.5%) to +14.8 Mt (43%), offset by decreases to Road Transportation ranging from -1.0 Mt (-0.8%) to -20.9 Mt (-14%) over the same timeframe. These changes to subsector totals are primarily due to the updated method to better allocate RESD fuel between on-road vehicles and off-road vehicles/equipment.

At the subcategory level for years 1990 to 1999, Heavy-Duty Diesel Vehicles, Light-Duty Gasoline Vehicles and Light-Duty Gasoline Trucks contribute to the majority of the increases observed within Road Transportation whereas Off-Road Other Transportation contributes to the majority of the decreases observed within Off-Road Transportation. In years 2000 and later, Heavy-Duty Diesel Vehicles and Heavy-Duty Gasoline Vehicles contribute to the majority of the decreases observed within Road Transportation whereas increases to Off-Road Commercial & Institutional and Off-Road Manufacturing, Mining & Construction contribute to the majority of the increases observed within Off-Road Transportation. For Road Transportation, the reallocation of emissions amongst subcategories is primarily the result of changes to on-road vehicle populations, on-road vehicle kilometre accumulation rates and the transition to an improved on-road vehicle emissions model that includes updated energy consumption rates. For Off-Road Transportation, the reallocation of emissions amongst subcategories is primarily due to changes in off-road vehicle/equipment populations.

For more details about the methodological changes implemented relating to Transport, please refer to Annex 3.1.

Energy (Fugitives)

Significant recalculations occurred in the Oil and Natural Gas category of the Fugitives subsector for the entire time series. Overall, emissions were revised downwards from 1990–2019, ranging from -0.79 Mt (1.1%) in 2015 to -3.1 Mt (4.1%) in 2006. In 2020, emissions were revised upwards by +5.7 Mt (11.7%). These recalculations resulted from several methodological updates with various impacts:

1. Alberta reported venting: from 1990–2019, vented volumes reported by operators (i.e. reported venting) in Alberta did not include emissions from pneumatic instruments, compressor seals, and glycol dehydrators, which necessitated separate estimates for these sources. Effective January 1, 2020, Alberta changed the reporting requirements to include pneumatic instruments, compressor seals, and glycol dehydrators in the reported venting volumetric data. To account for the discrepancy in the definition of vent gas that arose from this change, the methodology for reported venting emissions was updated to incorporate emissions data from Alberta's OneStop reporting system. For specific details on how OneStop data is incorporated to better achieve methodological consistency from 2020 onwards, see Annex 3.2 section A3.2.2.1.5. This methodological change only impacted 2020, resulting in an upward revision of 3.6 Mt.
2. Fugitive Emissions Model (FEM): See Annex 3.2, section A3.2.2.1.3 for more details about the FEM method for estimating emissions from fugitive equipment leaks, pneumatics, and compressor seals at upstream oil and gas facilities. Improvements were implemented for several model parameters, including facility counts, gas composition data, and other source specific parameters used in the FEM, which cumulatively resulted in downward revisions from 1990–2020, ranging from -0.011 Mt in 2020 to -4.8 Mt in 2006. Refinements made specifically to fugitive equipment leak estimates for 2020 had an upward impact on emissions, but overall the updates resulted in downward revisions due to the inclusion of province specific facility counts and gas composition data for Saskatchewan, as well as other facility count updates in British Columbia, Alberta, and Manitoba.
3. Post-meter fugitives: for the first time, post-meter fugitives were included as an emissions source. Post-meter emissions include fugitives downstream of gas meters. Post-meter emissions arise from leaks in natural gas appliances in the residential and commercial sector, from leaks in natural gas vehicles, and from leakage at industrial facilities. For details on the methodology, see Annex 3.2, section A3.2.2.7. Inclusion of post-meter fugitives for the entire time series lead to increases ranging from 1.1 Mt in 1990 to a maximum of 1.9 Mt in 2020.

4. Abandoned oil and gas wells: changes involved the adoption of Canada specific EFs for methane, in addition to updated methodologies for estimating the number of abandoned wells in each province. Nationally, these updates resulted in upward revisions in all years, ranging from 0.11 Mt in 1990 to 0.28 Mt in 2019. See Annex 3.2, section A3.2.2.6 for details on the EFs and well counts used in the new methodology.
5. Newfoundland and Labrador flaring: new EFs for flaring at Newfoundland offshore facilities were developed from GHGRP reported emissions and volumes of gas flared reported to the Canada-Newfoundland Offshore Petroleum Board (CNLOPB). See Annex 3.2 section 3.2.2.1.2 for additional details. Implementation of this update resulted in upward revisions from 1997–2003 and downward revisions from 2004–2020, with a maximum increase of 0.20 Mt in 1998 and a maximum decrease of -0.07 Mt in 2018.
6. Surface casing vent flow (SCVF): estimates for Alberta and British Columbia are based on operator reported data collected by each province, as described in Annex 3.2 section A3.2.2.1.4. Updated provincial reports and corrections to well status dates in the methodology resulted in downward revisions from 1990–2019 with a maximum decrease of -0.06 Mt in 1998, and an upward revision of 0.02 Mt in 2020.

