

# NATIONAL INVENTORY REPORT 1990–2023: GREENHOUSE GAS SOURCES AND SINKS IN CANADA

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

PART 1

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*Rapport d'inventaire national 1990–2023 : Sources et puits de gaz à effet de serre au Canada*

# FOREWORD

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

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

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

This report represents the efforts of many years of team work and builds on the results of previous reports, published in 1992, 1994, and yearly from 1996 to 2024. Ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce their uncertainties as far as practicable.

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## Executive Summary

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Overall coordination of Canada's National Inventory Report was led by Raphaëlle Pelland St-Pierre. Centralized data compilation and the generation of comprehensive emission tables were led by Amélie Amiot. Compilation of uncertainty estimates as well as key category analyses were led by Pegah Bauco and Amélie Amiot. Layout of the National Inventory Report for publication was led by Marida Waters with the support of Jorge Aranda Fernandez and Bruna Sunye. Translation services were provided by Katryn Lamoureux, Bruna Sunye and Kim Thibault. Jorge Aranda Fernandez developed the webpages related to this publication, under Amélie Amiot's supervision. Special thanks to Areej Mahmoud and Julius Moore for the development of the model used to submit data to the CRTs. The coordination and submission of the CRTs was led by Catherine Robert.

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# LIST OF COMMON ABBREVIATIONS AND UNITS

## Abbreviations

AAFC .....	Agriculture and AgriFood Canada
BCER .....	British Columbia Energy Regulator
BCOGC .....	British Columbia Oil and Gas Commission
CAC .....	criteria air contaminant
CAPP .....	Canadian Association of Petroleum Producers
CBM-CFS3 .....	Carbon Budget Model of the Canadian Forest Sector version 3
CCS .....	carbon capture and storage
CCTUS .....	carbon capture, transport, use and storage
CEEDC .....	Canadian Energy and Emissions Data Centre
CEPA 1999 .....	<i>Canadian Environmental Protection Act, 1999</i>
CEPEI .....	Canadian Energy Partnership for Environmental Innovation
CFC .....	chlorofluorocarbon
CFS .....	Canadian Forest Service
COA .....	<i>Census of Agriculture</i>
CRT .....	Common Reporting Tables
DOC .....	degradable organic carbon or dissolved organic carbon
DOM .....	dead organic matter
ECCC .....	Environment and Climate Change Canada
EF .....	emission factor
EFW .....	energy from waste
EO .....	Earth Observation
EOR .....	enhanced oil recovery
FRD .....	facility-reported data
GDP .....	gross domestic product
GHG .....	greenhouse gas
GHGRP .....	Greenhouse Gas Reporting Program
GWP .....	global warming potential
HCFC .....	hydrochlorofluorocarbon
HFC .....	hydrofluorocarbon
HWP .....	harvested wood products
ICSR .....	Industrial Chemicals and Synthetic Resins
IEA .....	International Energy Agency
IPCC .....	Intergovernmental Panel on Climate Change
IPPU .....	Industrial Processes and Product Use
LDAR .....	Leak Detection and Repair

LMC .....	Land Management Change
LTO .....	landing and takeoff
LULUCF .....	Land Use, Land-Use Change and Forestry
MMV .....	Measurement, Monitoring and Verification
MPGs .....	modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement
MSW .....	municipal solid waste
N/A .....	not available
NFCMARS-HWP .....	National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products
NIR .....	National Inventory Report
NM VOC .....	non-methane volatile organic compound
NRCan .....	Natural Resources Canada
ODS .....	ozone-depleting substance
OECD .....	Organisation for Economic Co-operation and Development
PFC .....	perfluorocarbon
QA .....	quality assurance
QC .....	quality control
RES D .....	<i>Report on Energy Supply and Demand in Canada</i>
RU .....	reconciliation unit
SCR .....	selective catalytic reduction
SLC .....	Soil Landscapes of Canada
SMR .....	steam methane reformation
SOC .....	soil organic carbon
StatCan .....	Statistics Canada
UOG .....	upstream oil and gas
VKT .....	vehicle kilometres travelled
UNFCCC .....	United Nations Framework Convention on Climate Change

## Chemical Formulas

C .....	carbon
CaCO <sub>3</sub> .....	calcium carbonate; limestone
CaO .....	calcium oxide; lime; quicklime; calcined limestone
CF <sub>4</sub> .....	carbon tetrafluoride; perfluoromethane
C <sub>2</sub> F <sub>6</sub> .....	carbon hexafluoride; perfluoroethane
CH <sub>4</sub> .....	methane
CO .....	carbon monoxide
CO <sub>2</sub> .....	carbon dioxide
CO <sub>2</sub> eq .....	carbon dioxide equivalent
H <sub>2</sub> S .....	hydrogen sulphide
Mg .....	magnesium
MgCO <sub>3</sub> .....	magnesite; magnesium carbonate
MgO .....	magnesia; magnesium oxide
N .....	nitrogen

NF <sub>3</sub> .....	nitrogen trifluoride
NH <sub>3</sub> .....	ammonia
NH <sub>4</sub> <sup>+</sup> .....	ammonium
NH <sub>4</sub> NO <sub>3</sub> .....	ammonium nitrate
N <sub>2</sub> O .....	nitrous oxide
N <sub>2</sub> O-N .....	nitrous oxide emissions represented in terms of nitrogen
NO <sub>3</sub> <sup>-</sup> .....	nitrate
NO <sub>x</sub> .....	nitrogen oxides
SF <sub>6</sub> .....	sulphur hexafluoride
SiC .....	silicon carbide

## Notation Keys

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

## Units

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

# EXECUTIVE SUMMARY

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## ES.1. Key Points

- In 2023, Canada’s greenhouse gas (GHG) emissions were 694 megatonnes of carbon dioxide equivalent (Mt CO<sub>2</sub> eq),<sup>1</sup> a decrease of 65 Mt (8.5%) from 2005 (excluding the Land Use, Land-Use Change and Forestry sector), and a decrease of 6.0 Mt (0.9%) from 2022.
- Emissions from electricity decreased by 67 Mt (-58%) over this period driven by the phase-out of coal-fired electricity generation. Oil and gas emissions increased by 13 Mt (7%), although emissions peaked in 2014 at 228 Mt and have since decreased by 20 Mt (-9%) to 208 Mt in 2023, consistent with measured decreases of fugitive methane sources in recent years.
- The emissions intensity for the entire Canadian economy (GHG per gross domestic product [GDP]) has continued to decline; in 2023 it had declined by 45% since 1990 and by 34% since 2005.
- As with every National Inventory Report (NIR) edition, improvements have been implemented resulting in revisions to previously published data. Overall, this edition of the inventory incorporates downward revisions of 2.8 Mt in 2005 and 7.9 Mt in 2022, relative to the previously published inventory in 2024. Enhanced methods use Canadian-specific studies and knowledge, facilitate the adoption of new scientific data and better reflect evolving technologies and industry practices.
- Canada’s NIR is a scientific report which, along with other publications such as Canada’s Biennial Transparency Report and Canada’s 2030 Emissions Reduction Plan, informs and supports decision-making to reduce Canada’s GHG emissions and combat climate change.
- Consistent with [Canada’s Nationally Determined Contribution](#), progress towards Canada’s targets is measured by combining information from Canada’s NIR to its LULUCF (Land Use, Land-Use Change and Forestry) contribution in accordance with Canada’s approach to LULUCF accounting, which is reported separately in [Canada’s First Biennial Transparency Report](#).

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

## ES.2. Introduction

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

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

Canada's official GHG inventory is prepared and submitted annually to the UNFCCC in accordance with the modalities, procedures and guidelines (MPGs) for the transparency framework for action and support referred to in Article 13 of the Paris Agreement, adopted through Decision 18/CMA.1 in 2018.<sup>2</sup> The annual inventory submission under the UNFCCC consists of the NIR and Common Reporting Tables (CRTs), submitted by April 15 of each year.

The GHG inventory includes emissions and removals of carbon dioxide (CO<sub>2</sub>), and emissions of methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF<sub>6</sub>) and nitrogen trifluoride (NF<sub>3</sub>) in five sectors (Energy, Industrial Processes and Product Use [IPPU], Agriculture, Waste, and Land Use, Land-Use Change and Forestry [LULUCF]). The GHG emission and removal estimates contained in Canada's GHG inventory are developed using methodologies consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. In line with the principle of continuous improvement, the underlying data and methodology for estimating emissions are revised over time; hence, total emissions in all years are subject to change as both data and methods are improved (see section [ES.8](#)).

In 2021, Canada formally submitted its enhanced Nationally Determined Contribution (NDC) to the UNFCCC, committing to cut its GHG emissions by 40%–45% below 2005 levels by 2030 (see The NIR: Scientific Evidence for Decision Makers box that follows). Canada submitted its NDC for 2035 to the UNFCCC in February 2025. With this new NDC, Canada commits to reducing GHG emissions by 45%-50% below 2005 levels by 2035. Since 2005 was adopted as a base year for Canada's targets, many of the metrics in this report are presented in that context, in addition to the 1990 base year as required by the MPGs. In keeping with the reporting requirements, the GHG inventory reports annual emissions from 1990 up to and including the year ending 15 ½ months prior to its submission to the UNFCCC in April (e.g., 2023 for the 2025 edition of the inventory). For the first time, in December 2024, Canada's Preliminary Greenhouse Gas Emissions were published ahead of the final NIR, representing a publication date of less than 12 months following the latest reported year.

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

Section [ES.3](#) of this Executive Summary provides an overview of the latest information on Canada's net anthropogenic GHG emissions and links this information to relevant indicators of the Canadian economy. Section [ES.4](#) outlines the major trends in emissions by IPCC sectors over the 2005–2023 period.

For the purposes of analyzing economic trends and policies, emissions have been allocated to the economic sector from which they originate. Section [ES.5](#) presents Canada's emissions broken down by the following economic sectors: Oil and Gas, Electricity, Transport, Heavy Industry, Buildings, Agriculture, and Waste and others.<sup>3</sup> Throughout this report, the word “sector” generally refers to activity sectors as defined by the IPCC for national GHG inventories, except when the expression “economic sectors” is used in reference to the Canadian context.

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

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

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

## The NIR: Scientific Evidence for Decision Makers

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

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

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

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

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

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

### ES.3. Overview of National GHG Emissions (1990–2023)

Canada accounts for approximately 1.4% of global GHG emissions (Climate Watch, 2025 for the year 2021), making it the 12th largest emitter. While Canada is one of the highest per capita emitters, per capita emissions have declined since 2005 from 24 t CO<sub>2</sub> eq/capita to 17 t CO<sub>2</sub> eq/capita in 2023 (StatCan, n.d.[a]).<sup>4</sup>

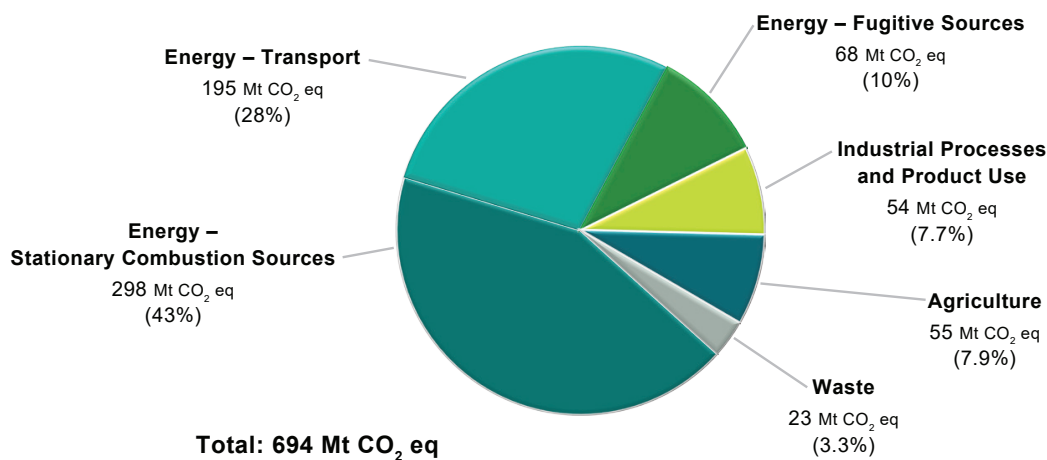
#### Emission Breakdown by Sector (2023)

In 2023, Canada's GHG emissions were 694 Mt CO<sub>2</sub> CO<sub>2</sub> eq, excluding the LULUCF sector.<sup>5</sup> The Energy sector (consisting of Stationary Combustion Sources, Transport and Fugitive Sources) emitted the largest share (81%) of Canada's total GHG emissions ([Figure ES–1](#)). The remaining emissions were generated by the Agriculture and IPPU sectors, with contributions from the Waste sector. When included with emissions from other sectors, LULUCF sector emissions corresponded to 0.6% of the national total in 2023.

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

<sup>5</sup> Unless explicitly stated otherwise, all emissions estimates given in Mt represent emissions of GHGs in Mt CO<sub>2</sub> eq.

Figure ES-1 **Breakdown of Canada's Emissions by Intergovernmental Panel on Climate Change Sector (2023)**

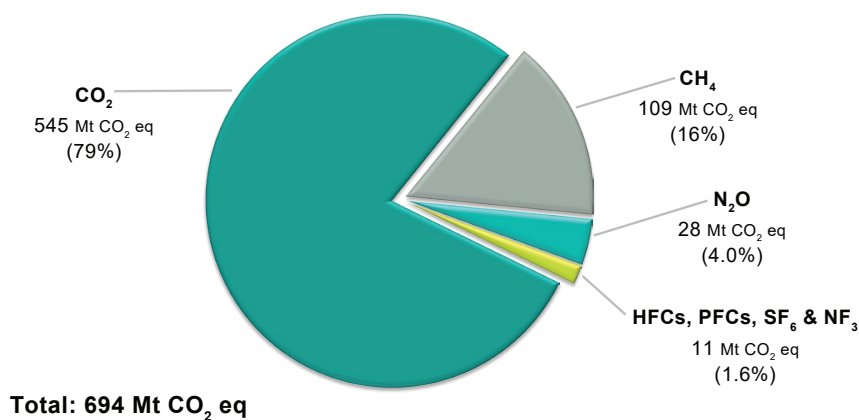


Note: Totals may not add up due to rounding.

## Emission Breakdown by GHG (2023)

Canada's emissions profile is similar to most industrialized countries, in that CO<sub>2</sub> is the largest contributor to total emissions, accounting for 545 Mt or 79% of total emissions in 2023, as shown by the largest part of Figure ES-2. Most CO<sub>2</sub> emissions in Canada result from the combustion of fossil fuels. CH<sub>4</sub> emissions in 2023 amounted to 109 Mt or 16% of Canada's total and is the second-largest contributor. These emissions consist largely of fugitive<sup>6</sup> emissions from oil and natural gas systems (50 Mt), agriculture (31 Mt) and landfills (20 Mt). Emissions of N<sub>2</sub>O accounted for 28 Mt or 4.0% of Canada's emissions in 2023, which mostly arise from agricultural soil management (18 Mt). Emissions of synthetic gases (HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub>) accounted for less than 2% of national emissions.

Figure ES-2 **Breakdown of Canada's Emissions by GHG (2023)**



Note: Totals may not add up due to rounding.

<sup>6</sup> Includes flaring, venting and unintentional release of GHGs during the extraction, processing, transformation and delivery of fossil fuels to the point of final use.

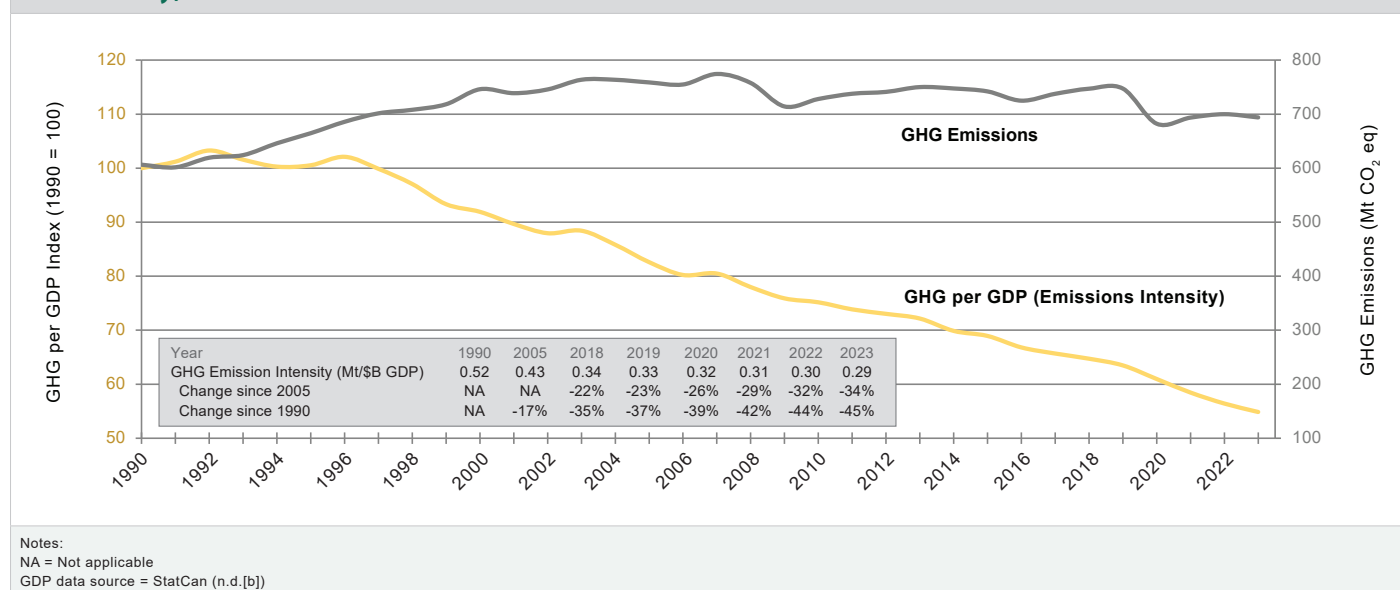
## Changes in Total Emissions (1990–2023)

After fluctuations in recent years, overall, Canada's GHG emissions in 2023 have decreased by 65 Mt or 8.5% since 2005. In general, year-to-year fluctuations are superimposed over trends observed over a longer period. During the period covered in this report, Canada's economy grew more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (GHG per GDP) has continued to decline; in 2023 it had declined by 45% since 1990 and by 34% since 2005 (Figure ES–3). The decline in emissions intensity can be attributed to factors such as fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.

Over the 2013–2023 period, total emissions decreased by 56 Mt or 7.5%. Since 2013, significant decreases occurred from Oil and Natural Gas Fugitive Sources (-33 Mt or -33%) as well as Public Electricity and Heat Production (-29 Mt or -34%). These decreases can be explained mostly by methane emission reductions from conventional oil and gas activities (more specifically from decreased venting) as well as the phase-out of coal-fired electricity generation and increased electricity generation from renewable sources. In contrast, from 2013 to 2023, Oil and Gas Extraction combustion emissions increased by 16 Mt (18%). Emissions from some transport sources increased as well, notably Other Transportation<sup>7</sup> by 8.4 Mt (18%) and Light-Duty Gasoline Trucks by 7.9 Mt (17%). These increases can be attributed mainly to continued production growth in Canada's oil sands operations and an increase in the off- and on-road vehicle fleet, leading to more kilometres driven overall.