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 2015–2020 resulted in recalculated emissions for that period, with downward revisions in each year ranging from -0.002 Mt in 2015 to -0.21 Mt in 2020.
2. Formation CO_2: estimates were revised upward by 0.10 Mt in 2019 and by 0.16 Mt in 2020 due to updated activity data for shrinkage at gas processing facilities.
3. Reported venting: emissions for Saskatchewan and British Columbia were recalculated using updated reported vent volumes, leading to revisions from 2013–2020 ranging from a decrease of -0.11 Mt in 2017 to an increase of 0.12 Mt in 2019.
4. Petroleum refining: minor recalculations occurred throughout the time series, as estimates were revised downward in 1990, 1992, 1995, 1998–2002, and 2004–2018 with a maximum decrease of -0.004 Mt in 2010, upward revisions in all other years with a maximum of 0.02 Mt in 2020.

Industrial Processes and Product Use

There were recalculations for the IPPU sector for the whole time series (1990–2020), ranging from-0.60 Mt to +0.029 Mt.

Emissions for the Non-Energy Products from Fuels and Solvent Use category have undergone recalculations for the years 1990 to 2020 due to revisions to Statistics Canada's RESD data and the implementation of two methodological changes, the update to the anthracite EF and the change to feedstock utilisation for the production of ethylene. The changes ranged from -0.48 Mt to +0.24 Mt, with 2017 to 2020 being the years most impacted. For the Iron and Steel Production category, a recalculation for 2017 to 2020 was due to revisions to facility reported data to the GHGRP, ranging from +0.0003 Mt in 2017 to +0.12 Mt in 2020. For the Cement Production category, there were updates to the facility-reported data for 2018, as well as a correction to the Tier 3 calculation methodology to add CO_2 emissions from CKD not recycled to the kiln for 2017 to 2020. These resulted in recalculations for 2017 to 2020, ranging from 0.035 Mt in 2017 to 0.088 Mt in 2020.

Emission values for the Ammonia Production category have undergone recalculations, ranging from -0.17 Mt to -0.0049 Mt, for 1990 to 2020 due to a methodological change that accounted for carbon capture and storage (CCS) activities in emissions estimates and the use of the corrected recovery factor of CO_2 consumed in the production of urea. Emissions from Ethylene Production were recalculated due to a methodological change that incorporated changes to feedstock use at two facilities for 2016 to 2020, which ranged in impact from -0.03 Mt in 2017 and -0.43 Mt in 2019.

Other Uses of Urea emissions estimates were recalculated downwards for all years, with a maximum change of -0.071 Mt in 2014. These recalculations were caused by upward revisions to Statistic Canada's export data for urea and urea-ammonium-nitrate fertilizer mixes for all years, as well as revised estimates for urea used as diesel exhaust fluid in selective catalytic reduction (SCR) vehicles for 2008 to 2020 due to Energy (Transport) methodological updates.

Agriculture

Recalculations in the Agriculture sector were primarily driven by the integration of the 2021 census of agriculture that resulted in significant recalculations to years 2018 through to 2020. Other important recalculations resulted from (i) activity data updates associated with revisions to annual survey products, (ii) the addition of nitric oxide to indirect emissions from storage and handling of dairy and swine manure, and (iii) minor error corrections related to soil N_2O emissions.

As a result of these recalculations, agricultural emissions were revised downward by 43 kt in 1990 and 29 kt in 2005, and revised upward by 0.33 Mt in 2020.

Refer to Table 8–4 for more details on implemented improvements.

Waste

Recalculations in the Waste sector resulted in a decrease in emission estimates of 5.4, 7.0, and 5.7 Mt in 1990, 2005, and 2020, respectively. The recalculations include: two method changes, occurring in the Industrial Wood Waste Landfills and Solid Waste Disposal (Landfills) subsectors.

The largest recalculation in the Waste sector was a result of updates to the material parameters used in the first order decay model for estimating emissions at Solid Waste Disposal (Landfill) facilities. These adjustments decrease emission estimates by 3.5 Mt in 1990, 4.8 Mt in 2005, and 5.0 Mt in 2020, compared to the previous inventory.

Industrial wood waste landfill emissions were recalculated based on new information available for Canadian pulp and paper industry waste management practices, as well as new activity data. Material parameters used in the first order decay model were revised to account for the new information. These changes resulted in decreased emission estimates of 2.0, 2.3, and 0.8 Mt in 1990, 2005, and 2020, respectively.