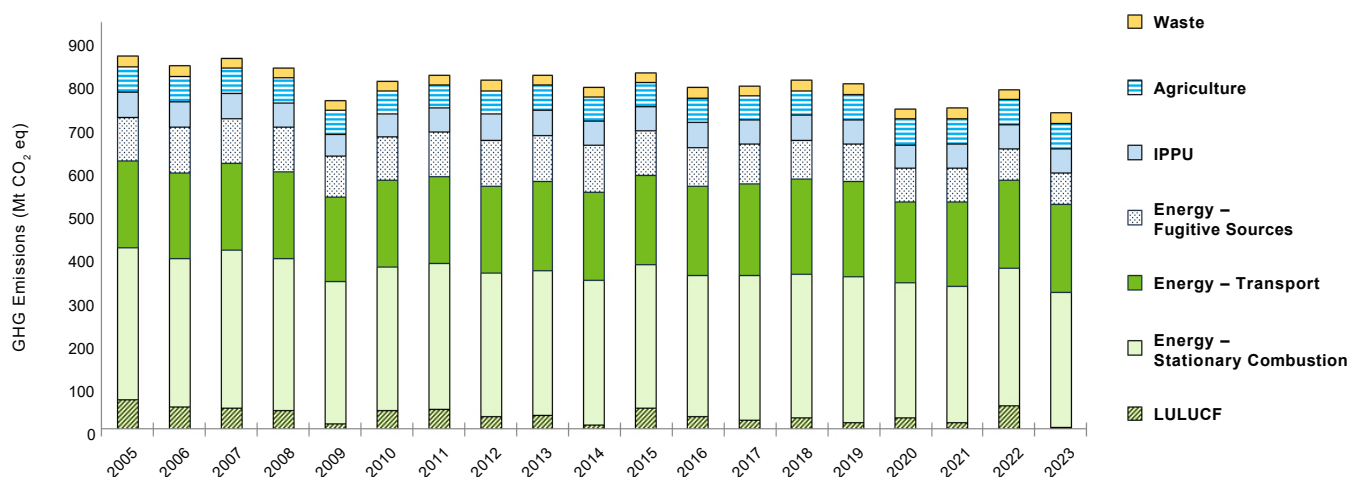
When observing long-term emission trends, large-scale events can have a significant impact on a portion of the time-series analyzed and should be considered. The years 2020 and 2021 were marked by the COVID-19 pandemic. This coincides with an abrupt decrease of 65 Mt (8.7%) in total GHG emissions between 2019 and 2020, with almost half from Transport (-31 Mt or -15%). The year after, between 2020 and 2021, emissions increased slightly by 11 Mt (1.7%) and between 2021 and 2022 they continued to increase by 6.3 Mt (0.9%), while remaining below their 2019 pre-pandemic levels. Finally, in the latest year, between 2022 and 2023, emissions decreased by 6.0 Mt (0.9%). Impacts of the pandemic, more pronounced in 2020, are now harder to distinguish in the latest years. Notwithstanding the abrupt decrease between 2019 and 2020, and recent year changes, the general breakdown of emissions by IPCC sector has not substantially changed over time (Figure ES–4).

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



<sup>7</sup> Other Transportation includes consumption of fuels (excluding the biogenic CO<sub>2</sub> emissions from ethanol and biodiesel) by mobile combustion devices not licensed to operate on roads, as well as transportation and distribution of crude oil, natural gas and other products by pipelines.

Figure ES-4 Trends in Canadian GHG Emissions by Intergovernmental Panel on Climate Change Sector (2005–2023)



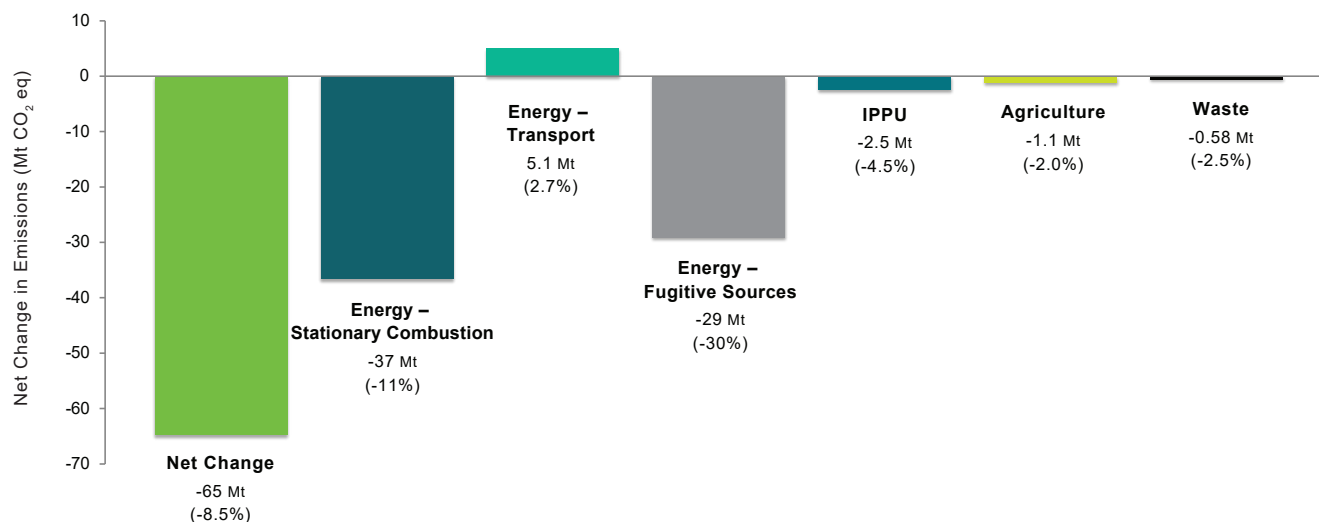
## ES.4. GHG Emissions and Trends by Intergovernmental Panel on Climate Change Sector

### Trends in Emissions (2005–2023)

Over the 2005–2023 period, total emissions are down by 65 Mt or 8.5%. The Energy sector dominated, with emission decreases of 37 Mt (11%) from Stationary Combustion Sources and 29 Mt (30%) from Fugitive Sources (Table ES-1). Transport associated fuel combustion emissions increased by 5.1 Mt (2.7%). Over the same period, emissions are down by 2.5 Mt (4.5%) in the IPPU sector and 1.1 Mt or 2.0% in the Agriculture sector. The Waste sector emissions have remained relatively stable with a decrease of 0.58 Mt (2.5%) (Figure ES-5).

Chapter 2 provides more information on GHG emissions trends since 1990 and 2005 and their drivers.<sup>8</sup> Further breakdowns of emissions and a complete time series can be found at [open.canada.ca](http://open.canada.ca).

Figure ES-5 Changes in Emissions by IPCC Sector (2005–2023)



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

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

GHG Categories		GHG Emissions (Mt CO <sub>2</sub> eq)						
		2005	2018	2019	2020	2021	2022	2023
<b>TOTAL<sup>a, b</sup></b>		<b>759</b>	<b>747</b>	<b>747</b>	<b>682</b>	<b>694</b>	<b>700</b>	<b>694</b>
<b>ENERGY</b>		<b>623</b>	<b>615</b>	<b>616</b>	<b>552</b>	<b>562</b>	<b>568</b>	<b>562</b>
<b>a. Stationary Combustion Sources</b>		<b>335</b>	<b>319</b>	<b>322</b>	<b>299</b>	<b>301</b>	<b>304</b>	<b>298</b>
	Public Electricity and Heat Production	123	71	70	62	62	58	58
	Petroleum Refining Industries	19	13	15	14	14	15	14
	Oil and Gas Extraction	63	105	106	101	105	106	107
	Mining	4.3	6.0	6.0	5.2	5.8	5.8	5.5
	Manufacturing Industries	47	42	42	39	40	40	40
	Construction	1.4	1.4	1.4	1.4	1.4	1.6	1.5
	Commercial and Institutional	32	37	38	35	33	35	33
	Residential	43	40	41	38	37	39	35
	Agriculture and Forestry	2.2	3.2	3.3	3.0	3.2	3.3	3.3
<b>b. Transport</b>		<b>190</b>	<b>209</b>	<b>209</b>	<b>178</b>	<b>187</b>	<b>195</b>	<b>195</b>
	Aviation	7.7	8.7	8.6	4.7	5.6	7.7	8.4
	Road Transportation	122	132	132	112	117	121	122
	Railways	6.5	6.5	6.5	6.0	5.9	5.8	5.9
	Marine	4.1	3.7	3.7	3.3	3.2	3.6	3.7
	Other Transportation	50	58	58	52	55	56	56
<b>c. Fugitive Sources</b>		<b>98</b>	<b>88</b>	<b>84</b>	<b>75</b>	<b>75</b>	<b>70</b>	<b>68</b>
	Coal Mining	1.5	1.6	1.6	1.4	1.4	1.4	1.6
	Oil and Natural Gas	96	86	83	73	73	69	67
<b>d. CO<sub>2</sub> Transport and Storage</b>		<b>0.00</b>	<b>0.00</b>	<b>0.06</b>	<b>0.11</b>	<b>0.03</b>	<b>0.04</b>	<b>0.04</b>
<b>INDUSTRIAL PROCESSES AND PRODUCT USE</b>		<b>56</b>	<b>55</b>	<b>54</b>	<b>51</b>	<b>53</b>	<b>53</b>	<b>54</b>
<b>a. Mineral Products</b>		<b>10</b>	<b>8.7</b>	<b>8.9</b>	<b>8.2</b>	<b>9.0</b>	<b>8.4</b>	<b>8.8</b>
<b>b. Chemical Industry</b>		<b>10</b>	<b>6.4</b>	<b>6.2</b>	<b>5.9</b>	<b>5.7</b>	<b>5.7</b>	<b>5.6</b>
<b>c. Metal Production</b>		<b>21</b>	<b>16</b>	<b>15</b>	<b>14</b>	<b>15</b>	<b>15</b>	<b>16</b>
<b>d. Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub></b>		<b>4.8</b>	<b>11</b>	<b>11</b>	<b>11</b>	<b>11</b>	<b>11</b>	<b>10</b>
<b>e. Non-Energy Products from Fuels and Solvent Use</b>		<b>10</b>	<b>12</b>	<b>12</b>	<b>11</b>	<b>12</b>	<b>12</b>	<b>12</b>
<b>f. Other Product Manufacture and Use</b>		<b>0.51</b>	<b>0.65</b>	<b>0.62</b>	<b>0.66</b>	<b>0.66</b>	<b>0.61</b>	<b>0.65</b>
<b>AGRICULTURE</b>		<b>56</b>	<b>54</b>	<b>54</b>	<b>56</b>	<b>55</b>	<b>56</b>	<b>55</b>
<b>a. Enteric Fermentation</b>		<b>35</b>	<b>27</b>	<b>27</b>	<b>27</b>	<b>27</b>	<b>27</b>	<b>26</b>
<b>b. Manure Management</b>		<b>8.7</b>	<b>7.9</b>	<b>7.9</b>	<b>7.8</b>	<b>7.9</b>	<b>7.8</b>	<b>7.7</b>
<b>c. Agricultural Soils</b>		<b>12</b>	<b>16</b>	<b>16</b>	<b>18</b>	<b>17</b>	<b>18</b>	<b>18</b>
<b>d. Field Burning of Agricultural Residues</b>		<b>0.05</b>	<b>0.05</b>	<b>0.05</b>	<b>0.06</b>	<b>0.04</b>	<b>0.05</b>	<b>0.05</b>
<b>e. Liming, Urea Application and Other Carbon-Containing Fertilizers</b>		<b>1.4</b>	<b>2.6</b>	<b>2.7</b>	<b>3.0</b>	<b>3.1</b>	<b>2.9</b>	<b>3.1</b>
<b>WASTE</b>		<b>24</b>	<b>23</b>	<b>23</b>	<b>23</b>	<b>23</b>	<b>23</b>	<b>23</b>
<b>a. Landfills</b>		<b>21</b>	<b>20</b>	<b>20</b>	<b>20</b>	<b>20</b>	<b>20</b>	<b>20</b>
<b>b. Biological Treatment of Solid Waste</b>		<b>0.24</b>	<b>0.38</b>	<b>0.38</b>	<b>0.38</b>	<b>0.50</b>	<b>0.50</b>	<b>0.50</b>
<b>c. Incineration and Open Burning of Waste</b>		<b>0.34</b>	<b>0.17</b>	<b>0.17</b>	<b>0.15</b>	<b>0.15</b>	<b>0.17</b>	<b>0.16</b>
<b>d. Wastewater Treatment and Discharge</b>		<b>2.2</b>	<b>2.7</b>	<b>2.7</b>	<b>2.6</b>	<b>2.6</b>	<b>2.6</b>	<b>2.6</b>
<b>LAND USE, LAND-USE CHANGE AND FORESTRY</b>		<b>66</b>	<b>24</b>	<b>15</b>	<b>25</b>	<b>15</b>	<b>51</b>	<b>4.2</b>
<b>a. Forest Land</b>		<b>135</b>	<b>60</b>	<b>40</b>	<b>40</b>	<b>34</b>	<b>22</b>	<b>24</b>
<b>b. Cropland</b>		<b>- 20</b>	<b>- 20</b>	<b>- 15</b>	<b>- 13</b>	<b>- 16</b>	<b>25</b>	<b>- 22</b>
<b>c. Grassland</b>		<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
<b>d. Wetlands</b>		<b>2.7</b>	<b>2.5</b>	<b>2.7</b>	<b>2.9</b>	<b>2.8</b>	<b>2.6</b>	<b>2.6</b>
<b>e. Settlements</b>		<b>4.7</b>	<b>5.4</b>	<b>5.3</b>	<b>5.3</b>	<b>5.5</b>	<b>5.2</b>	<b>5.0</b>
<b>f. Harvested Wood Products</b>		<b>- 57</b>	<b>- 24</b>	<b>- 18</b>	<b>- 10</b>	<b>- 12</b>	<b>- 4.0</b>	<b>- 5.1</b>

## Notes:

Totals may not add up due to rounding.

0.00 Indicates emissions were truncated due to rounding.

a. National totals calculated in this table do not include emissions and removals reported in LULUCF.

b. This summary data is presented in more detail at [open.canada.ca](https://open.canada.ca).

## Energy – 2023 GHG Emissions (562 Mt)

In 2023, GHG emissions from the IPCC Energy sector (562 Mt) were 9.7% lower than in 2005 (623 Mt). Within the Energy sector, emissions increased by 44 Mt (70%) from Oil and Gas Extraction, 6.0 Mt (12%) from Other Transportation, 1.1 Mt (49%) from Agriculture and Forestry, and 1.1 Mt (26%) from Mining. These emissions were offset by decreases of 65 Mt (53%) from Public Electricity and Heat Production, 29 Mt (30%) from Fugitive Sources, 8.1 Mt (19%) from the Residential sector, 6.4 Mt (14%) from Manufacturing Industries, and 4.4 Mt (24%) from Petroleum Refining.

### Stationary Combustion Sources (298 Mt)

From 2005 to 2023, stationary combustion emissions from Oil and Gas Extraction increased 44 Mt (70%), consistent with a 242% rise in crude bitumen and synthetic crude oil production from Canada's oil sands operations.

Decreasing electricity generation from coal and refined petroleum product (RPP) usage (by 77% and 79%, respectively) and an increase in the amount of low-emitting generation in the mix were the largest drivers of the 65 Mt (53%) decrease in emissions associated with Public Electricity and Heat Production between 2005 and 2023. Since 2005, reduced consumption of more GHG-intensive fossil fuels (coal and RPPs), accounted for 41% of the decrease in emissions from Public Electricity and Heat Production. Significant emission reductions in GHG-intensive fossil fuels occurred in Ontario (99%), Manitoba (91%), Alberta (83%), New Brunswick (71%), Nova Scotia (62%), and Saskatchewan (27%). Emission fluctuations over the period reflect variations in the mix of electricity generation sources. Since 2005, the increase in electricity generated from low-emitting sources accounted for 44% of the decrease in emissions.

The 8.1 Mt (19%) decrease in emissions in the Residential category between 2005 and 2023 is largely driven by energy efficiency improvements, with smaller decreases due to warmer weather and reduced consumption of light fuel oil offset by an increase in population and floor space.

GHG emissions from fuel consumption in Manufacturing Industries decreased by 6.4 Mt (14%) between 2005 and 2023, consistent with a 14% decrease in energy use (StatCan, n.d.[c]). The decrease occurred in Other Manufacturing (-3.2 Mt or -20%), Pulp and Paper (-1.6 Mt or -19%), Cement (-1.5 Mt or -30%), Non-Ferrous Metals (-0.73 Mt or -19%), and Iron and Steel (-0.45 Mt or -9.0%), in contrast with an increase in Chemicals (1.1 Mt or 13%).

Since 2005, one petroleum refinery in Alberta has permanently closed (2012), while four have converted to terminal and renewable energy production facilities including one in Ontario (2005), Quebec (2010), Nova Scotia (2013), and Newfoundland and Labrador (2020) contributing to the decrease of 4.4 Mt (24%) in Petroleum Refining Industries emissions.

### Transport (195 Mt)

Most transport emissions in Canada are related to Road Transportation, which includes personal transportation (light-duty vehicles and trucks) and heavy-duty vehicles. The general growth trend in road transportation emissions through the time-series is largely due to an increase in driving: more cars and trucks on the road using more fuel and therefore generating greater emissions, despite continued reductions in the emissions produced by each individual vehicle. Further, despite a reduction in kilometres driven per vehicle, the total population of the vehicle fleet in 2023 had increased by 32% since 2005 leading to more kilometres driven overall. Also contributing to more vehicle kilometers driven over this time period, within the total vehicle population, there was a decrease in the number of cars; and an increase in the number of heavy-duty vehicles that typically contribute more vehicle kilometers travelled per vehicle.

From 2005 to 2019, emissions from Transport have generally increased. From 2019 to 2020, the start of the COVID-19 pandemic, Transport emissions decreased below 2005 levels as travel from aircraft and light-duty on-road vehicles decreased. From 2021 to 2023, as travel demand began to return to pre-pandemic levels, Transport emissions increased by 8.6 Mt, bringing them 5.1 Mt above 2005 levels but still below pre-pandemic levels in 2019.

### Fugitive Sources (68 Mt)

Fugitive Sources are comprised of flaring, venting and unintentional emissions from fossil fuel production (coal, oil and natural gas) with emissions from the oil and gas industry generally accounting for approximately 98% of total fugitive emissions in Canada. Since 2005, almost 220 000 productive oil and gas wells have been drilled and the annual number of producing wells has increased by 4%. Crude oil and natural gas production has also increased by 47%, mostly due to Canada's Oil Sands. Even with the increased output and activity, Fugitive Sources emissions have decreased by 29 Mt (30%). This includes a 5.6% increase from 98 Mt in 2005 to a peak in 2014 of 103 Mt. Since 2014, emissions have decreased by 35 Mt (34%) as a result of measures to increase the conservation of natural gas (comprised mainly of CH<sub>4</sub>) and federal and provincial measures to reduce methane emissions from the upstream oil and gas industry. The reduction of emissions coinciding with increased production highlights the reduction in emission intensities that have been achieved (see [Chapter 2](#) for more details).

## Carbon Capture and Storage (37 kt)

Carbon capture involves the capture of anthropogenic CO<sub>2</sub> from industrial processes or fuel combustion sources. The captured CO<sub>2</sub> is transported to, and injected at, long-term storage (LTS) facilities or enhanced oil recovery (EOR) sites. Injection into LTS began in 2016, and in 2023 approximately 1.1 Mt of captured CO<sub>2</sub> was placed in geological formations for LTS. EOR use of industrial captured CO<sub>2</sub> began in 2000, and in 2023 about 3.2 Mt of captured CO<sub>2</sub> was injected to support EOR operations, of which approximately 1.1 Mt was imported from the United States. At 2023 year-end, a cumulative total of 8.3 Mt of captured CO<sub>2</sub> was placed in LTS and 51.13 Mt was injected for EOR.