Land Use, Land-Use Change and Forestry

Recalculations also occurred in the estimates of emissions and removals from the LULUCF sector, notably in the Forest Land and Cropland categories. The most important recalculations were due to alignment of activity data to the 2021 Census of Agriculture that resulted in significant recalculations for 2018 through to 2020; corrections to 2020 insect activity data; a correction to slashburning activity levels in British Columbia that impacted years 1990 to 2005 and implementation of a regeneration delay for a fraction of naturally disturbed stands. Other less significant recalculations occurred in the Forest Land, Wetlands and Harvested Wood Products categories mainly due to updated assumptions for deforestation pre-disturbance forest type proportions, addition of forest-cleared and flooded areas associated to a hydro-related large event in Quebec, updated 2020 activity data for peat extraction, and updated activity data related to bioenergy and conventional forest harvest.

The combined impact of these and other minor recalculations in the LULUCF sector increased the estimates of net removals by 1.0 Mt (+1.5%) for 1990, 1.3 Mt (+31%) for 2005, and 6.6 Mt (+98%) in 2020.

Refer to Table 8–4 and Chapter 6 for more details on implemented improvements.

Table 8–3 **Summary of Recalculations by Sector**

	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2016	2017	2018	2019	2020	(1990–2020)	(2005–2020)
ENERGY (Stationary Combustion)										
Previous Submission (2022 NIR)	277 706	344 409	339 046	313 005	318 102	322 706	321 686	299 897	8.0%	-11.5%
Current Submission (2023 NIR)	277 940	344 828	339 171	314 553	317 990	321 141	321 626	297 756	7.1%	-12.2%
Change in Emissions	**234**	**418**	**125**	**1 548**	**-112**	**-1 566**	**-60**	**-2 140**	-	-
	0.1%	**0.1%**	**0.0%**	**0.5%**	**0.0%**	**-0.5%**	**0.0%**	**-0.7%**	-	-
ENERGY (Transport)										
Previous Submission (2022 NIR)	144 881	177 448	189 858	200 333	207 546	215 020	216 440	189 933	31.1%	0.0%
Current Submission (2023 NIR)	145 493	178 199	190 657	196 029	202 486	208 680	210 047	178 731	22.8%	-6.3%
Change in Emissions	**612**	**751**	**800**	**-4 304**	**-5 060**	**-6 340**	**-6 393**	**-11 202**	-	-
	0.4%	**0.4%**	**0.4%**	**-2.1%**	**-2.4%**	**-2.9%**	**-3.0%**	**-5.9%**	-	-
ENERGY (Fugitive)										
Previous Submission (2022 NIR)	49 575	71 753	72 793	67 929	67 920	68 215	66 249	49 689	0.2%	-31.7%
Current Submission (2023 NIR)	48 132	70 138	70 059	66 051	65 952	66 116	64 388	55 400	15.1%	-20.9%
Change in Emissions	**-1 443**	**-1 615**	**-2 735**	**-1 878**	**-1 968**	**-2 099**	**-1 861**	**5 710**	-	-
	-2.9%	**-2.3%**	**-3.8%**	**-2.8%**	**-2.9%**	**-3.1%**	**-2.8%**	**11.5%**	-	-
IPPU										
Previous Submission (2022 NIR)	56 961	54 080	56 591	54 515	52 680	53 895	53 478	50 331	-11.6%	-11.1%
Current Submission (2023 NIR)	56 966	54 022	56 509	54 229	52 442	53 868	52 882	50 360	-11.6%	-10.9%
Change in Emissions	**5**	**-57**	**-82**	**-286**	**-238**	**-27**	**-595**	**29**	-	-
	0.0%	**-0.1%**	**-0.1%**	**-0.5%**	**-0.5%**	**-0.1%**	**-1.1%**	**0.1%**	-	-
AGRICULTURE										
Previous Submission (2022 NIR)	41 183	51 013	54 176	53 054	52 043	53 178	53 280	55 160	33.9%	1.8%
Current Submission (2023 NIR)	41 140	50 960	54 147	52 948	52 088	53 488	53 618	55 491	34.9%	2.5%
Change in Emissions	**-43**	**-53**	**-29**	**-106**	**44**	**311**	**338**	**332**	-	-
	-0.1%	**-0.1%**	**-0.1%**	**-0.2%**	**0.1%**	**0.6%**	**0.6%**	**0.6%**	-	-
WASTE										
Previous Submission (2022 NIR)	24 417	28 284	28 717	26 257	26 722	26 990	27 150	27 344	12.0%	-4.8%
Current Submission (2023 NIR)	18 933	21 317	21 675	21 116	21 274	21 322	21 118	21 050	11.2%	-2.9%
Change in Emissions	**-5 484**	**-6 967**	**-7 042**	**-5 141**	**-5 448**	**-5 668**	**-6 032**	**-6 294**	-	-
	-22.5%	**-24.6%**	**-24.5%**	**-19.6%**	**-20.4%**	**-21.0%**	**-22.2%**	**-23.0%**	-	-
LULUCF										
Previous Submission (2022 NIR)	-63 537	-36 496	-4 228	-10 606	-17 020	-8 468	-15 935	-6 761	-89.4%	59.9%
Current Submission (2023 NIR)	-64 507	-37 777	-5 542	-10 956	-16 227	-11 294	-18 821	-13 388	-79.2%	141.6%
Change in Emissions	**-970**	**-1 281**	**-1 314**	**-350**	**793**	**-2 825**	**-2 886**	**-6 627**	-	-
	1.5%	**3.5%**	**31.1%**	**3.3%**	**-4.7%**	**33.4%**	**18.1%**	**98.0%**	-	-

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. Improvements that lead to recalculations of estimates must be applied across the time series to maintain 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.

Table 8–4 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[1] 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[2].

Methodological changes made this year that addressed the ERTs recommendations include the following:

- updated EF and energy content for anthracite coal
- estimation of nitric oxide emissions from manure management for dairy cattle and swine
- estimation of CO_2, CH_4 and N_2O emissions from lubricating oil combusted in two-stroke engines distinctly from motor gasoline
- updated (for 1990 to 2017) the CO_2 recovery factor for the production of urea, used in the category of Ammonia Production
- estimation and reporting of land area in CRF table 4.1 separately for unmanaged forest, this change has no impact on GHG estimates

8.2.2. 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories

The 2006 IPCC Guidelines contain internationally agreed-upon methodologies for use by countries to estimate GHG emissions and to report to the UNFCCC (IPCC, 2006). These guidelines were developed by the IPCC at the invitation of the UNFCCC. The 2006 IPCC Guidelines encourage the use of country-specific refined methodologies for estimating emissions, including complex modelling approaches at higher tiers.

The 2006 IPCC Guidelines became the methodological reference in 2015, in accordance with the revised UNFCCC Reporting Guidelines on Annual Inventories for Annex I Parties (UNFCCC Reporting Guidelines), as adopted in Decision 24/CP.19 at COP 19 in Warsaw in 2013.

8.2.3. Continuous Improvements

The GHG inventory team also identifies improvements based on evolving science, quality assurance / quality control (QA/QC) and verification activities (in accordance with the QA/QC Plan), and new and innovative modelling approaches or new sources of activity data. Implementation of the improvements is prioritized by taking into consideration the outcomes of the key category and uncertainty analysis, the level of effort and the significance of the improvements. Examples of continuous improvement activities implemented in this year's inventory include:

- updated method to allocate fuel reported in the RESD between on-road vehicles and off-road vehicles/equipment
- updates to off-road vehicle/equipment population estimates
- updates to activity data and parameters used in the Fugitive Emissions Model (FEM) to calculate emissions from pneumatics, compressor seals and equipment leaks in the oil and gas industry
- inclusion of post-meter fugitive CO_2 and CH_4 emissions from natural gas use
- updated CO_2 and CH_4 EF for natural gas combustion and flaring at Newfoundland offshore oil production facilities
- incorporation of facility-reported activities that qualify as CCS in the calculation of the ammonia production emissions
- alignment of activity data with the 2021 Census of Agriculture

1 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

2 https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports-2019

- implementation of a regeneration delay for a fraction of naturally disturbed forest stands
- updates to pre-disturbance forest type proportion assumptions used for forest conversion
- 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 planned improvements to the national GHG inventory are contained in an *Inventory Improvement Plan* that identifies and tracks planned improvements to emission estimates (including underlying activity data, EFs and methodologies). The planned improvements are based on recommendations from internal sources and external review processes and on collaborative work between inventory sector experts and industry, other government departments and academia.

Planned improvement activities (Table 8–5) are prioritized by taking into consideration key category analysis, QA/QC activities, uncertainty assessments, the level of effort and the significance of the improvements. Although the quantification of uncertainty for the emission estimates (Annex 2) helps prioritize improvement activities for future inventories, uncertainty itself is not an indicator of potential future changes resulting from continuous improvement activities. The *Inventory Improvement Plan* is updated annually to track progress in implementing improvements to the inventory. Table 8–4 and Table 8–5 are updated as planned improvements are implemented each year.

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, 2022) 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 consists of projects that (1) can be operationalized[3] 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 2023 GHG inventory submission represents the fourth edition of the 3-year rolling (2023 to 2025) 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 8–4.

Several improvements are planned for the Forest Land category in the next 2024 inventory submission, some details on the most significant changes and the expected impacts are provided in Chapter 6.3.1.6.