Due to the increase in activity associated with this category, fugitive emissions from CO<sub>2</sub> capture, transport, use and storage increased from 0.09 kt in 2005 to 37 kt in 2023. See Chapter 3, section 3.4, for more details on carbon capture and storage volumes and associated emissions.

## Industrial Processes and Product Use – 2023 GHG Emissions (54 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 54 Mt (7.7%) to Canada's 2023 emissions.

Between 2005 and 2023, process emissions from most IPPU categories decreased. Lower cement and lime production, and closures or indefinite idling of multiple facilities contributed to an emission decrease of 0.9 Mt (10%). Emissions from the Iron and Steel Industry decreased by 1.3 Mt (12%) during the period because of the closure of a facility in 2013. The Aluminium Industry also saw a decline in its process emissions of 2.2 Mt (27%), largely due to the implementation of technological improvements and the shutdown of older smelters using Söderberg technology. The closure of primary magnesium plants in 2007 and 2008 as well accounted for 1.2 Mt (83%) of the overall decrease. Another emission decrease of 2.3 Mt (100%) came from the 2009 closure of the sole Canadian adipic acid plant located in Ontario.

A notable exception to the overall decrease in IPPU emissions was the 5.4 Mt (113%) increase in emissions from the use of HFCs to replace chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) since 2005. However, since 2018, HFC emissions have been decreasing, primarily due to a reduction in HFC imports, coinciding with the implementation of federal regulations gradually phasing down HFCs.<sup>9</sup>

## Agriculture – 2023 GHG Emissions (55 Mt)

The Agriculture sector covers non-energy GHG emissions related to the production of crops and livestock. In 2023, emissions from Agriculture accounted for 55 Mt, or 7.9% of total GHG emissions for Canada, including 28% and 76% of national CH<sub>4</sub> and N<sub>2</sub>O emissions, respectively.

The main drivers of the emission trend in the Agriculture sector are the fluctuations in livestock populations and the application of inorganic nitrogen fertilizers to agricultural soils mainly in the Prairie provinces. Since 2005, fertilizer use has increased by 92%, while major livestock populations peaked in 2005, then decreased sharply until 2011. As a result, emissions in 2023 are roughly equivalent to 2005, though the contribution of emissions from crop production has increased relative to the livestock sector. In 2023, emissions from livestock feed consumption and digestion (enteric fermentation) accounted for 48% of total agricultural emissions, and the application of inorganic nitrogen fertilizers accounted for 19% of total agricultural emissions.

## Waste – 2023 GHG Emissions (23 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from Waste contributed 23 Mt (3.3%) to Canada's total emissions in 2023.

The primary sources of emissions in 2023 for the Waste sector are Landfills (20 Mt or 86% of total emissions from this sector), including municipal solid waste (MSW) and industrial wood waste disposal. Wastewater Treatment and Discharge accounted for 2.6 Mt (11%) of the Waste sector emissions. Other sources include Biological Treatment of Solid Waste (composting) (2.2%), and Incineration and Open Burning of Waste (0.7%).

Between 2005 and 2023, emissions from MSW landfills decreased by 3.6%. Of the 33 Mt CO<sub>2</sub> eq of CH<sub>4</sub> generated by MSW landfills in 2023, 19 Mt CO<sub>2</sub> eq (57%) were emitted to the atmosphere, while 12 Mt CO<sub>2</sub> eq (37%) were captured by landfill gas collection facilities and flared or used for energy (compared to 29% in 2005). The remaining 2.1 Mt (6.3%) is assumed to be oxidized through landfill cover materials.

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

## The Key Contribution of Facility Data to GHG Estimates

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

Since 2004, Environment and Climate Change Canada's (ECCC) [Greenhouse Gas Reporting Program \(GHGRP\)](#) has been collecting and publishing facility-reported GHG emissions information annually. Industrial process emissions reported to the GHGRP are directly incorporated in the NIR's IPPU sector for cement, lime and aluminium production, as are volumes of CO<sub>2</sub> captured, transported, injected and stored in geological reservoirs. Emissions from waste incineration and industrial wastewater are also directly included in the NIR. Work is ongoing to integrate more facility-reported data in the national GHG inventory. Technical specifications of industrial fuel and raw material reported to the GHGRP are also used to verify and improve the quality of industrial process emissions estimates. 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 Industry Classification Systems (see Annex 4 for more detail). The national energy balance is largely based on facility data collected by Statistics Canada and is the key data source used to estimate fuel combustion emissions for space heating to electricity generation and industrial, manufacturing and transportation activities. Statistics Canada also collects facility data on behalf of ECCC on chemical and petrochemical production.

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

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

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

### Land Use, Land-Use Change and Forestry – 2023 (Net GHG Source of 4.2 Mt)

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

In this sector, the net flux is calculated as the sum of CO<sub>2</sub> and non-CO<sub>2</sub> emissions to the atmosphere and CO<sub>2</sub> removals from the atmosphere. In 2023, this net flux amounted to a net source of 4.2 Mt.

Net fluxes from the LULUCF sector over recent years have fluctuated between net emissions of 4.2 Mt and 68 Mt. Fluctuations are driven by the variability in crop yields and by variations in emissions from HWP and removals from Forest Land, which are closely tied to forest harvest rates.

Estimates from the forest sector are split between anthropogenic emissions and removals associated with forest management and HWP, and emissions and removals resulting from the natural cycles of disturbances in managed forests (wildfires and insects). The combined net flux from Forest Land and HWP—from forest harvest—fluctuated from a net source of 80 Mt in 2005 to a net source of 19 Mt in 2023. This was a result of decreases in harvest rates and longer-term effects of disturbance history—natural and anthropogenic—on the overall age structure of the Canadian managed forest. In 2023, an additional 5 Mt CO<sub>2</sub> eq of carbon was sequestered to the global pool of HWP coming from Canadian Forests; however 67% of carbon in the HWP pool, that was disposed of or consumed as bioenergy, was associated with short-lived products and bioenergy production.

In most years, cropland contributed to net removals ranging from 1.6 Mt (1991) to 42 Mt (2014). Net emissions occurred due to drought in recent years—specifically 2002, 2003 and 2022—that resulted in low yields and consequently carbon loss from soils as in these years, decomposition rates were higher than carbon input rates to soils. Net removals have increased, on average, as a result of improved soil management practices including conservation tillage and an overall

gradual increase in crop productivity resulting from improved and more intensive practices such as the reduced use of summer fallow. Interannual variability occurs throughout the time series, reflecting weather-related impacts to crop production. Since 2005, a decline in net removals from a decrease in perennial land cover has largely offset removals resulting from increasing yields and there is, subsequently, no clear trend.

The conversion of forests to other land uses is a prevalent practice in Canada and is mainly due to resource extraction and cropland expansion. Emissions resulting from forest conversion in the years 2005 to 2023 have fluctuated around 17 Mt.

## Using Atmospheric Measurements to Improve Inventory Estimates

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

Other approaches to estimating emissions have recently emerged, based on inverse modelling of GHG emissions or removals derived from measurements of atmospheric gas concentrations. These approaches are 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).

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

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

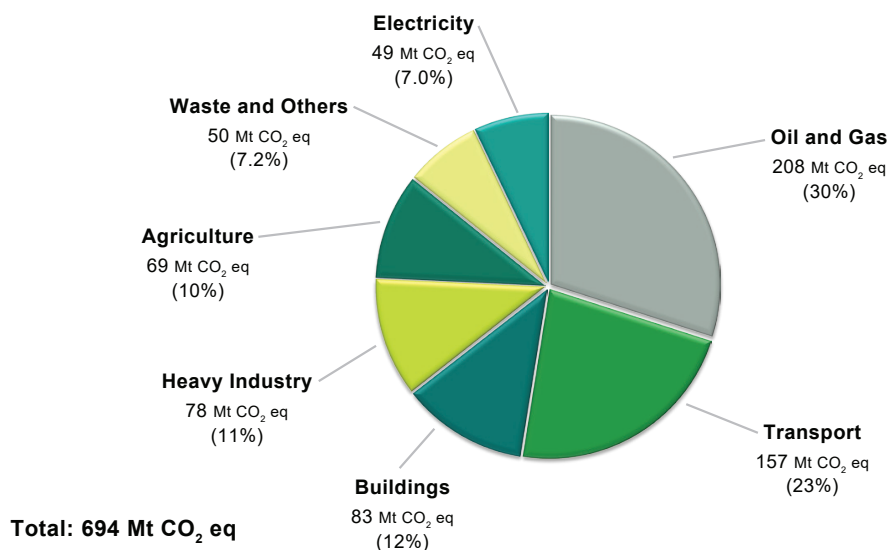
## ES.5. Canadian Economic Sectors

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

Overall, GHG emissions trends in Canada’s economic sectors are consistent with those described for similar IPCC sectors (Figure ES–6). The most notable trends in Canada’s emission profile between 2005 and 2023 were from Electricity as well as Oil and Gas sources, Electricity decreasing by 67 Mt and Oil and Gas, increasing by 13 Mt. Over the same period, in addition to Oil and Gas sources, Agriculture is the only other sector that showed emission increases (Table ES–2). The emission trends in Oil and Gas are mainly due to the production growth in Canada’s oil sands operations (52 Mt) offset by methane emission reductions from conventional oil and gas activities (-33 Mt). Emissions from Electricity decreased, driven by the phase-out of coal-fired electricity generation. Emissions from Heavy Industry, Waste and others and Buildings also decreased over this period. Since 2005, Transport emissions have generally increased, with a notable decrease in 2020. Emissions in 2023 from the Transport economic sector are similar to 2005 levels.

Further information on economic sector trends can be found in Chapter 2, section 2.4. 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 as well as in the GHG data files at [open.canada.ca](https://open.canada.ca).

Figure ES-6 **Breakdown of Canada's GHG Emissions by Economic Sector (2023)**



Note: Totals may not add up due to rounding.

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

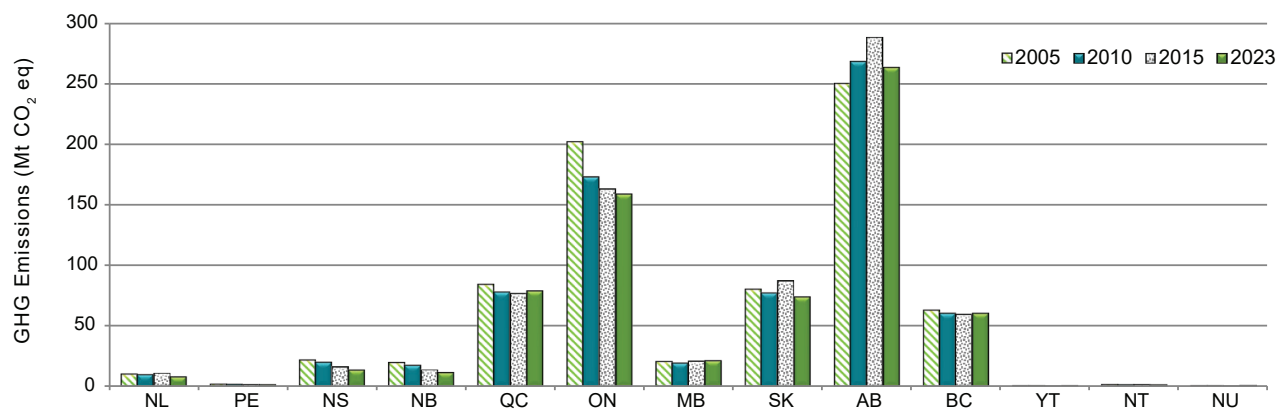
Economic sector	GHG Emissions (Mt CO <sub>2</sub> eq)							Change (Mt CO <sub>2</sub> eq)	Change (%)
	2005	2018	2019	2020	2021	2022	2023	2005–2023	2005–2023
<b>NATIONAL TOTAL</b>	<b>759</b>	<b>747</b>	<b>747</b>	<b>682</b>	<b>694</b>	<b>700</b>	<b>694</b>	<b>-65</b>	<b>-8.5%</b>
Oil and Gas	194	223	222	204	211	209	208	13	6.9%
Electricity	116	63	62	54	52	49	49	-67	-58%
Transport	156	169	169	142	149	155	157	0.37	0.2%
Heavy Industry	88	80	79	75	78	78	78	-9.5	-11%
Buildings	85	92	94	88	85	88	83	-2.0	-2.3%
Agriculture	66	69	69	70	69	70	69	3.7	5.6%
Waste and Others	54	52	52	48	49	50	50	-3.9	-7.2%

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

## ES.6. Provincial and Territorial GHG Emissions

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

Historically, Alberta and Ontario have been the highest-emitting provinces, representing 38% and 23% of the national total in 2023, respectively. Since 2005, emission patterns in these two provinces have diverged. Those in Alberta have increased by 13 Mt (5.1%) since 2005, primarily because of the expansion of oil and gas operations (Figure ES-7). In contrast, Ontario's emissions have decreased by 44 Mt (22%) since 2005, owing primarily to the closure of coal-fired electricity generation plants. Overall, emissions have decreased in eight provinces and one territory between 2005 and 2023, while emissions of two provinces and two territories have increased (Table ES-3).

Figure ES-7 **GHG Emissions by Province and Territory in 2005, 2010, 2015 and 2023**Table ES-3 **Greenhouse Gas Emissions by Province and Territory, Selected Years**

Year	GHG Emissions Totals (Mt CO <sub>2</sub> eq)									Change (Mt CO <sub>2</sub> eq)	Change (%)
	2005	2010	2015	2018	2019	2020	2021	2022	2023	2005–2023	2005–2023
<b>CANADA</b>	<b>759</b>	<b>728</b>	<b>742</b>	<b>747</b>	<b>747</b>	<b>682</b>	<b>694</b>	<b>700</b>	<b>694</b>	<b>-65</b>	<b>-8.5%</b>
NL	10	10	11	11	11	8.6	8.0	8.1	7.9	-2.4	-23%
PE	1.9	1.8	1.5	1.6	1.6	1.6	1.6	1.6	1.6	-0.30	-16%
NS	22	20	16	17	16	14	14	14	14	-8.4	-38%
NB	20	18	14	13	13	11	12	12	11	-8.4	-42%
QC	85	78	77	80	82	75	78	79	79	-5.6	-6.6%
ON	202	173	163	164	165	149	152	158	159	-44	-22%
MB	21	19	21	22	22	21	21	22	21	0.59	2.8%
SK	80	77	87	89	86	75	76	75	74	-6.5	-8.1%
AB	251	268	289	283	285	266	268	265	263	13	5.1%
BC	63	60	60	65	63	59	61	62	60	-2.8	-4.5%
YT	0.56	0.65	0.53	0.64	0.69	0.59	0.65	0.66	0.67	0.11	19%
NT	1.7	1.5	1.6	1.4	1.4	1.2	1.3	1.4	1.4	-0.36	-21%
NU	0.59	0.60	0.63	0.74	0.73	0.63	0.70	0.70	0.71	0.13	22%

Note:  
Totals may not add up due to rounding.

## ES.7. Key Category Analysis

The 2006 IPCC Guidelines (IPCC, 2006) define procedures for selecting estimation methods and defining which are most suited to national circumstances, considering the available knowledge and resources. Identifying and prioritizing methodology improvements is a good practice that can be facilitated by the identification of key categories, ensuring the most efficient use of available resources. This annual analysis is required by the MPGs. Key categories are prioritized because their estimates have a significant influence on the national total, in terms of the absolute level of emissions, the trend assessment, or both. For the 1990–2023 GHG inventory, level and trend key category assessments were performed according to the Tier 1 approach (IPCC, 2006).

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

1. Stationary Fuel Combustion – Manufacturing Industries and Construction, CO<sub>2</sub>
2. Fuel Combustion – Road Transportation, CO<sub>2</sub>
3. Stationary Fuel Combustion – Energy Industries, CO<sub>2</sub>

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

1. LULUCF – Forest Land Remaining Forest Land, CO<sub>2</sub>
2. LULUCF – Harvested Wood Products, CO<sub>2</sub>
3. Stationary Fuel Combustion – Energy Industries, CO<sub>2</sub>

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

## ES.8. Inventory Improvements

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

The 2025 edition of the GHG inventory incorporates methodological improvements in the estimation of multiple emission sources. Notably and among others, fugitive emission estimates from activities in the natural gas transmission, storage and distribution industries were revised. Furthermore, updated activity data and emission factors for drained organic soils were integrated into the Agriculture and LULUCF Cropland estimates. Additionally refinements occurred in the LULUCF sector, with revisions to biomass C change associated with land use change events as well as the integration of improved emission and removal factors for peat extraction under the Wetlands land use category, and revisions to harvest rates affecting Forest Land and HWP. Finally, a change in the allocation of emissions and removals between the categories Forest Land and HWP improves the comparability of Canada's reporting of the Forest Sector internationally. Overall, without the LULUCF sector, the recalculations resulted in -2.8 Mt in 2005 and -7.9 Mt in 2022. The improved methods use Canadian-specific studies and knowledge, adopt the most up-to-date activity data and better reflect evolving technologies and industry practices. [Chapter 8](#) of the present report provides greater detail on the impacts of current inventory improvements on the overall emission trends.

Improvements to inventory estimates are anticipated in future editions of this report. For example, and amongst several planned improvements, in the Energy sector for Transport, the migration to the United States Environmental Protection Agency's (U.S. EPA) MOtor Vehicle Emission Simulator 5 (MOVES5) model is planned. Improvements expected in the LULUCF sector include tracking of emissions and removals resulting from land use change from oil and gas development, the growth of urban trees and the inclusion of methane emissions from the creation of reservoirs. Refer to [Chapter 8](#) for details on the planned improvements and for a complete list covering all sectors. For additional detail on LULUCF planned improvements of methods related to Forests, refer to the [Improvement Plan for Forest and Harvested Wood Products Greenhouse Gas Estimates](#).

## ES.9. National Inventory Arrangements

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

### Structure of Submission

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

Part 1 of the NIR, in accordance with MPG requirements, includes chapters 1 to 8:

- [Chapter 1](#) provides an overview of Canada's legal, institutional and procedural arrangements, along with cross-cutting information, for producing the inventory, and a description of Canada's GHGRP and how the facility-reported data are integrated in the inventory.
- [Chapter 2](#) provides an analysis of Canada's GHG emission trends and a breakdown of emission trends by Canadian economic sectors.
- Chapters [3](#) to [7](#) provide descriptions and additional analysis for each sector.
- [Chapter 8](#) presents a summary of the recalculations and, implemented and planned improvements.

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

Part 3 comprises annexes 8 to 13, which present rounding procedures, summary tables of GHG emissions at the national level and for each provincial and territorial jurisdiction, sector and gas, as well as additional details on the GHG intensity of electricity generation. Detailed GHG data are also available at [open.canada.ca](https://open.canada.ca).

The complete NIR, in PDF format, can be accessed on the Government of Canada's [publications website](#). ECCC is streamlining NIR content, including a transition away from heavy amounts of data in the PDF format of the report to greater data availability in various formats on [open.canada.ca](https://open.canada.ca). If you have any questions or would like to share views on this, please contact us at [ges-ghg@ec.gc.ca](mailto:ges-ghg@ec.gc.ca).

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# CHAPTER 1

## NATIONAL CIRCUMSTANCES, INSTITUTIONAL ARRANGEMENTS, AND CROSS-CUTTING INFORMATION

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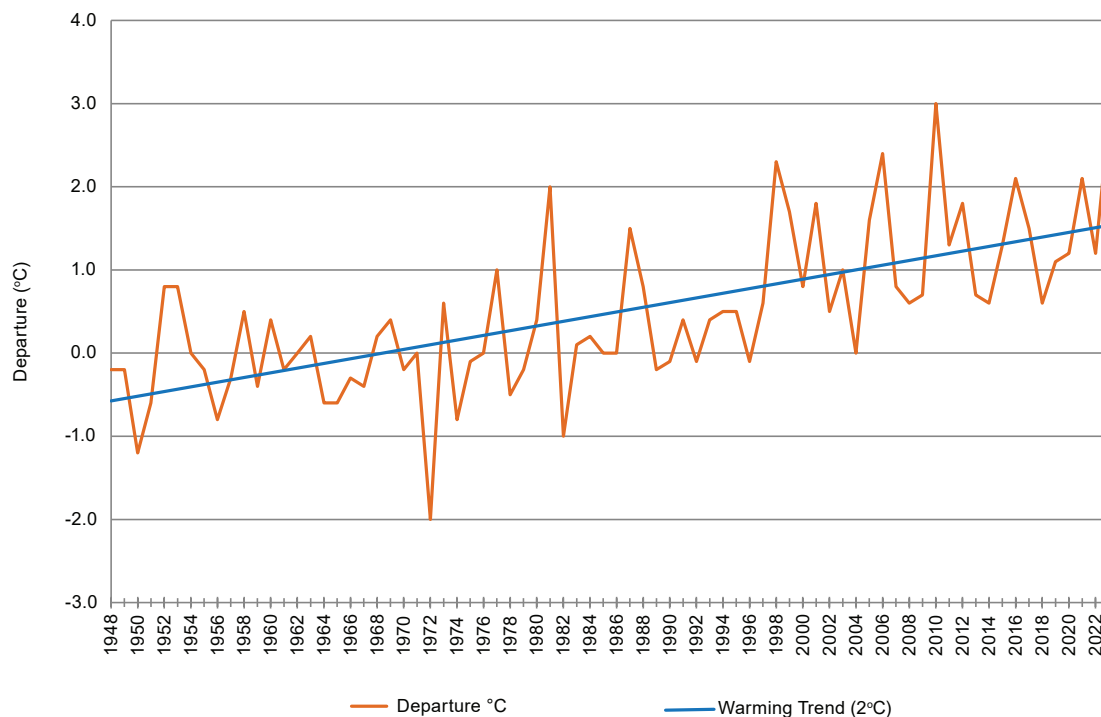
### 1.1. Greenhouse Gas Inventories and Climate Change

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

Climate change has caused widespread and rapid changes resulting in impacts on human and natural systems. It has caused substantial damage and increasingly irreversible losses to ecosystems (IPCC, 2023). Atmospheric concentrations of GHGs have increased significantly since pre-industrial times across the globe. Since 1750, the concentration of atmospheric carbon dioxide (CO<sub>2</sub>) has increased by 151%; methane (CH<sub>4</sub>), by 265%; and nitrous oxide (N<sub>2</sub>O), by 125% (WMO, 2024). Observed increases in well-mixed GHG concentrations since around 1750 are unequivocally caused by GHG emissions from human activities over this period (IPCC, 2023).

In Canada, the impacts of climate change may be observed in the increase in extreme weather events, reduction in freshwater resources, increase in the risk and severity of forest fires and pest infestations, reduction in Arctic ice, and acceleration of glacial melting. Canada's national average temperature for 2023 was 2.8°C above the baseline average (defined as the mean over the 1961–1990 reference period) (see [Figure 1–1](#)). Based on preliminary data, the year 2023 ranked the 2nd warmest observed since nationwide recording began in 1948. Average annual temperatures have remained above the baseline average since 2005, with a warming trend of 2°C over the past 76 years (ECCC, 2024). Canada's climate is and will continue to warm rapidly, at a rate that is already two times faster than the global average and three times faster in the North. Emissions must be reduced to limit the extent of climate change and avoid ecological and socio-economic tipping points, understanding that climate change impacts will continue even after global net-zero emissions are achieved (ECCC, 2023a).

Figure 1-1 Annual Canadian Temperature Departures and Long-Term Trend, 1948–2023



Note:  
Source: ECCC (2024)

### 1.1.1. Background to Canada's National Greenhouse Gas Inventory

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

To achieve its objective and implement its provisions, the Paris Agreement sets out several guiding principles and commitments. Specifically, Article 13 of this agreement establishes an enhanced transparency framework (ETF) for action and support. It requires all Parties to gather and share information on GHG emissions, national policies, best practices and progress towards their emissions targets among other items. Precisely, it also commits the signatories to develop, periodically update, publish, and make available to the Conference of the Parties (COP) their national inventories of anthropogenic<sup>1</sup> emissions by sources, and removals by sinks, of seven GHGs. Canada, as a developed Party under the UNFCCC, is required by the Convention to submit its national GHG inventory every year. In addition, all Parties under the Paris Agreement ETF are required to submit to the UNFCCC a Biennial Transparency Report (BTR)<sup>2</sup> every two years. In support of Article 13, Decision CMA.1 of FCCC/Cp/2018/L.13 established the modalities, procedures, and guidelines (MPGs) for the transparency framework for action and support including the requirements for National Inventory Reports. A suggested general outline of the National Inventory Report (NIR) was also established in Decision 5/CMA.3 in 2021.

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

<sup>2</sup> The BTR include information on progress towards Nationally Determined Contributions (NDCs), policies and measures, climate change impacts and adaptation, levels of financial, technology development and transfer and capacity-building support, and areas of improvement. It also summarizes some of the information presented in the NIR. The first BTR submission was due by the end of 2024.

Canada's annual submission of the NIR is comprised of an inventory report and a set of data tables, referred to as the Common Reporting Tables (CRTs), to be submitted together by April 15 of each year under the Paris Agreement and UNFCCC. This edition of the NIR documents Canada's annual GHG emission estimates for the 1990–2023 period based on international agreed upon reporting requirements and formats.<sup>3</sup> The 2024 edition was the first to be submitted under the Paris Agreement.<sup>4</sup>

### 1.1.2. Metrics and Global Warming Potentials

Since 2005 was adopted as a base year for Canada's Nationally Determined Contribution (NDC) and emission reduction targets, many of the metrics in this report are presented in that context, in addition to the 1990 base year as required by the MPGs. Each type of GHG has a unique atmospheric lifetime and heat-trapping potential. The radiative forcing<sup>5</sup> effect of a gas in the atmosphere is a quantification of its ability to cause atmospheric warming. Direct radiative forcing occurs when the gas itself is a GHG, whereas indirect forcing occurs when atmospheric condition and non-GHG species chemically transform to a GHG, such as carbon monoxide (CO) to carbon dioxide (CO<sub>2</sub>), 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<sub>2</sub>. A GHG's GWP value accounts for the instantaneous radiative forcing caused by an incremental concentration increase, as well as the lifetime of the gas; it is a relative measure of the warming effect that the emission of a radiative gas (i.e., a GHG) might have on the surface atmosphere.

The GWP concept was developed to allow a comparison of the ability of each GHG to trap heat in the atmosphere relative to CO<sub>2</sub>, as well as characterize GHG emissions by how much CO<sub>2</sub> is required to produce a similar warming effect over a given time period. This is the carbon dioxide equivalent (CO<sub>2</sub> eq) value and is calculated by multiplying the amount of the gas by its associated GWP. This normalization to CO<sub>2</sub> eq enables the quantification of total national emissions expressed as CO<sub>2</sub> eq.

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

3 For ease of reference please refer to the following documents:

Paris Agreement: [https://unfccc.int/sites/default/files/resource/parisagreement\\_publication.pdf](https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf)

MPGs: [https://unfccc.int/sites/default/files/resource/l23\\_0.pdf?download](https://unfccc.int/sites/default/files/resource/l23_0.pdf?download)

Guidelines for the operationalizing of the MPGs (i.e., suggested reporting structure): [https://unfccc.int/sites/default/files/resource/CMA2021\\_L10a2E.pdf](https://unfccc.int/sites/default/files/resource/CMA2021_L10a2E.pdf)

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

5 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 <sup>a</sup>	Atmospheric Lifetime (years)
Carbon dioxide	CO <sub>2</sub>	1	Variable
Methane <sup>b,c</sup>	CH <sub>4</sub>	28	12.4
Nitrous oxide	N <sub>2</sub> O	265	121
Sulphur hexafluoride	SF <sub>6</sub>	23 500	3 200
Nitrogen trifluoride	NF <sub>3</sub>	16 100	500
<b>Hydrofluorocarbons (HFCs)</b>			
HFC-23	CHF <sub>3</sub>	12 400	222
HFC-32	CH <sub>2</sub> F <sub>2</sub>	677	5.2
HFC-41	CH <sub>3</sub> F	116	2.8
HFC-43-10mee	CF <sub>3</sub> CHFCHFCF <sub>2</sub> CF <sub>3</sub>	1 650	16.1
HFC-125	CHF <sub>2</sub> CF <sub>3</sub>	3 170	28.2
HFC-134	CHF <sub>2</sub> CHF <sub>2</sub>	1 120	9.7
HFC-134a	CH <sub>2</sub> FCF <sub>3</sub>	1 300	13.4
HFC-143	CH <sub>2</sub> FCHF <sub>2</sub>	328	3.5
HFC-143a	CH <sub>3</sub> CF <sub>3</sub>	4 800	47.1
HFC-152	CH <sub>2</sub> FCH <sub>2</sub> F	16	0.40
HFC-152a	CH <sub>3</sub> CHF <sub>2</sub>	138	1.5
HFC-161	CH <sub>3</sub> CH <sub>2</sub> F	4	0.18
HFC-227ea	CF <sub>3</sub> CHFCF <sub>3</sub>	3 350	38.9
HFC-236cb	CH <sub>2</sub> FCF <sub>2</sub> CF <sub>3</sub>	1 210	13.1
HFC-236ea	CHF <sub>2</sub> CHFCF <sub>3</sub>	1 330	11
HFC-236fa	CF <sub>3</sub> CH <sub>2</sub> CF <sub>3</sub>	8 060	242
HFC-245ca	CH <sub>2</sub> FCF <sub>2</sub> CHF <sub>2</sub>	716	6.5
HFC-245fa	CHF <sub>2</sub> CH <sub>2</sub> CF <sub>3</sub>	858	7.7
HFC-365mfc	CH <sub>3</sub> CF <sub>2</sub> CH <sub>2</sub> CF <sub>3</sub>	804	8.7
<b>Perfluorocarbons (PFCs)</b>			
PFC-14	CF <sub>4</sub>	6 630	50 000
PFC-116	C <sub>2</sub> F <sub>6</sub>	11 100	10 000
PFC-218	C <sub>3</sub> F <sub>8</sub>	8 900	2 600
PFC-31-10	C <sub>4</sub> F <sub>10</sub>	9 200	2 600
PFC-318	c-C <sub>4</sub> F <sub>8</sub>	9 540	3 200
PFC-41-12	n-C <sub>5</sub> F <sub>12</sub>	8 550	4 100
PFC-51-14	n-C <sub>6</sub> F <sub>14</sub>	7 910	3 100
PFC-91-18	C <sub>10</sub> F <sub>18</sub>	7 190	2 000
PFC-c216	c-C <sub>3</sub> F <sub>6</sub>	9 200	3 000

Notes:

a. Source: Table 8.A.1 in IPCC (2013).

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

c. Fossil methane has been excluded as agreed upon per UNFCCC Decision 5/CMA.3.

## 1.2. Canada's National Circumstances and Institutional Arrangements

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

### 1.2.1. National Entity and Focal Point

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

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

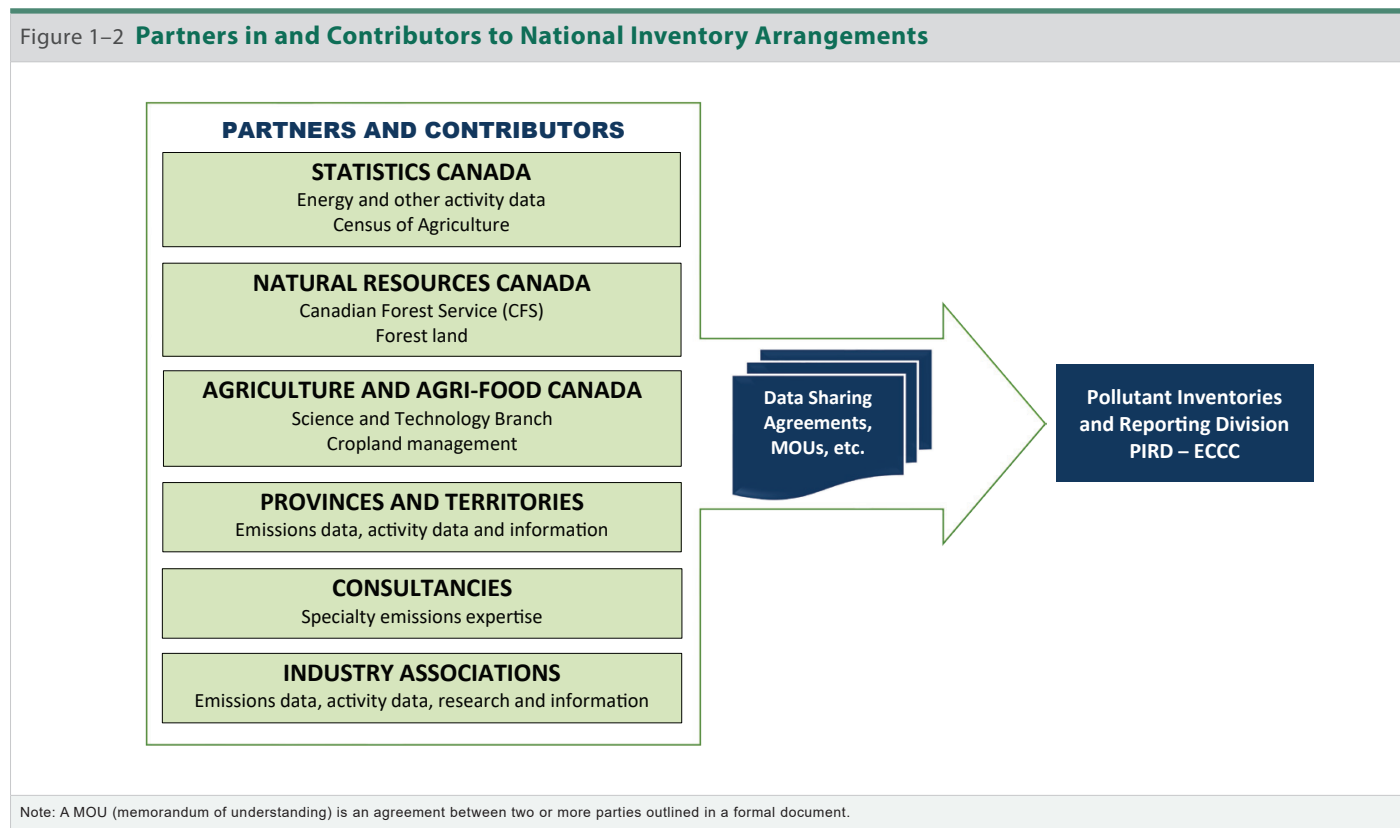
An overview of the institutional arrangements and inventory preparation process is provided in the following sections.

### 1.2.2. Institutional Arrangements

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

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

Figure 1–2 identifies the various partners in and contributors to Canada's national inventory and their contribution to its development.



### 1.2.2.1. Statistics Canada

As Canada's national statistical agency, Statistics Canada provides ECCC with a large portion of the underlying activity data for estimating the GHG emissions in the Energy and the Industrial Processes and Product Use (IPPU) sectors. Statistics Canada is responsible for the collection, compilation, and dissemination of Canada's energy balance in its annual *Report on Energy Supply and Demand in Canada* (RESO) (Statistics Canada, No date). The energy balance utilises a number of Statistics Canada surveys, including, among others, the annual Industrial Consumption of Energy (ICE) survey, which collects energy consumption data from various industries. Energy balance figures are transmitted annually to ECCC according to the terms of a Letter of Agreement between the two departments.

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

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

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

ECCC has officially assigned responsibilities to Agriculture and Agri-Food Canada (AAFC) and the Canadian Forest Service of Natural Resources Canada (NRCAN/CFS) for the development of key components of the Land Use, Land-Use Change and Forestry (LULUCF) sector, which has been formalized through memoranda of understanding (MOUs).

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

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

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

### 1.2.2.3. Other Agreements and Data Sources

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

In 2013, an amended bilateral agreement was signed with the Aluminium Association of Canada (AAC), the initial intent of which was to provide ECCC with annual process-related emission estimates for CO<sub>2</sub>, PFCs and SF<sub>6</sub>. Since the GHGRP has supplied some of these data since 2017, the purpose of the agreement with AAC has evolved, now consisting of the provision, upon request, of supporting data and information on the emission factors (EFs) and parameters used to derive emission estimates. ECCC has also signed an agreement with the Canadian Electricity Association (CEA) to obtain data on SF<sub>6</sub> emissions and other areas related to power transmission systems.

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

Under its [Greenhouse Gas Reporting Program \(GHGRP\)](#),<sup>6</sup> ECCC collects emissions and other supporting data (e.g., activity data) annually from facilities across Canada that emit large quantities of GHGs. These facility-level data are used directly in the national inventory estimates for specific sectors, and in addition, play a key role in the overall inventory development process, where they are used to compare and verify certain inventory estimates in the NIR. For more information on the facility-level data reported under the GHGRP and specific uses in the NIR, see section [1.4.4](#).

<sup>6</sup> <https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/facility-reporting.html>

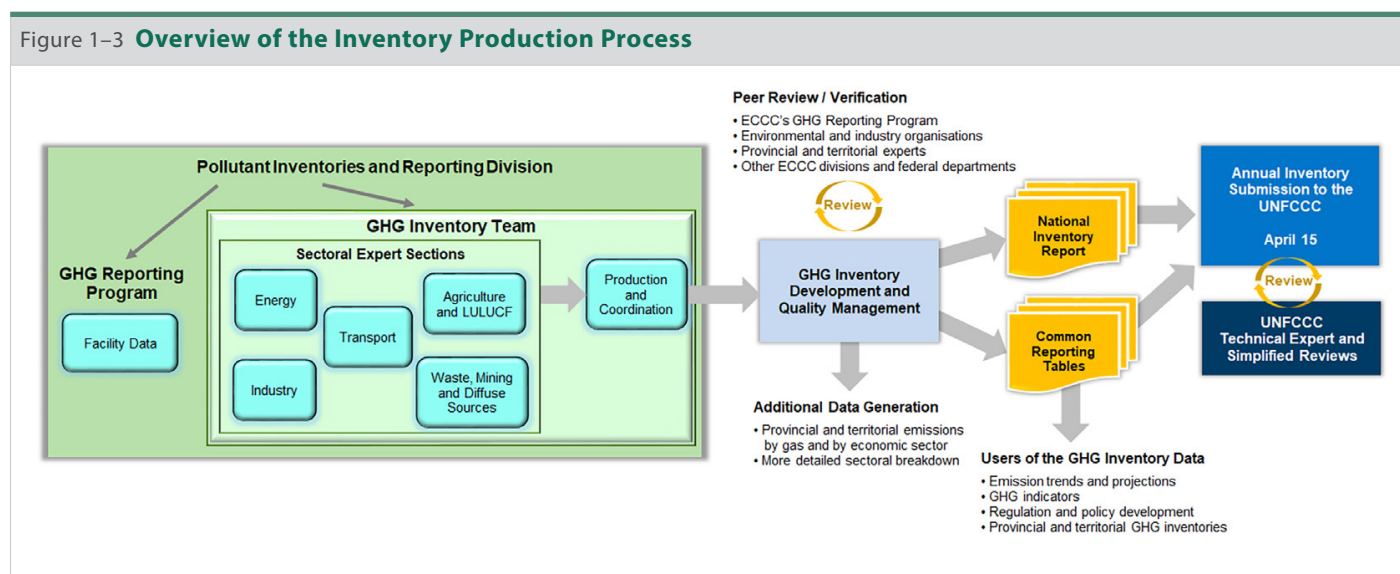
When required, and resources permitting, contracts are concluded with consulting firms and universities to conduct in-depth studies—for example, on developing or updating country-specific EFs.