3 "Operationalized" means being incorporated into the annual inventory production process.

Table 8–4 **Improvements to Canada's 2023 NIR**

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Energy (Transport)	Marine Navigation (CRF 1.A.3.d) Fishing (CRF 1.A.4.c.iii) Other Mobile (Military Navigation) (CRF 1.A.5.b)	Updated marine activity for the 2019 and 2020 calendar years.	Marine activity data update: Revisions to the activity data (Marine Emissions Inventory Tool) for the 2015, 2016, 2017, and 2018 calendar years and new activity data for the 2019 and 2020 calendar years were incorporated into the marine consumption-based model.	Continuous improvement	Annex 3.1.4.2.3
	Road Transportation (CRF 1.A.3.b) Off-Road Transportation (General)	Updated method to allocate fuel reported in the RESD between on-road vehicles and off-road vehicles/equipment.	This improvement factors in reporting guidance from a RESD feeder survey, Annual Survey of End Use of Refined Petroleum Products, to better define volumes of fuel consumed by on-road vehicles and off-road vehicles/equipment.	Continuous improvement	Annex 3.1.4.2.1
	Road Transportation (CRF 1.A.3.b)	Updates to on-road vehicle population estimates.	On-road vehicle populations used for emissions modelling have been updated for the entire time series to improve consistency with annual road motor vehicle registration totals reported by Statistics Canada.	Continuous improvement	Annex 3.1.4.2.1
	Road Transportation (CRF 1.A.3.b)	Updates to on-road vehicle kilometre accumulation rates.	On-road kilometre accumulation rates used for emissions modelling have been updated for the entire time series, developed from recent inspection and maintenance data.	Continuous improvement	Annex 3.1.4.2.1
	Road Transportation (CRF 1.A.3.b)	Expanded CH_4 and N_2O emission factors for on-road vehicles.	This improvement introduces distinct CH_4 and N_2O emission factors for light-duty gasoline vehicles compliant with Tier 3 motor vehicle emission and fuel standards.	Continuous improvement	Annex 6.1.6
	Road Transportation (CRF 1.A.3.b)	Transition to an improved on-road vehicle emissions model.	ECCC has adopted the United States Environmental Protection Agency's most recent motor vehicle emission simulator MOVES3. Some benefits of transitioning from MOVES2014b to MOVES3 are updated energy consumption rates and adjusted modelling to better account for vehicle starts and long-haul truck hoteling.	Continuous improvement	Annex 3.1.4.2.1
	Off-Road Transportation (General)	Updates to off-road vehicle/equipment population estimates.	Off-road vehicle/equipment populations used for emissions modelling have been updated for the entire time series, using the latest in-service engine population data from Power Systems Research.	Continuous improvement	Annex 3.1.4.2.1
	Off-Road Transportation (General)	Estimation of CO_2, CH_4 and N_2O emissions from lubricating oil combusted in two-stroke engines distinctly from motor gasoline.	This improvement estimates proportions of modelled fuel consumption output from two-stroke motor gasoline engines to be lubricating oil and applies newly developed CO_2, CH_4 and N_2O emission factors to estimate lubricating oil volumes.	UNFCCC ERT recommendation	Annex 3.1.4.2.1 Annex 6.1.6
Energy (Combustion)	Public Electricity and Heat Production (CRF 1.A.1.a)	Updated CO_2 EFs and energy content for petroleum coke.	This update improves the accuracy of the petroleum coke CO_2 EF with new detailed facility-level information. Analytical information about the petroleum coke consumed was provided back to 2010, which has allowed ECCC to develop industry specific CO_2 EFs and corresponding energy content.	Continuous improvement	Annex 6.1.2
	Energy Industries (CRF 1.A.1) Manufacturing Industries and Construction (CRF 1.A.2)	Updated CO_2 EFs and energy content for anthracite coal.	This update improves the accuracy of the anthracite coal CO_2 EF with values that are more representative of the coal consumed in Canada.	UNFCCC ERT recommendation	Annex 6.1.3
	Manufacture of Solid Fuels and Other Energy Industries (CRF 1.A.1.c)	Updated CO_2 and CH_4 EFs for natural gas combustion at Newfoundland and Labrador offshore oil production facilities.	Since all gas produced at the offshore facilities is either flared, used as fuel or injected into the formation, we assume that the carbon content (and therefore the CO_2 emission factor) of fuel gas is consistent with that of flared gas. New CO_2 emission factors for natural gas combustion at Newfoundland offshore facilities were developed using GHGRP facility-reported CO_2 emissions from flaring and volumes of gas flared reported to the Canada-Newfoundland Offshore Petroleum Board (CNLOPB). The CH_4 emission factor for natural gas fuel combustion was modified to reflect that gas turbines are the main combustion technology being used at the offshore facilities.	Continuous improvement	Annex 6.1.1