### 1.2.3. Inventory Preparation Process

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

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

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



#### Phase 1: Inventory Planning

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

#### Phase 2: Inventory Preparation

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

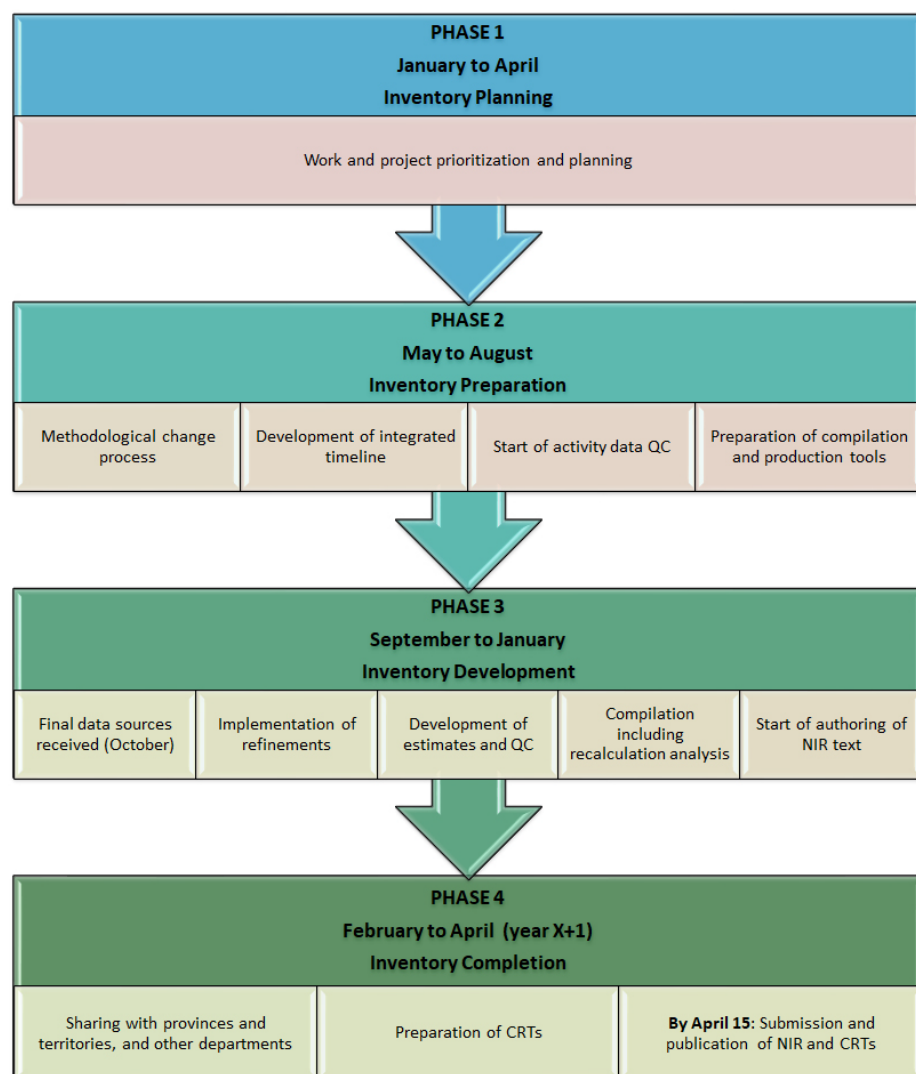
### Phase 3: Inventory Development

Methodologies, including those updated from continuous improvement activities, are finalized, reviewed and approved by the end of September. Most of the activity data collection, compilation and review process is completed by October. After that, refinements are fully implemented and the data are entered in emission quantification tools, for example spreadsheets, scripts and queries. In November and December, draft estimates are developed by designated inventory experts, compiled and then, internally reviewed. QC checks and recalculation analysis are performed on the compiled emission estimates. In December, the first version of the compiled draft preliminary estimates are ready. For the first time, in December 2024, Canada's Preliminary Greenhouse Gas Emissions at the national level were published in a preliminary release. During the inventory development phase, the authoring of the report also begins.

### Phase 4: Inventory Completion

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

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



### 1.2.4. Archiving system

In keeping with the reporting requirements and for record purposes, the material to be archived includes all information for the reported time series, including all disaggregated emission factors and activity data, all documentation about generating and aggregating data, including QA/QC, review results and planned inventory improvements. The archived information is managed and kept in internal servers. Furthermore, all references cited in Canada's NIR are compiled and archived in the integrated electronic reference library every year.

### 1.2.5. Processes for the Official Consideration and Approval of the Inventory

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

### 1.2.6. Annual Inventory Reviews

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

As part of the annual inventory cycle and up to 2023, Canada's inventory submission was typically reviewed annually by an Expert Review Team (ERT) following agreed-upon UNFCCC review guidelines<sup>7</sup> as adopted in Decision 13/CP.20 in 2014. Starting in 2025, in accordance with Decision 18/CMA.1 (2018) and under Article 13 of the Paris Agreement, information submitted by each Party will undergo a technical expert review (TER) consistent with the MPGs. Every 2 years, these reviews will examine the information presented in the NIR and BTR.<sup>8</sup> On the years that a BTR is not due to the UNFCCC, Canada's GHG inventory will undergo a simplified review, consisting of an initial assessment of completeness and consistency with the MPGs conducted by the UNFCCC Secretariat. The information reviewed for this type of review is mostly quantitative, from the CRTs. Once finalized, findings from all reviews are made public by the UNFCCC.<sup>9</sup>

For more information on the review process and improvements implemented following recommendations, refer to [Chapter 8](#).

## 1.3. Methodologies and Data Sources

As required by the MPGs, the GHG emission and removal estimates contained in Canada's GHG inventory are developed using methodologies consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). The inventory is divided into the following five IPCC main sectors—Energy, IPPU, Agriculture, LULUCF, and Waste—each of which is further subdivided into subsectors or categories. The emissions and removals of seven direct GHGs: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub> are estimated. In some cases, while not mandatory in the reporting requirements, the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019) is also used to further improve methodologies and increase accuracy.

While not mandatory, the MPGs encourage Parties to provide information on the following indirect GHGs: SO<sub>x</sub>, NO<sub>x</sub>, CO and NMVOCs (see Annex 7). For all sectors except LULUCF, these gases are inventoried and reported separately to the United Nations Economic Commission for Europe.<sup>10</sup>

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

The 2006 IPCC Guidelines and 2019 Refinement to the guidelines (IPCC, 2006, 2019) specify tiers that represent the level of methodological complexity applied in the emissions estimates. Tier 1 is defined as the simplest, Tier 2 is defined as intermediate, and Tier 3 is defined as the most complex in terms of methodology and data requirements. The choice

<sup>7</sup> 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>.

<sup>8</sup> Further details about the scope of technical expert reviews, including on exclusions from its scope, are available in the MPGs.

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

<sup>10</sup> Information on Canada's ozone and aerosol precursors, including CO, NO<sub>x</sub>, NMVOC and SO<sub>x</sub>, can be found in Canada's Air Pollutant Emission Inventory, which is available online at [www.canada.ca/APEI](http://www.canada.ca/APEI).

of methodology tier can be based on multiple factors, but it is suggested that higher tier methods are selected for key categories. Category-specific decision trees are available in the 2006 IPCC Guidelines to support these choices. Key categories are summarized in the Executive Summary and available in Annex 1. A summary of the methodology tiers used in the estimation of each GHG category is provided in [Table 1–2](#). For detail on methodologies, refer to Annex 3.

Table 1–2 <b>Summary of Methodology Tiers used in the NIR by Category</b>		
GHG Categories		Methodology Tier
<b>ENERGY</b>		
<b>a. Stationary Combustion Sources</b>		
Public Electricity and Heat Production		2,3
Petroleum Refining Industries		2
Oil and Gas Extraction		2
Mining		2
Manufacturing Industries		2,3
Construction		2
Commercial and Institutional		2
Residential		2
Agriculture and Forestry		2
<b>b. Transport</b>		
Aviation		2,3
Road Transportation		2,3
Railways		1,2
Marine		1,2
Other Transportation		2,3
<b>c. Fugitive Sources</b>		
Coal Mining		2,3
Oil and Natural Gas		2,3
<b>d. CO<sub>2</sub> Transport and Storage</b>		-
<b>INDUSTRIAL PROCESSES AND PRODUCT USE</b>		
<b>a. Mineral Products</b>		
Cement Production		2,3
Lime Production		2,3
Mineral Product Use		1,2,3
<b>b. Chemical Industry</b>		
Ammonia Production		2,3
Nitric Acid Production		1,2,3
Adipic Acid Production		1,2,3
Petrochemical and Carbon Black Production		1,2,3
<b>c. Metal Production</b>		
Iron and Steel Production		1,2,3
Aluminium Production		2,3
Magnesium Production and Casting		1,2,3
<b>d. Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub></b>		1,2
<b>e. Non-Energy Products from Fuels and Solvent Use</b>		1
<b>f. Other Product Manufacture and Use</b>		1,3
<b>AGRICULTURE</b>		
<b>a. Enteric Fermentation</b>		1,2
<b>b. Manure Management</b>		1,2
<b>c. Agricultural Soils</b>		1,2
<b>d. Field Burning of Agricultural Residues</b>		1
<b>e. Liming, Urea Application and Other Carbon-Containing Fertilizers</b>		1
<b>WASTE</b>		
<b>a. Landfills</b>		2
<b>b. Biological Treatment of Solid Waste</b>		3
<b>c. Incineration and Open Burning of Waste</b>		1,2,3
<b>d. Wastewater Treatment and Discharge</b>		2,3
<b>LAND USE, LAND-USE CHANGE AND FORESTRY</b>		
<b>a. Forest Land</b>		1,3
<b>b. Cropland</b>		1,2
<b>c. Grassland</b>		1
<b>d. Wetlands</b>		2
<b>e. Settlements</b>		2,3
<b>f. Harvested Wood Products</b>		3

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

Emissions and removals for LULUCF are mainly based on empirical relationships that estimate biological processes, such as decomposition and photosynthesis as influenced by ecological and climatic factors. Manipulated biological systems monitored in LULUCF, such as agricultural lands, managed forests, 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. These systems require a combination of repeated measurements and modelling to estimate emissions from and removals and continual vigilance to assure that they consider the most recent scientific understanding of these processes. The need to separate anthropogenic impacts from large natural fluxes, which is unique to these systems, creates an additional challenge.

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

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

### 1.3.1. Treatment of Confidentiality Issues

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

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

## 1.4. Quality Assurance, Quality Control and Verification

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

### 1.4.1. Overview of Canada's Quality Management System

The development of Canada's GHG inventory is based on a continuous process of data collection, methodological refinement, and review. QA/QC procedures take place at all stages of the inventory development cycle. To ensure that a high-quality inventory is produced every year, a national inventory quality management system has been developed and implemented for the annual compilation and publication of the national GHG inventory. The quality management system includes a QA/QC plan; information creation, documentation and archiving processes; a standardized process for implementing methodological changes; identification of key roles and responsibilities; and a timeline for completing the various NIR-related tasks and activities. Further details on QA/QC and verification activities are available in [Chapter 3](#) to [Chapter 7](#).

### 1.4.2. Canada's Quality Assurance/Quality Control Plan

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

### 1.4.2.1. Quality Control Procedures

Quality control procedures consist of routine technical checks to 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 CRT online tool by the national inventory compiler and reviewer, and the tables are reviewed by the sector experts, for the entire time series of CRT. The category-specific Tier 1 QC procedures complement the general inventory QC procedures and are directed at specific types of data. These procedures require knowledge of the specific category, including methodologies, types of data available and the parameters associated with emissions or removals. To facilitate these Tier 1 checks, checklists have been developed to standardize and document the QC procedures. The QC checklists include a record of any corrective action taken and refer to supporting documentation.

A Tier 2 QC assessment is an opportunity to critically review a specific category or categories. A comprehensive assessment is required to ensure that the category will remain current and relevant for several years beyond the analysis year. This investigation is typically broad and uses a variety of sector-specific approaches, including assessments of the continued applicability of methods, EFs, activity data, uncertainty and others, and lays the foundation for future activities by developing and prioritizing recommendations for improvement. The Tier 2 QC checks may be documented with a standard checklist or an in-depth study to provide a comprehensive assessment.

### 1.4.2.2. Quality Assurance Procedures

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

### 1.4.2.3. Verification

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

## 1.4.3. Planning and Prioritization of Improvements

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

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

### 1.4.4. The Greenhouse Gas Reporting Program

In March 2004, the Government of Canada established the GHGRP to collect GHG emissions information annually from facilities across the country. Under this mandatory reporting program, requirements are described in the legal notice issued under section 46(1) of the *Canadian Environmental Protection Act, 1999* (Canada, 1999) and published biennially in the *Canada Gazette*.<sup>11</sup> The GHGRP, developed and administered by ECCC, allows the Government of Canada to continuously track GHG emissions from individual facilities to inform the public, improve the national GHG inventory and guide regulatory initiatives.

In December 2016, the Government of Canada published a Notice of Intent to inform stakeholders of its aim to expand the GHGRP, and specific requirements were expanded progressively over two phases during 2017 and 2018. This expansion was in order to enable the direct use of the reported data in the national GHG inventory, increase the consistency and comparability of GHG data across jurisdictions, and obtain a more comprehensive picture of Canadian facility-level emissions. Starting in 2017, the existing reporting threshold was lowered (from 50 kt to 10 kt CO<sub>2</sub> eq.), thereby requiring all facilities with annual GHG emissions exceeding 10 kt CO<sub>2</sub> eq. to report their emissions to the program. Facilities in 13 industry sectors were also required to use prescribed methods outlined in the Canada's Greenhouse Gas Quantification Requirements manual (ECCC, 2023b) to quantify their emissions and to provide additional information on their calculations. These industry sectors were: cement, lime, aluminium, iron and steel manufacturing; producers of ethanol, ammonia, nitric acid and hydrogen; electricity and heat generation plants; mining operations, petroleum refineries, pulp and paper production, and base metal production facilities. Facilities involved in CO<sub>2</sub> capture, transport, injection and geological storage activities were also required to report on these activities and adhere to the prescribed methods, starting in 2017. ECCC continues to assess potential changes under the GHGRP and further expansion in future years.

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

Starting in 2022, key program changes were introduced for the reporting of 2022 and 2023 emissions. The expanded requirements for the sectors and activities identified above were maintained while some changes designed to improve the integration of facility-reported data (FRD) into the national GHG inventory were introduced. To date, facility-reported GHG information has been collected and published by the GHGRP for the period 2004 to 2023. In 2023, a total of 1862 facilities (mostly industrial) reported their GHG emissions to the program. The GHGRP website<sup>12</sup> provides public access to this GHG emission information (e.g., emission totals by gas by facility).

It is important to note that the GHGRP applies to specific emission sources at facilities and does not cover all sources of GHG emissions (e.g., road transportation, residential fuel combustion, and agricultural sources), while the NIR is a complete accounting of all GHG sources and sinks in Canada. In 2023, total facility-reported GHG emissions represented 42% of Canada's total GHG emissions (694 Mt) and 63% 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 1–5).

The GHGRP provides Canadians with information about large GHG emitters across Canada and yearly changes in their emission levels, which is also shared with provincial and territorial jurisdictions. In accordance with the 2006 IPCC Guidelines (IPCC, 2006), FRD—which include all required data and supporting information reported by those facilities subject to the expanded reporting requirements (see Schedule 3 of the notice)<sup>13</sup>—are used by inventory experts for improvements (e.g., to transparency, comparability, consistency, completeness or accuracy) when these data are assessed to be of good quality (see Table 1–3). Based on the information provided in Table 1–3, it is estimated that approximately 20% of the FRD collected by the GHGRP is used in some manner to generate specific NIR estimates. While not explicitly included in the table, additional FRD are utilized for various activities such as quality control and analysis.

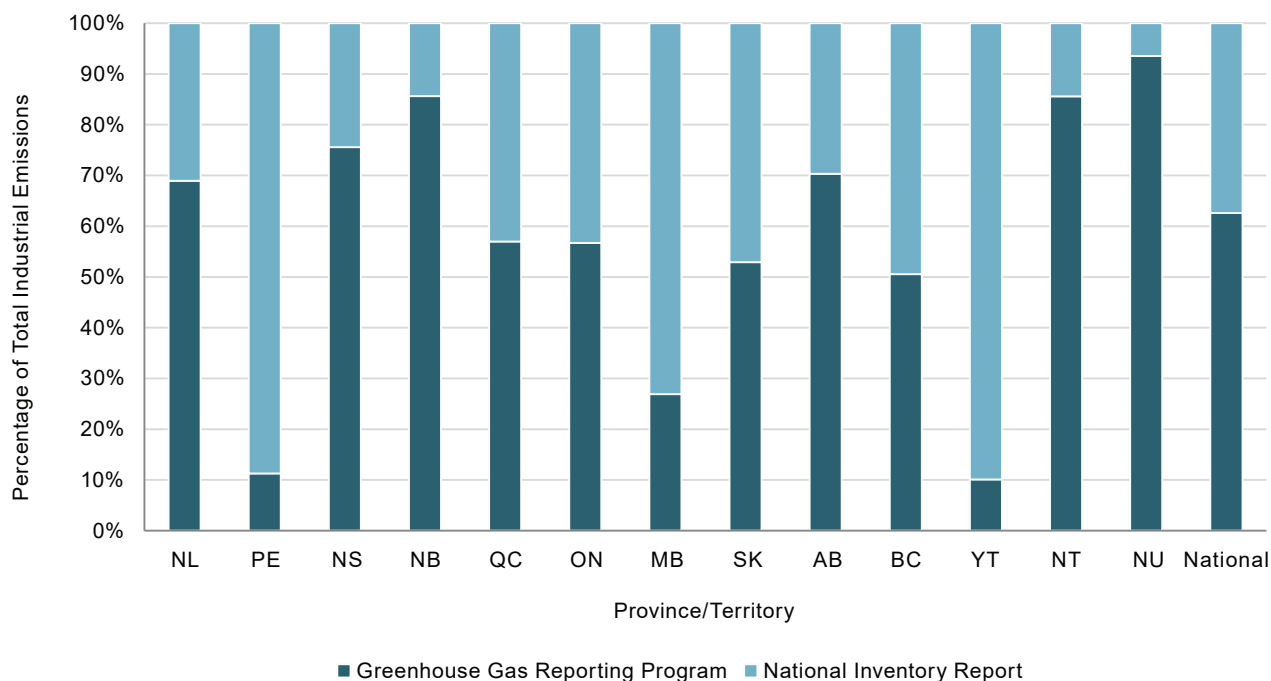
The objective of using FRD (collected under the GHGRP) in the national inventory is to help improve the quality of the inventory estimates by taking into account national circumstances such as industry-specific operations and process changes (e.g., process-specific or fuel-specific emission factors)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

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

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

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

Figure 1–5 **2023 Facility-Reported Emissions as a Percentage of Industrial Greenhouse Gas Emissions by Province and Territory**



**Notes:**

In this overview report, Canada's industrial GHG emissions include the following GHG categories from the *National Inventory Report 1990–2023: Greenhouse Gas Sources and Sinks in Canada*: Stationary Combustion Sources (except Residential), Transportation, Fugitive Sources, Industrial Processes and Product Use, and Waste.

\*The national total does not include data for Nunavut.

Prior to the integration of any FRD, several QA/QC assessment and analysis processes are performed to ensure the quality of the reported emission estimates in terms of transparency, accuracy, completeness, consistency and comparability. In response to the UNFCCC review recommendations from the 2021 cycle, explanations were added to the corresponding categories to indicate that the time-series consistency of the reported GHG emission estimates was addressed where FRD were used. In each category, the most suitable method described in the 2006 IPCC Guidelines (Volume 1, Chapter 5 of IPCC, 2006) was applied. More details are provided in the corresponding sections in [Chapter 3 \(Energy\)](#), [Chapter 4 \(IPPU\)](#) and [Chapter 7 \(Waste\)](#). Since FRD cover a significant part of industrial emissions in some provinces and territories ([Figure 1–5](#)), the enhanced data of this type that have been collected to date under the GHGRP expansion will continue to be reviewed, with the aim of 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 2023 Reported Emissions* (ECCC, 2025).

## 1.5. Uncertainty Assessment

While national GHG inventories should be accurate, complete, comparable, transparent and consistent, estimates will always inherently involve some uncertainty. Uncertainties<sup>14</sup> in the inventory estimates may be caused by systematic and/or random uncertainties in the input parameters or estimation models. Quantifying and reducing uncertainty may require in-depth reviews of the estimation models, improvements to the activity data regimes and the evaluation of EFs and other model parameters. In a limited number of cases, uncertainty may be reduced through a validation exercise using an independent data set, such as the total emissions reported by individual facilities in each industry sector. The 2006 IPCC Guidelines (IPCC, 2006) specify that the primary purpose of providing quantitative uncertainty information is to assist in setting priorities for the improvement of future inventories and to guide decisions about which methods to use. Typically, the uncertainties associated with trends and the national totals are much lower than those associated with individual gases and sectors.

<sup>14</sup> 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).

**Table 1–3 Use of Facility-Reported Data Collected Under the GHGRP in the NIR by Corresponding IPCC Sector and CRT Category**

IPCC Sector and CRT Category	FRD Obtained Under the GHGRP	Uses in NIR	NIR Reference for Additional Details
<b>Energy</b>			
1.A.1.a.i Electricity generation, solid fuels	Amount of CO <sub>2</sub> captured	Direct reporting	<ul style="list-style-type: none"> <li>• section 3.4</li> <li>• CRT Table 1.A(a)s1</li> </ul>
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	<ul style="list-style-type: none"> <li>• section 3.2</li> <li>• Annex 10</li> </ul>
1.A.2.f Non-metallic minerals	<ul style="list-style-type: none"> <li>• Quantities of mixed waste fuel used</li> <li>• CO<sub>2</sub> emissions</li> </ul>	<ul style="list-style-type: none"> <li>• Direct reporting</li> <li>• Input data for emission estimates</li> </ul>	<ul style="list-style-type: none"> <li>• section 3.2</li> <li>• CRT Table 1.A(a)s2</li> </ul>
1.B.2.c Oil, natural gas and other emissions from energy production – Venting and Flaring	Amount of CO <sub>2</sub> captured during petroleum refining and crude bitumen upgrading activities	Direct reporting	<ul style="list-style-type: none"> <li>• section 3.4</li> <li>• CRT Table 1.B.2</li> </ul>
1.C.1 Transport of CO <sub>2</sub>	Amount of captured CO <sub>2</sub> transported by pipelines	Input data for calculated values	<ul style="list-style-type: none"> <li>• section 3.4</li> <li>• CRT Table 1.C</li> </ul>
1.C.2 CO <sub>2</sub> injection and storage	Amount of captured CO <sub>2</sub> injected or stored	Input data for calculated values	<ul style="list-style-type: none"> <li>• section 3.4</li> <li>• CRT Table 1.C</li> </ul>
<b>IPPU</b>			
2.A.1 Cement production	<ul style="list-style-type: none"> <li>• CO<sub>2</sub> emissions</li> <li>• Clinker production, CaO content of clinker</li> <li>• CKD quantities, CaO content of CKD</li> </ul>	<ul style="list-style-type: none"> <li>• Direct reporting</li> <li>• Input data for emission estimates</li> <li>• Quality control</li> </ul>	section 4.2
2.A.2 Lime production	<ul style="list-style-type: none"> <li>• CO<sub>2</sub> emissions</li> <li>• Lime production, CaO and MgO contents of lime</li> <li>• By-product and waste quantities, CaO and MgO contents of by-product and waste</li> </ul>	<ul style="list-style-type: none"> <li>• Direct reporting</li> <li>• Input data for emission estimates</li> <li>• Quality control</li> </ul>	section 4.3
2.A.4.d Other Limestone and Dolomite Use	<ul style="list-style-type: none"> <li>• Quantities of limestone used in pulp and paper production</li> <li>• Quantities, carbon contents of limestone and dolomite used as flux in iron and steel production</li> </ul>	<ul style="list-style-type: none"> <li>• Input data for emission estimates</li> <li>• Quality control</li> </ul>	section 4.4
2.B.1 Ammonia production	<ul style="list-style-type: none"> <li>• Natural gas feedstock, carbon contents of natural gas</li> <li>• Urea production, CO<sub>2</sub> recovered for urea production</li> <li>• Amount of CO<sub>2</sub> captured</li> </ul>	<ul style="list-style-type: none"> <li>• Input data for emission estimates</li> <li>• Quality control</li> </ul>	section 4.5
2.B.2 Nitric acid production	<ul style="list-style-type: none"> <li>• Nitric acid production</li> <li>• N<sub>2</sub>O emission factors</li> <li>• N<sub>2</sub>O emissions</li> </ul>	<ul style="list-style-type: none"> <li>• Input data for emission estimates</li> <li>• Quality control</li> </ul>	section 4.6
2.C.1 Iron and steel production	<ul style="list-style-type: none"> <li>• Iron and steel production</li> <li>• Carbon contents of pig iron, crude steel produced in basic oxygen furnace (BOF) and electric arc furnace (EAF), and scrap steel</li> <li>• Emission factors for coke use, and electrode consumption in BOF and EAF</li> </ul>	<ul style="list-style-type: none"> <li>• Input data for emission estimates</li> <li>• Quality control</li> </ul>	section 4.10
2.C.3 Aluminium production	<ul style="list-style-type: none"> <li>• Aluminium production</li> <li>• CO<sub>2</sub>, CF<sub>4</sub>, C<sub>2</sub>F<sub>6</sub> and SF<sub>6</sub> emissions</li> </ul>	Direct reporting	section 4.12
<b>Waste</b>			
5.C.1 Waste incineration	GHG emissions	Direct reporting	<ul style="list-style-type: none"> <li>• section 7.5</li> <li>• section A3.6.3</li> </ul>
5.D Wastewater treatment	GHG emissions	Direct reporting of industrial wastewater emissions	<ul style="list-style-type: none"> <li>• section 7.6</li> <li>• section A3.6.4</li> </ul>

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

According to the error propagation method, the uncertainty for the national inventory, not including the LULUCF sector, is  $\pm 3\%$  for both the base year and 2023. The five emission source categories that contribute the most to uncertainty at the national level, for 2023, when LULUCF is not included are:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH<sub>4</sub>
2. Agriculture – Enteric Fermentation, CH<sub>4</sub>
3. Agriculture – Direct Agriculture Soils, N<sub>2</sub>O
4. Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries, CH<sub>4</sub>
5. Agriculture – Indirect Agriculture Soils, N<sub>2</sub>O

When the LULUCF emissions and removals are included, the uncertainty in the national total was found to be  $\pm 9\%$  for 2023 and  $\pm 11\%$  for the base year. For 2023, the top five contributors influencing the national uncertainty, when LULUCF is included, were:

1. LULUCF – Forest Land Remaining Forest Land, CO<sub>2</sub>
2. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH<sub>4</sub>
3. Agriculture – Enteric Fermentation, CH<sub>4</sub>
4. Agriculture – Direct Agriculture Soils, N<sub>2</sub>O
5. LULUCF – Conversion of Forest Land, CO<sub>2</sub>

## 1.6. Completeness Assessment

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

- sources/sinks that are not occurring in Canada
- data unavailability at the required category level
- methodological issues specific to national circumstances
- emission estimates that are considered insignificant<sup>15</sup>

Efforts are continuously being made to identify new or improved data sources or methodologies to provide estimates for those categories that are “not estimated.” Further details on the completeness of the inventory, including the source/sink category, notation key (either ‘NE’ – not estimated or ‘IE’ – included elsewhere) and explanation can be found in table 9 of the corresponding [CRTs](#)<sup>16</sup> associated with this NIR.

<sup>15</sup> 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<sub>2</sub> eq. The total national aggregate of estimated emissions for all gases and categories considered insignificant shall remain below 0.1% of the total national GHG emissions (as stated in the MPGs, paragraph 32).

<sup>16</sup> <https://unfccc.int/ghg-inventories-annex-i-parties/2025>

## GREENHOUSE GAS EMISSIONS TRENDS

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### 2.1. Summary of GHG Emissions Trends

In 2023, the most recent year for which data are available for this report, Canada's greenhouse gas (GHG) emissions were 694 megatonnes of carbon dioxide equivalent (Mt CO<sub>2</sub> eq), excluding the Land Use, Land-Use Change and Forestry (LULUCF) sector.<sup>1, 2</sup> This represents decreases of 65 Mt or 8.5% from 2005 emissions and of 6.0 Mt (0.9%) from 2022; in addition, emissions remained 53 Mt (7.1%) below pre-pandemic 2019 emission levels (Figure 2–1).<sup>3</sup> In terms of the overall trend since 1990, Canada's 2023 GHG emissions were 88 Mt (14%) below 1990 levels. The annual emissions steadily increased for the first 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 2023. Main emission trends and drivers since 1990 and 2005 are discussed in this chapter, while subsector-specific information is presented in each sectoral chapter (3 to 7).

Over the 2013-2023 period, total emissions decreased by 56 Mt or 7.5%. Since 2013, significant decreases occurred from Oil and Natural Gas Fugitive Sources (-33 Mt or -33%) as well as Public Electricity and Heat Production (-29 Mt or -34%). These decreases can be explained mostly by methane emission reductions from conventional oil and gas activities (more specifically from decreased venting) as well as the phase-out of coal-fired electricity generation and increased electricity generation from renewable sources. In contrast, from 2013 to 2023, Oil and Gas Extraction combustion emissions increased by 16 Mt (18%). Emissions from some transport sources also increased, notably Other Transportation<sup>4</sup> by 8.4 Mt (18%) and Light-Duty Gasoline Trucks by 7.9 Mt (17%). These increases can be attributed mainly to continued production growth in Canada's oil sands operations and an increase in the off- and on-road vehicle fleet, leading to more kilometres driven overall.

When observing long-term emission trends, large-scale events can have a significant impact on a portion of the time series analysis and should be considered. The years 2020 and 2021 were marked by the COVID-19 pandemic. This coincides with an abrupt decrease of 65 Mt (8.7%) in total GHG emissions between 2019 and 2020, with almost half of the decrease from Transport (-31 Mt or -15%). The year after, between 2020 and 2021, emissions increased slightly by 11 Mt (1.7%) and between 2021 and 2022 they continued to increase by 6.3 Mt (0.9%), while remaining below their 2019 pre-pandemic levels. Finally, in the latest year, between 2022 and 2023, emissions decreased by 6.0 Mt (0.9%). Impacts of the pandemic, more pronounced in 2020, are now harder to distinguish in the latest years. Notwithstanding the abrupt decrease between 2019 and 2020, and recent year changes, the general breakdown of emissions by sector (IPCC or economic) has not substantially changed over time.

1 Unless explicitly stated otherwise, all emissions estimates given in Mt represent emissions of GHGs in Mt CO<sub>2</sub> eq.

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

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

4 Other Transportation includes consumption of fuels (excluding the biogenic CO<sub>2</sub> emissions from ethanol and biodiesel) by mobile combustion devices not licensed to operate on roads, as well as transportation and distribution of crude oil, natural gas and other products by pipelines.

Figure 2–1 **Canadian GHG Emission Trend (excluding the Land Use, Land-Use Change and Forestry Sector) (1990–2023)**

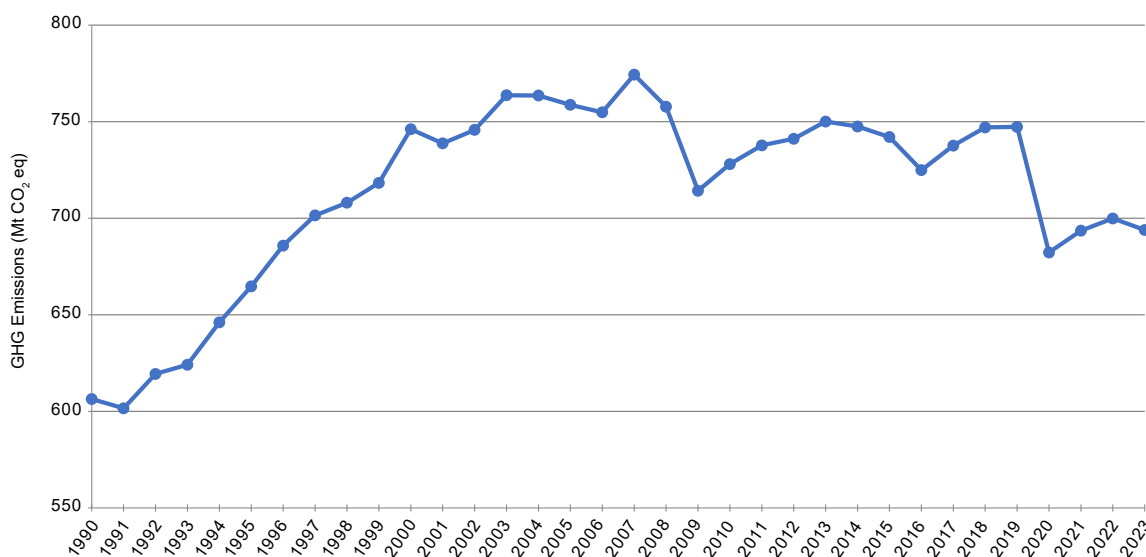
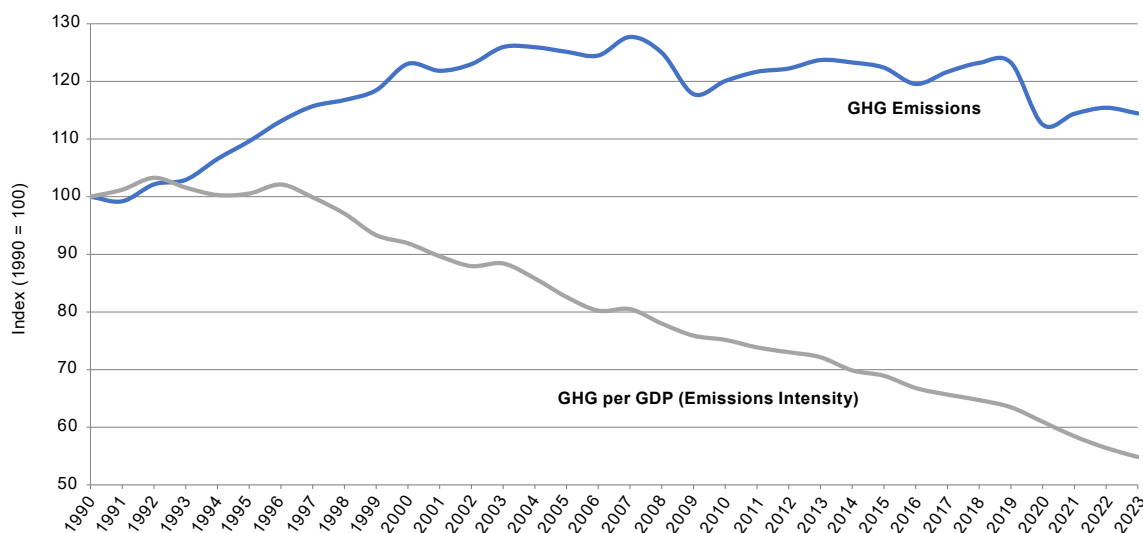


Figure 2–2 **Indexed Trend in GHG Emissions and GHG Emissions Intensity (excluding the Land Use, Land-Use Change and Forestry Sector) (1990–2023)**



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

In general, year-to-year fluctuations are superimposed over trends observed over a longer period. During the period covered in this report, Canada's economy grew more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (GHGs per gross domestic product [GDP]) has continued to decline in 2023, by 45% since 1990 and by 34% since 2005 (Figure 2–2 and Table 2–1). The decline in emissions intensity can be attributed to factors such as fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.

Canada accounts for approximately 1.4% of global GHG emissions (Climate Watch, 2025 for the year 2021), making Canada the 12th largest emitter of GHGs. While Canada's per capita emissions have declined since 2005 from 24 t CO<sub>2</sub> eq/capita to 17 t CO<sub>2</sub> eq/capita in 2023 (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 2023 can be found on [open.canada.ca](https://open.canada.ca/).<sup>5</sup>

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

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

Year	1990	2005	2018	2019	2020	2021	2022	2023
<b>Total GHG Emissions (Mt)</b>	<b>606</b>	<b>759</b>	<b>747</b>	<b>747</b>	<b>682</b>	<b>694</b>	<b>700</b>	<b>694</b>
Change since 2005 (%)	NA	NA	-1.5%	-1.5%	-10%	-8.6%	-7.8%	-8.5%
Change since 1990 (%)	NA	25%	23%	23%	13%	14%	15%	14%
<b>GDP<sup>a</sup> (Billion 2017\$)</b>	<b>1 156</b>	<b>1 751</b>	<b>2 200</b>	<b>2 244</b>	<b>2 133</b>	<b>2 262</b>	<b>2 365</b>	<b>2 411</b>
Change since 2005 (%)	NA	NA	26%	28%	22%	29%	35%	38%
Change since 1990 (%)	NA	51%	90%	94%	85%	96%	105%	109%
<b>GHG Intensity (Mt/\$B GDP)</b>	<b>0.52</b>	<b>0.43</b>	<b>0.34</b>	<b>0.33</b>	<b>0.32</b>	<b>0.31</b>	<b>0.30</b>	<b>0.29</b>
Change since 2005 (%)	NA	NA	-22%	-23%	-26%	-29%	-32%	-34%
Change since 1990 (%)	NA	-17%	-35%	-37%	-39%	-42%	-44%	-45%

Notes:

NA = Not applicable

a. Data source: StatCan (n.d.[a])

### 2.1.1. Provincial and Territorial GHG Emissions Trends

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

Historically, Alberta and Ontario have been the highest-emitting provinces, accounting for 38% and 23% of Canada's total emissions in 2023, respectively. Since 2005, emission patterns in these two provinces have diverged. Those in Alberta have increased by 13 Mt (5.1%) since 2005, primarily because of the expansion of oil and gas operations (Table 2-2). Specifically, Oil and Gas emissions in Alberta have increased by 35 Mt, but have been offset by decreases in Electricity (-28 Mt). In contrast, Ontario's emissions have decreased by 44 Mt (22%) since 2005, including a decrease of 26 Mt in the Electricity sector, owing primarily to the closure of coal-fired electricity generation plants. Overall, emissions have decreased in eight provinces and one territory between 2005 and 2023, while emissions of two provinces and two territories have increased (Table 2-2).