Table 8–4 **Improvements to Canada's 2023 NIR** (cont'd)

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 – Venting and Flaring (CRF 1.B.2.c)	Updates to Alberta reported venting.	Alberta OneStop data is used in place of Petrinex reported venting for the year 2020. This partially addresses the methodological inconsistency introduced by changes to definitions of fuel gas, flare gas and vent gas which came into effect January 1, 2020, and were discussed in the 2022 submission of the NIR.	Continuous improvement	Annex 3.2.2.1.2
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Updates to activity data and parameters used in the Fugitive Emissions Model (FEM) to calculate emissions from pneumatics, compressor seals and equipment leaks in the oil and gas sector.	Several improvements were made to activity data and modelling parameters used in the FEM, including: • Updated Saskatchewan gas composition data • Updated Saskatchewan facility counts derived from 2013–2020 Petrinex data which also resulted in updates to 1990–2012 backcasted facility counts • Updated Manitoba facility counts derived from 2020 Petrinex data which also resulted in updates to 1990–2019 backcasted facility counts • Updates to British Columbia, Alberta and Saskatchewan satellite battery and compressor station counts using provincial data • Incorporation of provincial regulatory compliance data from Alberta and British Columbia to refine assumptions regarding Leak Detection and Repair (LDAR) compliance	Continuous improvement	Annex 3.2.2.1.3
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Inclusion of post-meter fugitive CO_2 and CH_4 emissions from natural gas use.	Post-meter fugitive CO_2 and CH_4 emission estimates from natural gas appliances in the residential and commercial sector, natural gas vehicles, and industrial consumption of natural gas are now included in the inventory. Previously, they were not estimated.	Continuous improvement	Annex 3.2.2.7
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Updated emission factors and activity data used to estimate emissions from abandoned oil and gas wells.	New CH_4 emission factors derived from Canadian-specific measurement studies of abandoned (plugged) and inactive/suspended (unplugged) oil and gas wells were incorporated into emission estimates. Well counts were updated to include ancillary oil and gas wells (e.g., injection, disposal, etc.) in Alberta and unplugged well counts were updated for Alberta and British Columbia in order to improve the accuracy of historical estimates.	Continuous improvement	Annex 3.2.2.6
	Fugitive Emissions from Fuels – Oil and Natural Gas – Venting and Flaring (CRF 1.B.2.c)	Updated CO_2 and CH_4 EFs for natural gas flaring at Newfoundland and Labrador offshore oil production facilities.	New CO_2 and CH_4 emission factors (EFs) for natural gas flaring at Newfoundland offshore facilities were developed using GHGRP facility-reported CO_2 and CH_4 emissions from flaring and flare gas volumes reported to the Canada-Newfoundland Offshore Petroleum Board (CNLOPB).	Continuous improvement	Annex 3.2.2.1.2
IPPU	Cement Production (CRF 2.A.1)	Update of Tier 3 methodology.	The CO_2 emissions from CKD not recycled to the kiln were previously incorrectly subtracted in the calculation of the total process CO_2 emissions from cement production. The Tier 3 methodology has been corrected so the CO_2 emissions from CKD not recycled to the kiln are now added in the calculation of the total CO_2 emissions from cement production, as stated in Canada's GHGRP Quantification Requirements.	Continuous improvement	Chapter 4
	Ammonia Production (CRF 2.B.1)	Inclusion of CCS activities.	Facility-reported emissions quantities that qualify as CCS were subtracted from gross ammonia production emissions in the calculation of net ammonia production emissions for years 1990 to 2020.	Continuous improvement	Chapter 4, Annex 3.3.1
	Ammonia Production (CRF 2.B.1)	Correction of CO_2 recovery factor.	The CO_2 recovery factor for the production of urea was updated for 1990 to 2017. This is to not factor in CO_2 emissions that may occur during the production of urea, as per ERT's recommendation.	UNFCCC ERT recommendation	Chapter 4
	Ethylene Production (CRF 2.B.8.b)	Update of CO_2 and CH_4 EF.	The Ethylene Production model was updated with changes to the CO_2 and CH_4 EF for two facilities due to modifications in the type of feedstock used beginning in 2016 to present.	Continuous improvement	Chapter 4
	Product Uses as Substitutes for ODS – Foam Blowing Agents - PFCs (CRF 2.F.2)	Implementation of an IPCC 2006 Tier 2 approach.	Emissions from PFCs used as Foam Blowing Agents were previously estimated using a general Tier 1 approach. A review of activity data found that sub-application information, allowing for the application of a Tier 2 method, is available. As such, Tier 2 emission factors corresponding to the sub-application were selected from the 2006 IPCC Guidelines, and associated emission estimates are revised.	Continuous improvement	Chapter 4

Table 8–4 **Improvements to Canada's 2023 NIR** (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Agriculture	Enteric Fermentation (CRF 3.A) Manure Management (CRF 3.B) Agricultural Soils (CRF 3.D) Field Burning of Agricultural Residues (CRF 3.F)	Census update.	Alignment of activity data with the 2021 Census of Agriculture.	Continuous improvement	Chapter 5 Annex 3.4.1
	Indirect N_2O Emissions (CRF 3.B.2.5)	Nitric oxide emissions from manure management.	Estimation of volatilization of NO_x from the management of dairy and swine manure	UNFCCC ERT recommendation	Chapter 5.3.3 Annex 3.4.4.2
LULUCF	Forest Land Remaining Forest Land (CRF 4.A.1)	Several improvements applied to forest estimates including corrections slash burning and firewood harvest data in British Columbia and 2020 insect activity data.	Improvements applied include: i) corrections to British Columbia estimates related to slash burning targets and firewood harvest spatial locations; ii) corrections to 2020 insect activity data; iii) initial refinement of post-fire default regeneration assumptions; and iv) estimated areas of unmanaged forest to be reported in CRF Table 4.1.	Continuous improvement UNFCCC ERT recommendation	Chapter 6.3.1 Annex 3.5.2
	Land Converted to Forest Land (CRF 4.A.2)	Initial estimates associated to recent afforestation.	Developed methodology for incorporating pre-planting carbon (C) stocks into the estimation of the initial C content for recent afforestation sites.	Continuous improvement	Chapter 6.3.2 Annex 3.5.2.6
	Cropland Remaining Cropland (CRF 4.B.1)	Census update.	Alignment of activity data with the 2021 Census of Agriculture.	Continuous improvement	Chapter 6.5 Annex 3.5.4
	Cropland Remaining Cropland (CRF 4.B.1) Harvested Wood Products (CRF 4.G)	Woody biomass improvements.	Improved time series of activity data associated to woody biomass originating from trees and shrubs in agricultural land by applying an interpolation method to the transition between the two 1990–2000 and 2000–2010 activity data sampling periods of digital air photos.	Continuous improvement	Chapter 6.4 and 6.5 Annex 3.5.3 and 3.5.4
	Land Converted to Cropland (CRF 4.B.2) Land Converted to Wetlands (CRF 4.D.2) Land Converted to Settlements (CRF 4.E.2) Harvested Wood Products (CRF 4.G)	Updated deforestation pre-type assumptions.	Refined the temporal resolution of deforestation pre-disturbance forest type assumptions. This update replaced the static pre-type proportions with pre-type proportions that vary with time and RU, for years since 2005	Continuous improvement	Chapter 6.9 Annex 3.5.2.6
Waste	Solid Waste Disposal (CRF 5.A)	Medium term improvements.	No improvements are planned for the short term other than routine activity data updates. Over the medium to long-term, planned improvements such as incorporating facility based GHG data, review and use of direct CH_4 measurement techniques at landfills and improved characterization of Harvested Wood Products in the waste stream will be explored.	Continuous improvement	Chapter 7.2.5
	Municipal Wastewater Treatment/Discharge (CRF 5.D)	Update to septic use to include those used by medium size municipalities.	Based on a review of the available data it may be possible to further spatially disaggregate the percentages of population using private septic systems to include distinct regional use rates for medium sized cities (currently septic use is only assessed by major cities and the remainder of the province).	Continuous improvement	Annex 3.6.4

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Table 8–5 **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 - 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
	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 Oil and Gas Commission (BCOGC) 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)	Storage tank emissions.	Incorporate storage tank emission estimates into the Fugitive Emissions Model (FEM) previously developed to estimate emissions for pneumatics, compressor seals and equipment leaks in the oil and gas industry.	Continuous improvement	Data collection and analysis underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Analysis of aircraft measurement data to improve CH_4 estimates in the oil and gas industry.	Atmospheric measurements of CH_4 emissions from the oil and gas industry have identified a gap between bottom-up inventory estimates and top-down estimates using aircraft measurements, stationary towers and vehicles. Recent field campaigns in British Columbia, Alberta and Saskatchewan using low-altitude LiDAR measurement technology will be analysed to determine how the results can be used to improve CH_4 estimates from the oil and gas industry. The results of the analysis may be used to validate bottom-up models or, where the measurement data allows, be used to improve model parameters and estimates.	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 2016–2021. Historical emission estimates will be revised as required to reflect the most up-to-date data.	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.		