Figure 2-3 GHG Emissions by Province and Territory in 2005, 2010, 2015, and 2023

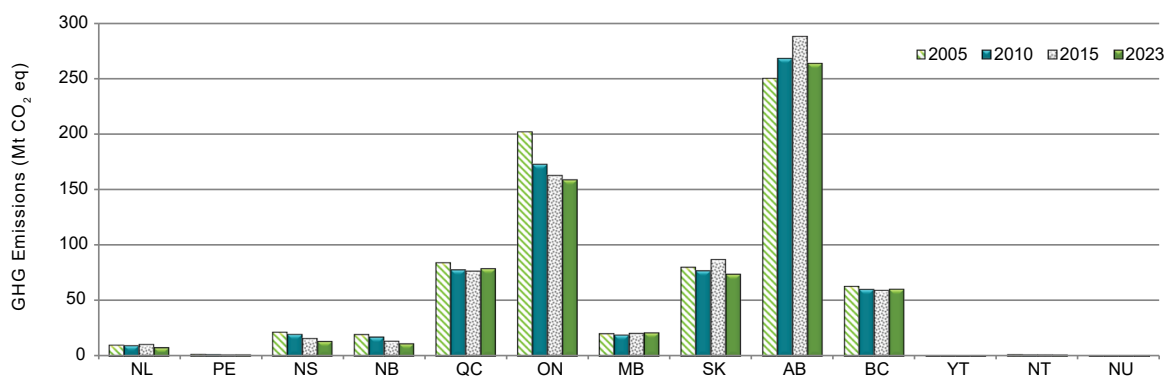


Table 2–2 **GHG Emissions by Province and Territory, Selected Year**

Province or Territory	GHG Emissions (Mt CO <sub>2</sub> eq)										Change (%)
	1990	2005	2010	2015	2018	2019	2020	2021	2022	2023	2005–2023
<b>TOTAL (CANADA)</b>	<b>606</b>	<b>759</b>	<b>728</b>	<b>742</b>	<b>747</b>	<b>747</b>	<b>682</b>	<b>694</b>	<b>700</b>	<b>694</b>	<b>-8.5%</b>
NL	9.5	10	10	11	11	11	8.6	8.0	8.1	7.9	-23%
PE	1.8	1.9	1.8	1.5	1.6	1.6	1.6	1.6	1.6	1.6	-16%
NS	20	22	20	16	17	16	14	14	14	14	-38%
NB	16	20	18	14	13	13	11	12	12	11	-42%
QC	84	85	78	77	80	82	75	78	79	79	-6.6%
ON	178	202	173	163	164	165	149	152	158	159	-22%
MB	18	21	19	21	22	22	21	21	22	21	2.8%
SK	49	80	77	87	89	86	75	76	75	74	-8.1%
AB	177	251	268	289	283	285	266	268	265	263	5.1%
BC	51	63	60	60	65	63	59	61	62	60	-4.5%
YT	0.55	0.56	0.65	0.53	0.64	0.69	0.59	0.65	0.66	0.67	19%
NT	NA	1.7	1.5	1.6	1.4	1.4	1.2	1.3	1.4	1.4	-21%
NU	NA	0.59	0.60	0.63	0.74	0.73	0.63	0.70	0.70	0.71	22%

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

## 2.2. GHG Emissions Trends by Gas

Canada's GHG emissions profile is similar to most industrialized countries, in that carbon dioxide (CO<sub>2</sub>) is the largest contributor to total emissions, accounting for 545 Mt or 79% of total emissions in 2023 (Figure 2–4). As a result, trends in CO<sub>2</sub> emissions follow the same pattern as total GHG emissions, as described in the previous section (Figure 2–1). Most of the CO<sub>2</sub> emissions in Canada result from the combustion of fossil fuels.

### Methane (CH<sub>4</sub>)

Methane (CH<sub>4</sub>) emissions in 2023 amounted to 109 Mt of CO<sub>2</sub> eq or 16% of Canada's total. These CH<sub>4</sub> emissions consist largely of fugitive emissions from oil and natural gas systems (50 Mt or 45%), agriculture (31 Mt or 28%), and landfills (municipal solid waste and industrial wood waste landfills) (20 Mt or 18%). Total CH<sub>4</sub> emissions have increased steadily since 1990, peaking in 2006 at 152 Mt (42% increase), then fluctuated until 2017 and decreased in recent years to reach a similar level to 1990 in 2023 (109 Mt) (Figure 2–5).

From 1990 to 2006, emissions from fugitive oil and gas increased by 33 Mt, agriculture by 10 Mt and landfills by 1.8 Mt with an overall increase of 45 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.<sup>6</sup>

From 2006 to 2019, CH<sub>4</sub> emissions decreased by 23 Mt. Of this decrease in emissions, 16 Mt occurred in the oil and gas industry due to reductions in venting emissions (-11 Mt), and the combination of improved leak detection and repair (LDAR) programs with a 9% decrease in natural gas production, both of which contributed to a further 4.8 Mt decrease in fugitive emissions from oil and gas systems. Agricultural CH<sub>4</sub> emissions decreased by 6.3 Mt (17%) between 2006 and 2011, mainly due to a 17% decline in beef cattle populations that led to a reduction in enteric fermentation emissions, but populations and emissions have since stabilized in the recent years. Landfills CH<sub>4</sub> emissions peaked in 2006 (21 Mt), after which they generally decreased. Overall, landfill emissions are down by 1.3 Mt between 2006 and 2023, primarily driven by an increase in methane recovered from Municipal Solid Waste Landfills (+3.1 Mt recovered) and a decrease in methane generated from Industrial Wood Waste Landfills (-0.33 Mt), offsetting an increase in methane generated from Municipal Solid Waste Landfills (+2.0 Mt).

The significant decrease (11 Mt) in CH<sub>4</sub> emissions between 2019 and 2020 coincides with federal regulations to reduce CH<sub>4</sub> emissions from the upstream oil and gas industry and equivalent provincial regulations in Saskatchewan, Alberta and British Columbia as fugitive CH<sub>4</sub> emissions from oil and gas operations decreased by 9.7 Mt over this period. Please see section 2.3.1.3 for more detailed discussion of the trends in emissions from fugitive sources. National CH<sub>4</sub> emissions continued to decrease between 2020 and 2023 (-9.0 Mt or -7.6%).

6 From 1990 to 2023, production of crude bitumen and synthetic crude oil from Canada's Oil Sands increased by nearly 850% with CO<sub>2</sub> eq emissions increasing by 480%. However, CH<sub>4</sub> emissions from the Oil Sands increased by only 139% and the contribution to total Oil and Gas CH<sub>4</sub> emissions increased from 3.7 % in 1990 to 8.9% in 2023, showing that the Oil Sands is not a significant source of CH<sub>4</sub> as compared to conventional oil and gas production.

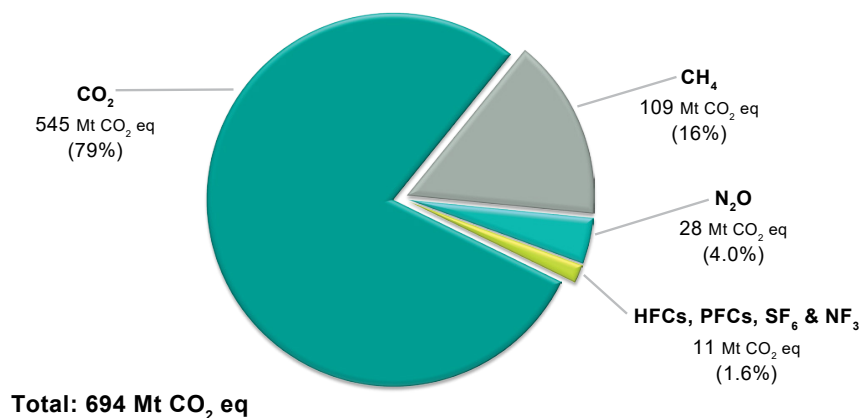
## Nitrous Oxide (N<sub>2</sub>O)

Nitrous oxide (N<sub>2</sub>O) emissions accounted for 28 Mt of CO<sub>2</sub> eq (4.0%) of Canada's emissions in 2023, down 2.5 Mt (8.3%) from 1990 levels and 0.59 Mt (2.1%) from 2005 levels. The primary source of N<sub>2</sub>O emissions is the application of nitrogen fertilizers to agricultural soils. In 2023, the Agriculture sector accounted for 76% of national N<sub>2</sub>O emissions, up from 44% in 1990 and 56% in 2005. Since 2005, nitrogen fertilizer use has increased by 69% and N<sub>2</sub>O emissions from nitrogen fertilizer use have increased by 79%. Since 1990, a 9.2 Mt decrease in N<sub>2</sub>O emissions has occurred due to the cessation of adipic acid production in Canada.

## Synthetic Gases (HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub>)

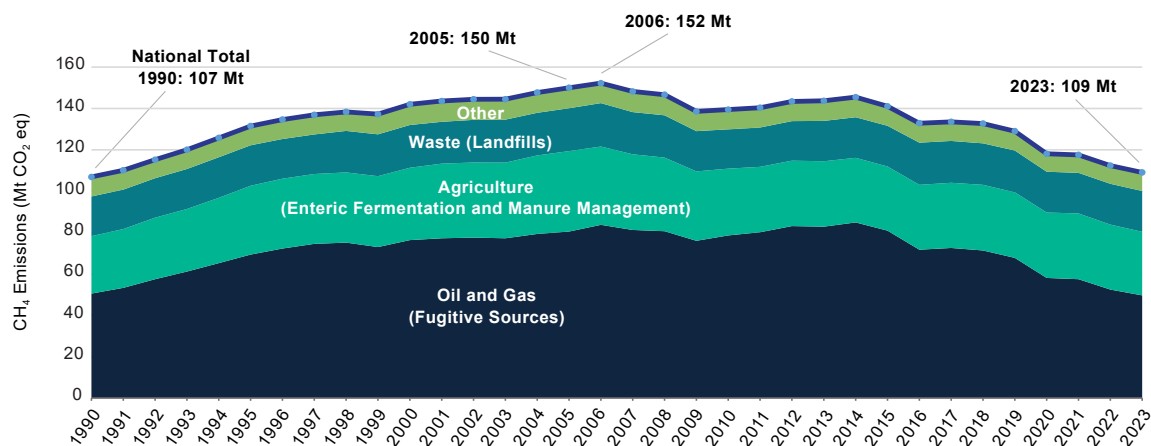
Emissions of synthetic gases, consisting of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF<sub>6</sub>) and nitrogen trifluoride (NF<sub>3</sub>), accounted for 11 Mt of CO<sub>2</sub> eq, or 1.6%, of Canada's emissions in 2023. From 1990 to 2023, emissions of HFCs rose by 9.4 Mt (1159%), while emissions of PFCs and SF<sub>6</sub> decreased by 6.1 Mt (89%) and 2.9 Mt (89%), respectively. Similar trends are observed since 2005, with a 5.4 Mt (113%) increase in HFC emissions, and 2.7 Mt (79%) and 1.1 Mt (74%) decreases in emissions of PFCs and SF<sub>6</sub>, respectively. Increases in HFC emissions can be explained by the replacement of ozone-depleting substances (ODS) with HFCs in refrigeration, air conditioning and foam blowing applications. Since 2018, HFC emissions have declined by 1.2 Mt (11%), coinciding with the 2019 implementation of federal regulations limiting net imports of HFCs as mandated under the Kigali Amendment to the Montreal Protocol. The decreases in emissions of PFCs are largely due to the modernization in the aluminium industry. The decreases in SF<sub>6</sub> are mainly due to a decline in the number of magnesium smelters and casters.

Figure 2-4 Breakdown of Canada's Emissions by GHG (2023)



Note: Totals may not add up due to rounding.

Figure 2-5 Methane Emissions Trends in Canada (1990–2023)



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

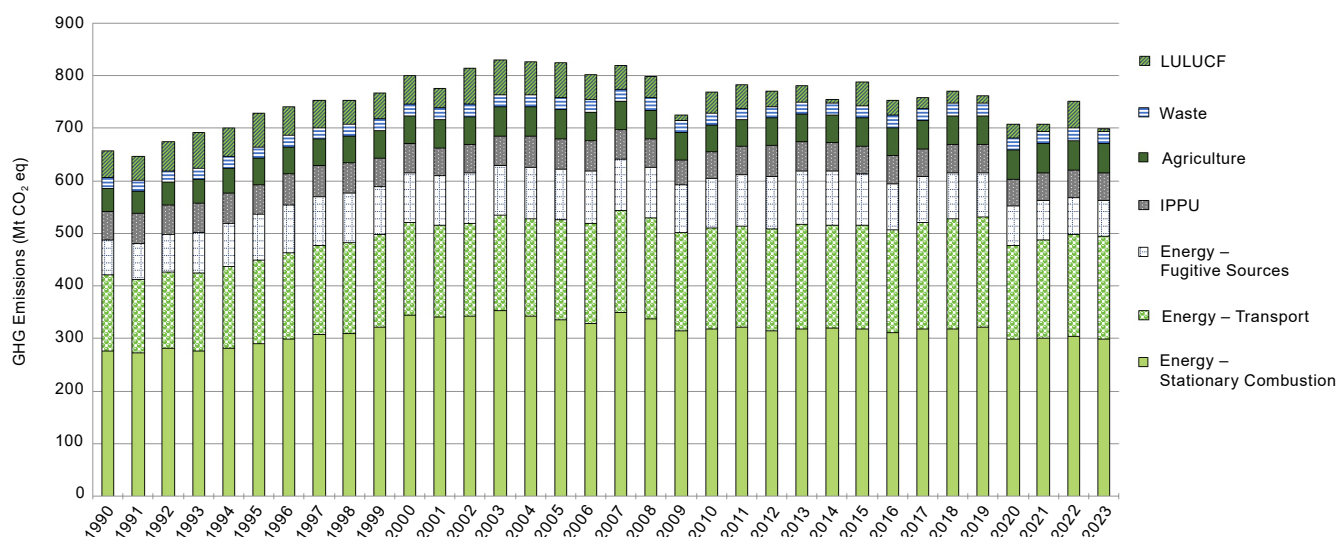
### 2.3. GHG Emissions Trends by IPCC Sector

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

In 2023, the Energy sector accounted for 562 Mt, or 81%, of Canada's total GHG emissions with the remainder being shared between Agriculture (55 Mt or 7.9%), IPPU (54 Mt or 7.7%) and Waste (23 Mt or 3.3%). When included with emissions from other sectors, LULUCF sector emissions corresponded to 0.6% of the 2023 national total. 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 1990–2023 period, with increases of 50 Mt (35%) in Transport, 22 Mt (7.8%) in Stationary Combustion, and 2.9 Mt (4.5%) in Fugitive Sources. Over the same period, emissions in the Agriculture sector increased by 13 Mt (30%), while the IPPU sector saw a decrease of 1.6 Mt (2.8%). Emissions in the Waste sector have increased by 1.6 Mt (7.5%) since 1990. Net emissions from the LULUCF sector were 50 Mt in 1990, and emissions increased on average through the 1990s and early 2000s, before generally trending downward to 4.2 Mt in 2023 (Figure 2-6 and Table 2-3).

Figure 2-6 Trends in Canadian GHG Emissions by IPCC Sector (1990–2023)



Over the 2005–2023 period, total emissions have decreased by 65 Mt or 8.5%. Two sources of the Energy sector dominated this trend, with emission decreases of 37 Mt (11%) in Stationary Combustion and 29 Mt (30%) in Fugitive Sources. Over the same period, emissions have decreased by 2.5 Mt (4.5%) in the IPPU sector and 0.58 Mt (2.5%) in the Waste sector. In contrast, emissions from Transport have increased by 5.1 Mt (2.7%) between 2005 and 2023. The Agriculture sector emissions have remained relatively stable with a 1.1 Mt or 2.0% decrease since 2005 (Figure 2–7). The net fluxes in the LULUCF sector demonstrate important interannual variability throughout the time series, but reached 66 Mt in 2005 and have trended downward since, reaching a low of 4.2 Mt in 2023, though emissions spiked to 51 Mt in 2022 due to the impact of drought on Cropland emissions (Figure 2–6).

Several emission sources, while not major contributors to Canada’s overall GHG emissions, have changed significantly since 1990. These include a 9.5 Mt (or 1158%) increase in emissions from the Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub>, a 6.4 Mt (109%) increase from the Non-Energy Products from Fuels and Solvent Use, a 1.9 Mt (160%) increase in CO<sub>2</sub> emissions from the application of lime, urea and carbon-containing fertilizers, and a 0.42 Mt (518%) increase in emissions from Biological Treatment of Solid Waste. Also included are decreases of 9.2 Mt (100%) from Adipic Acid Production, 2.9 Mt (92%) from Magnesium Production and Casting and 0.73 Mt (85%) from Nitric Acid Production.

Between 2005 and 2023, some of the noteworthy changes in emission sources that are minor contributors to the national total include emission increases of 5.5 Mt (113%) from the Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub>, 1.7 Mt (118%) of CO<sub>2</sub> emissions from the application of lime, urea and carbon-containing fertilizers and 0.26 Mt (106%) from Biological Treatment of Solid Waste. The decreases in emissions include a 2.3 Mt (100%) decrease from Adipic Acid Production, a 1.2 Mt (83%) decrease from Magnesium Production and Casting and a 0.94 Mt (88%) decrease from Nitric Acid Production.