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Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
IPPU	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	Initiated data collection / study
	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 Greenhouse Gas Reporting Program (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, emissions from anthracite coal use as a process input in titanium slag production and petroleum coke use as a process input in the titanium dioxide chloride process are currently reported as part of the Energy sector's CO_2 emissions associated with Non-Ferrous Metals. 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.	A part of the process, 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 direct reduced iron (DRI) method 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.	UNFCCC ERT recommendation	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 in-item HFC use.	A data gap exists with the in-item data that are available up to 2010. To fill this gap, statistics and import/export data will be examined to determine a method to arrive at HFC quantities. A voluntary survey will also be developed and sent out.	Continuous improvement	No significant progress made
	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 collection underway

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
IPPU (cont'd)	Other Limestone and Dolomite Use (CRF 2.A.4.d)	Resolve 2017–2019 activity data discrepancies and identify new activity data source (as necessary).	Potential discrepancies were observed in 2017–2019 data on limestone and dolomite use in various sectors, particularly for the iron and steel and ferrous foundry sectors. Investigations have been started and will be continued to determine whether corrections are needed and whether a new data source is needed.	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.	End-of-life EFs for HFCs in refrigeration and air conditioning applications are currently from the 2006 IPCC Guidelines. Information and data on HFC recovery at the end-of-life for refrigeration and air conditioning applications will be collected (e.g., from industry associations) and assessed to determine the feasibility of developing country-specific end-of-life EFs.	Continuous improvement	Data collection underway
	Semiconductor Manufacturing – NF_3, SF_6, PFCs (CRF 2.E.1)	Collection of activity data and EF information from end users.	The largest known semiconductor manufacturer in Canada was surveyed and provided use data on NF_3, SF_6, and PFCs (replacing sales data from voluntary gas distributor surveys). The company also provided information on the emissions abatement technology utilization and efficiency for each gas used. Other known semiconductor manufacturers, who are also purchasers of NF_3, SF_6, and PFCs, will be contacted to provide more accurate use quantities and to collect data that can be used to develop facility-specific EFs (where possible).	Continuous improvement	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 2012–2021 are calculated using gross economic output data for NAICS 334 – Computer and Electronic Product Manufacturing. Earlier in the time-series (1995–2009), SF_6 import data correlated closely with voluntary sales data reported to the inventory team by a handful of large distributors. 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 are over-estimated. The inventory team is exploring other data options for revising the model to eliminate the use of the discontinued SF_6 import data, including the possibility of relying solely on distributor sales data and user-level data, which would harmonize the SF_6 semiconductor estimate methodology with the PFC and NF_3 semiconductor estimate methodologies. The completeness of the current distributor sales data will be analyzed through sending surveys to international distributors to determine if they sell SF_6 directly to Canadian end-users.	Continuous improvement	Alternative methods being considered
	SF_6 and PFCs from other product use – SF_6 (CRF 2.G.2)	Data collection and significance assessment.	2014–2020 sales data collected from gas distributors through voluntary data surveys indicate that some end-users may use SF_6 and PFCs for applications mentioned in the 2006 IPCC Guidelines (vol. 3, chap. 8.3, pp. 8.23–8.34). 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. In addition, identified large end-users and relevant national agencies for certain applications (such as those knowledgeable on particle accelerators and ophthalmology uses) have been or will be sent surveys for recent years. 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 8–5 **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

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
LULUCF (cont'd)	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 others; 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 estimates of pre-1990 forest disturbances; ii) improved spatial distribution of harvest and volume to C; iii) update climate normal data; iv) integrate activity data associated to recent afforestation; v) provincial inventory updates; and vi) alignment of wood biomass data from different sectors.	Continuous improvement	Data analysis underway
	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
	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
	Flooded Land Remaining Flooded Land (CRF 4.D.1.1)	Improvements to peat extraction activity data.	Improvements to activity data from a new data agreement with Statistics Canada and addition of a new sampling point for 2020 to estimate extent of peatland areas disturbed by peat extraction with high-resolution satellite imagery.	Continuous improvement	Data collection underway
	Flooded Land Remaining Flooded Land (CRF 4.D.1.2) Land Converted to Flooded Land (CRF 4.D.2.2)	Development of activity data, parameters and EFs for CH_4 and CO_2 in flooded lands.	Improved 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.	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.	Continuous improvement	Data collection 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)	Medium term projects.	No improvements are planned over the short-term. 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 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	See Annex 3.6

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PART 2 AND PART 3

The 2023 edition of Canada's National Inventory Report (NIR) will be 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, 1990–2021
	10	Canada GHG emission tables by economic sector, 1990–2021
	11	Provincial and territorial GHG emission tables by IPCC sector, 1990–2021
	12	Provincial and territorial GHG emission tables by economic sector, 1990–2021
	13	Electricity in Canada: Summary and intensity tables

1 ECCC. 2023. Canada's Official Greenhouse Gas Inventory - Environment and Climate Change Canada Data. Available online at: https://data.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/?lang=en.