Figure 2–7 **Changes in GHG Emissions by IPCC Sector (2005–2023)**

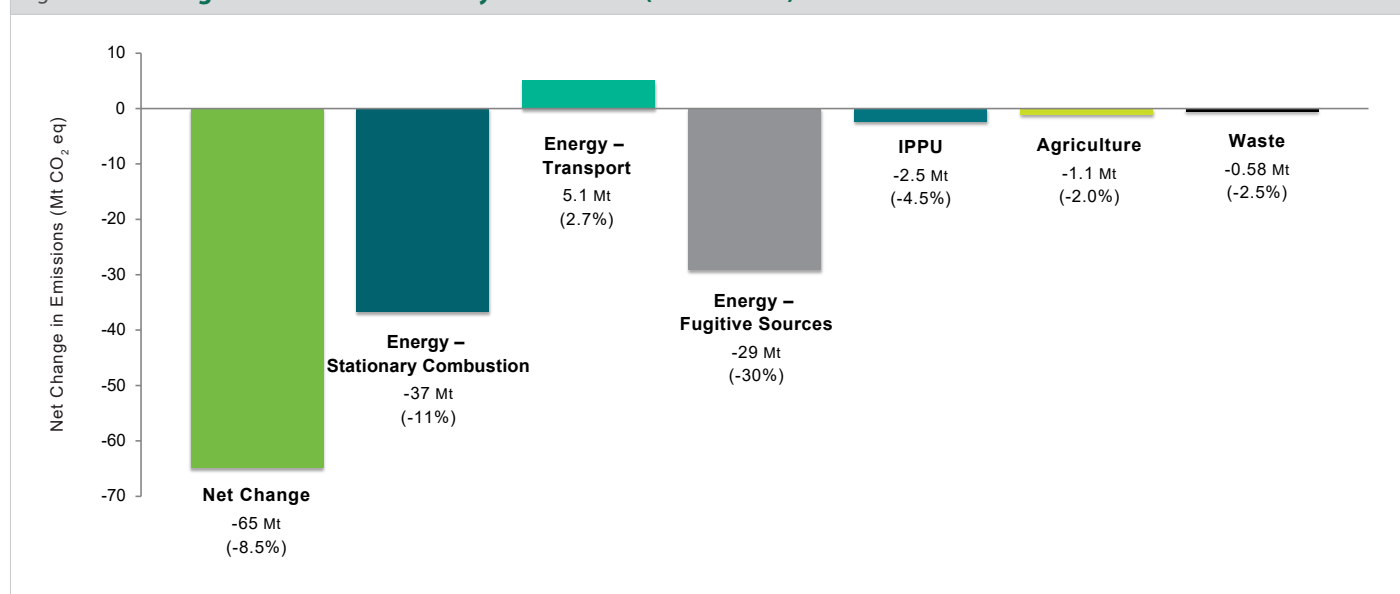


Table 2–3 **Canada’s GHG Emissions by IPCC Sector (1990–2023)**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>TOTAL<sup>a, b</sup></b>	<b>606</b>	<b>759</b>	<b>747</b>	<b>747</b>	<b>682</b>	<b>694</b>	<b>700</b>	<b>694</b>
<b>ENERGY</b>	<b>487</b>	<b>623</b>	<b>615</b>	<b>616</b>	<b>552</b>	<b>562</b>	<b>568</b>	<b>562</b>
<b>a. Stationary Combustion Sources</b>	<b>277</b>	<b>335</b>	<b>319</b>	<b>322</b>	<b>299</b>	<b>301</b>	<b>304</b>	<b>298</b>
Public Electricity and Heat Production	94	123	71	70	62	62	58	58
Petroleum Refining Industries	17	19	13	15	14	14	15	14
Oil and Gas Extraction	31	63	105	106	101	105	106	107
Mining	4.6	4.3	6.0	6.0	5.2	5.8	5.8	5.5
Manufacturing Industries	56	47	42	42	39	40	40	40
Construction	1.9	1.4	1.4	1.4	1.4	1.4	1.6	1.5
Commercial and Institutional	26	32	37	38	35	33	35	33
Residential	43	43	40	41	38	37	39	35
Agriculture and Forestry	2.4	2.2	3.2	3.3	3.0	3.2	3.3	3.3

Table 2–3 Canada's GHG Emissions by IPCC Sector (1990–2023) (cont'd)

GHG Source Category		GHG Emissions (Mt CO <sub>2</sub> eq)							
		1990	2005	2018	2019	2020	2021	2022	2023
b.	Transport	145	190	209	209	178	187	195	195
	Aviation	7.5	7.7	8.7	8.6	4.7	5.6	7.7	8.4
	Domestic Aviation (Civil)	7.3	7.5	8.4	8.3	4.6	5.4	7.5	8.2
	Military	0.23	0.26	0.25	0.24	0.18	0.20	0.20	0.20
	Road Transportation	92	122	132	132	112	117	121	122
	Light-Duty Gasoline Vehicles	44	41	32	31	24	25	26	25
	Light-Duty Gasoline Trucks	25	41	54	56	48	50	52	54
	Heavy-Duty Gasoline Vehicles	4.8	4.6	4.5	4.6	4.2	4.2	3.9	4.1
	Motorcycles	0.20	0.46	0.93	0.96	0.76	0.81	0.76	0.79
	Light-Duty Diesel Vehicles	0.37	0.66	0.46	0.42	0.31	0.33	0.36	0.33
	Light-Duty Diesel Trucks	0.99	0.75	0.76	0.79	0.64	0.77	0.98	0.94
	Heavy-Duty Diesel Vehicles	16	34	39	38	33	36	38	36
	Propane and Natural Gas Vehicles	0.76	0.02	0.11	0.14	0.15	0.16	0.17	0.16
	Railways	6.1	6.5	6.5	6.5	6.0	5.9	5.8	5.9
	Marine	3.2	4.1	3.7	3.7	3.3	3.2	3.6	3.7
	Domestic Navigation	2.3	3.2	3.4	3.3	3.0	2.9	3.3	3.5
	Fishing	0.87	0.87	0.19	0.19	0.18	0.20	0.18	0.16
	Military Water-Borne Navigation	0.03	0.03	0.11	0.13	0.11	0.13	0.11	0.11
	Other Transportation	36	50	58	58	52	55	56	56
	Off-Road Agriculture and Forestry	8.7	9.9	14	14	13	13	13	13
	Off-Road Commercial and Institutional	4.3	4.5	6.1	6.2	5.6	6.1	6.2	6.3
	Off-Road Manufacturing, Mining and Construction	12	16	20	20	18	18	19	18
	Off-Road Residential	0.37	1.2	1.0	1.0	0.97	0.92	0.85	0.84
	Off-Road Other Transportation	3.5	7.7	8.0	7.9	7.3	7.5	7.4	7.4
	Pipeline Transport	6.9	10	8.4	8.5	7.8	8.7	10	9.7
c.	Fugitive Sources	66	98	88	84	75	75	70	68
	Coal Mining	3.2	1.5	1.6	1.6	1.4	1.4	1.4	1.6
	Oil and Natural Gas	62	96	86	83	73	73	69	67
d.	CO <sub>2</sub> Transport and Storage	-	-	-	-	-	-	-	-
INDUSTRIAL PROCESSES AND PRODUCT USE		55	56	55	54	51	53	53	54
a.	Mineral Products	8.5	10.3	8.7	8.9	8.2	9.0	8.4	8.8
	Cement Production	5.8	7.6	7.0	7.2	6.7	7.4	6.8	7.3
	Lime Production	1.9	1.8	1.4	1.3	1.2	1.3	1.3	1.2
	Mineral Product Use	0.80	0.83	0.33	0.32	0.31	0.31	0.31	0.30
b.	Chemical Industry	16	10	6.4	6.2	5.9	5.7	5.7	5.6
	Ammonia Production	2.7	2.7	2.4	2.5	2.3	2.5	2.6	2.4
	Nitric Acid Production	0.87	1.1	0.24	0.23	0.17	0.19	0.13	0.13
	Adipic Acid Production	9.2	2.3	-	-	-	-	-	-
	Petrochemical and Carbon Black Production	3.5	3.9	3.7	3.5	3.5	3.0	3.0	3.0
c.	Metal Production	23	21	16	15	14	15	15	16
	Iron and Steel Production	10	11	10	9.6	8.1	9.5	9.0	9.5
	Aluminium Production	9.6	8.3	5.4	5.2	5.8	5.8	5.7	6.1
	Magnesium Production and Casting	3.2	1.4	0.14	0.29	0.10	0.14	0.17	0.25
d.	Production and Consumption of Halocarbons, SF <sub>6</sub> and NF <sub>3</sub>	0.82	4.8	11	11	11	11	11	10
e.	Non-Energy Products from Fuels and Solvent Use	5.9	9.9	12	12	11	12	12	12
f.	Other Product Manufacture and Use	0.36	0.51	0.65	0.62	0.66	0.66	0.61	0.65
AGRICULTURE		43	56	54	54	56	55	56	55
a.	Enteric Fermentation	25	35	27	27	27	27	27	26
b.	Manure Management	6.0	8.7	7.9	7.9	7.8	7.9	7.8	7.7
c.	Agricultural Soils	10	12	16	16	18	17	18	18
	Direct Sources	7.8	8.9	13	13	14	13	15	14
	Indirect Sources	2.3	2.7	3.5	3.5	3.7	3.5	3.6	3.7
d.	Field Burning of Agricultural Residues	0.24	0.05	0.05	0.05	0.06	0.04	0.05	0.05
e.	Liming, Urea Application and Other Carbon-Containing Fertilizers	1.2	1.4	2.6	2.7	3.0	3.1	2.9	3.1
WASTE		21	24	23	23	23	23	23	23
a.	Landfills	19	21	20	20	20	20	20	20
	Municipal Solid Waste Landfills	18	20	19	19	19	19	19	19
	Industrial Wood Waste Landfills	1.0	1.1	0.84	0.82	0.80	0.78	0.76	0.74
b.	Biological Treatment of Solid Waste	0.08	0.24	0.38	0.38	0.38	0.50	0.50	0.50
c.	Incineration and Open Burning of Waste	0.26	0.34	0.17	0.17	0.15	0.15	0.17	0.16
d.	Wastewater Treatment and Discharge	1.9	2.2	2.7	2.7	2.6	2.6	2.6	2.6
	Municipal Wastewater Treatment and Discharge	1.5	1.8	2.2	2.2	2.2	2.2	2.3	2.4
	Industrial Wastewater Treatment and Discharge	0.43	0.44	0.48	0.43	0.39	0.37	0.30	0.26
LAND USE, LAND-USE CHANGE AND FORESTRY		50	66	24	15	25	15	51	4.2
a.	Forest Land	73	135	60	40	40	34	22	24
b.	Cropland	5.5	-20	-20	-15	-13	-16	25	-22
c.	Grassland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
d.	Wetlands	5.1	2.7	2.5	2.7	2.9	2.8	2.6	2.6
e.	Settlements	4.8	4.7	5.4	5.3	5.3	5.5	5.2	5.0
f.	Harvested Wood Products	-38	-57	-24	-18	-10	-12	-4.0	-5.1

## Notes:

Totals may not add up due to rounding.

0.00 Indicates emissions were truncated due to rounding.

- Indicates no emissions.

a. National totals calculated in this table do not include emissions and removals reported in LULUCF.

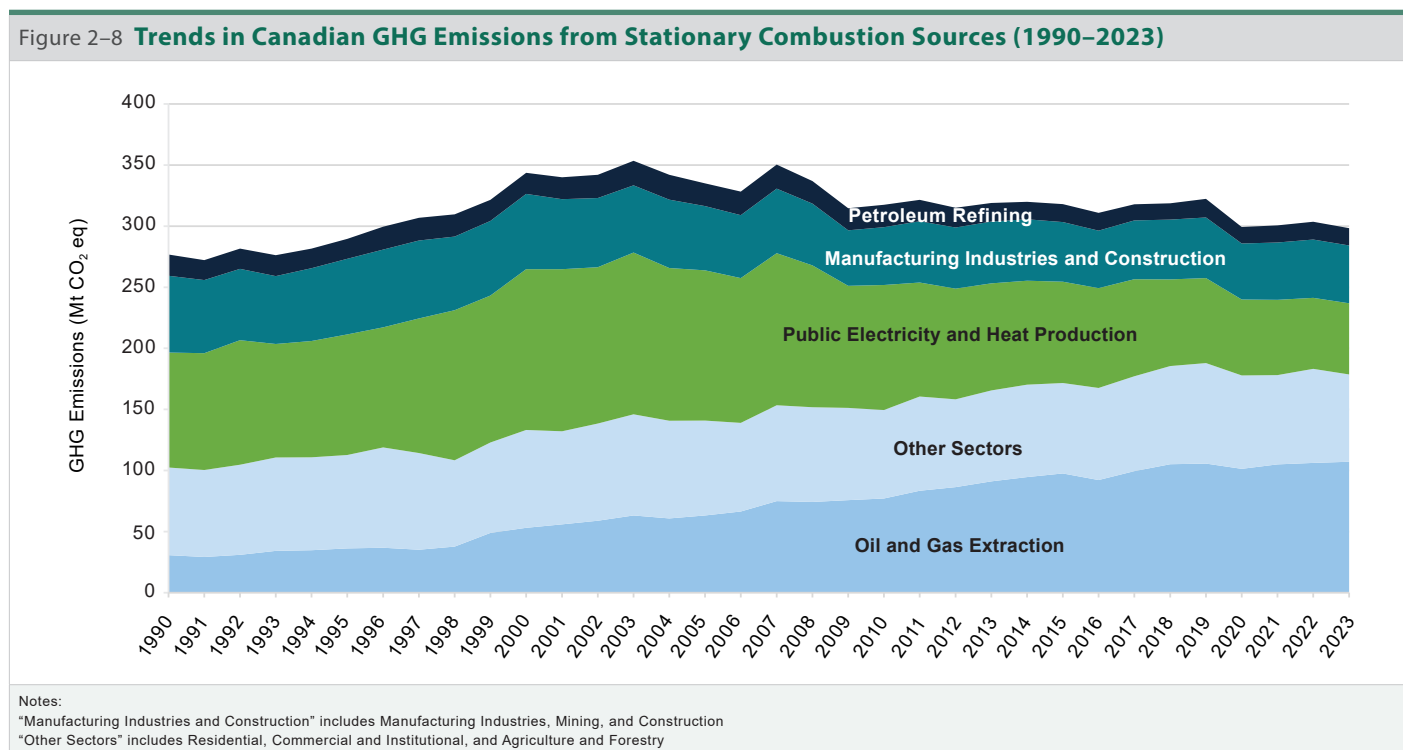
b. This summary data is presented in more detail at [open.canada.ca](https://open.canada.ca).

### 2.3.1. Energy Sector (2023 GHG emissions, 562 Mt)

In 2023, 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<sub>2</sub> Transport and Storage. [Chapter 3](#) provides a detailed description of each.

#### 2.3.1.1. Stationary Combustion Sources (2023 GHG Emissions, 298 Mt)

Stationary Combustion Sources account for 53% of emissions from the Energy sector. In 2023, emissions totalled 298 Mt, an increase of 7.8% from the 1990 emissions level of 277 Mt and a decrease of 11% from the 2005 emissions level of 335 Mt ([Figure 2–8](#), [Table 2–4](#)). Dominant categories in Stationary Combustion Sources are Oil and Gas Extraction as well as Public Electricity and Heat Production, which in 2023 contributed 36% and 20%, respectively, to total Stationary Combustion emissions. Manufacturing Industries, Residential Buildings, and Commercial and Institutional Buildings contributed 14%, 12% and 11%, respectively, of total Stationary Combustion emissions in 2023.



#### Public Electricity and Heat Production (2023 GHG emissions, 58 Mt)

Emissions from the Public Electricity and Heat Production category decreased by 38% (36 Mt) between 1990 and 2023.

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 2023, Statistics Canada (StatCan) data shows electricity generation (driven by demand) increased by 28% (StatCan, n.d. [c]), from 433 TWh<sup>7</sup> to 556 TWh. Despite the increase in demand over this period, GHG emissions dropped by 38% (36 Mt) between 1990 and 2023. Likewise, between 2005 and 2023, electricity generation rose by 1%, while corresponding emissions fell by 53% (65 Mt). Over both periods, the principal cause of the decrease in emissions is a considerably less GHG-intensive mix of sources used to generate electricity ([Figure 2–9](#)).

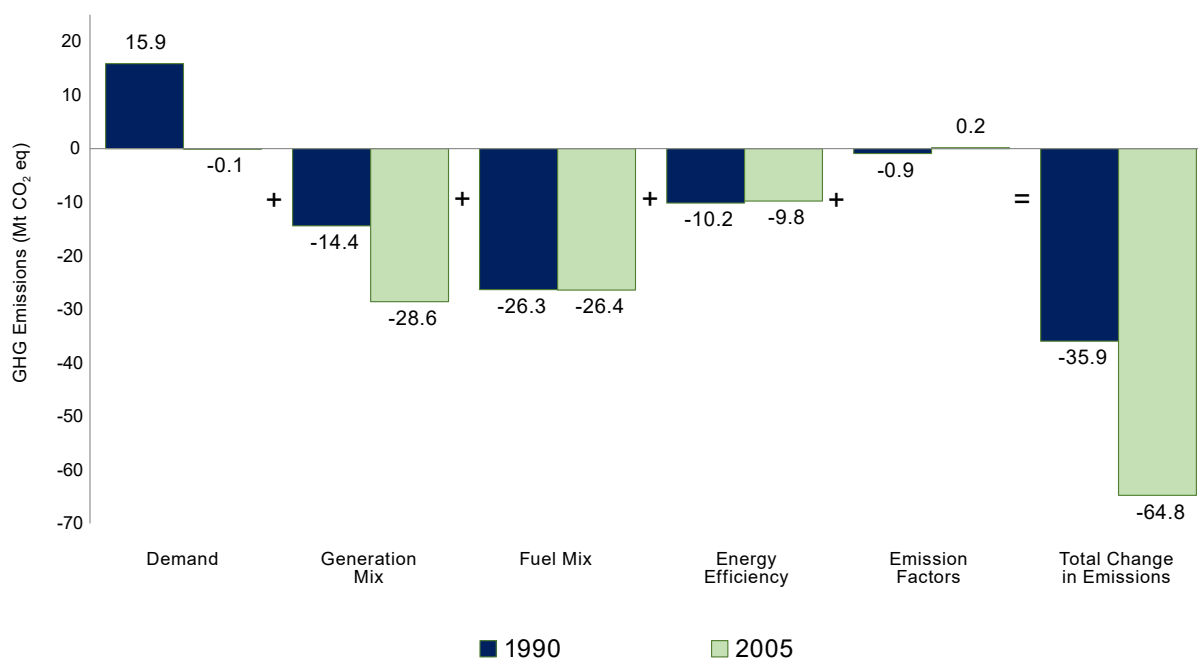
Low-emitting non-combustion sources—hydroelectric generation, nuclear power and non-hydro renewables (wind turbines, solar photovoltaic cells and tidal power)—accounted for 103% of the increased generation between 1990 and 2023 and for 82% of the total electricity generated in Canada in 2023. Hydroelectric generation alone accounted for 67% of the total electricity generated in 2023, followed by nuclear power generation at 15% and non-hydro-based renewables at 8%. The increased level of non-combustion sources in the generation mix in 2023 was the largest contributor to emission reductions since 2005 (29 Mt) ([Figure 2–9](#)).

<sup>7</sup> 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 <sub>2</sub> eq)								Change (%)	
	1990	2005	2018	2019	2020	2021	2022	2023	1990–2023	2005–2023
<b>STATIONARY COMBUSTION SOURCES</b>	<b>277</b>	<b>335</b>	<b>319</b>	<b>322</b>	<b>299</b>	<b>301</b>	<b>304</b>	<b>298</b>	<b>7.8%</b>	<b>-11%</b>
<b>Public Electricity and Heat Production</b>	<b>94</b>	<b>123</b>	<b>71</b>	<b>70</b>	<b>62</b>	<b>62</b>	<b>58</b>	<b>58</b>	<b>-38%</b>	<b>-53%</b>
<b>Petroleum Refining</b>	<b>17</b>	<b>19</b>	<b>13</b>	<b>15</b>	<b>14</b>	<b>14</b>	<b>15</b>	<b>14</b>	<b>-18%</b>	<b>-24%</b>
<b>Oil and Gas Extraction</b>	<b>31</b>	<b>63</b>	<b>105</b>	<b>106</b>	<b>101</b>	<b>105</b>	<b>106</b>	<b>107</b>	<b>249%</b>	<b>70%</b>
<b>Mining</b>	<b>4.6</b>	<b>4.3</b>	<b>6.0</b>	<b>6.0</b>	<b>5.2</b>	<b>5.8</b>	<b>5.8</b>	<b>5.5</b>	<b>18%</b>	<b>26%</b>
<b>Manufacturing Industries</b>	<b>56</b>	<b>47</b>	<b>42</b>	<b>42</b>	<b>39</b>	<b>40</b>	<b>40</b>	<b>40</b>	<b>-28%</b>	<b>-14%</b>
Iron and Steel	4.9	5.0	5.2	5.0	4.3	4.8	4.5	4.6	-7.4%	-9.0%
Non-Ferrous Metals	3.5	3.8	3.0	3.4	3.2	3.0	3.2	3.1	-13%	-19%
Chemicals	8.3	8.2	9.3	9.6	9.6	9.4	9.3	9.3	13%	13%
Pulp, Paper and Print	14	8.6	7.1	7.1	6.4	6.7	6.8	7.0	-52%	-19%
Cement	3.9	5.0	4.2	4.2	3.7	3.5	3.6	3.5	-10%	-30%
Other Manufacturing	21	16	13	13	12	12	13	13	-39%	-20%
<b>Construction</b>	<b>1.9</b>	<b>1.4</b>	<b>1.4</b>	<b>1.4</b>	<b>1.4</b>	<b>1.4</b>	<b>1.6</b>	<b>1.5</b>	<b>-20%</b>	<b>4.7%</b>
<b>Commercial and Institutional</b>	<b>26</b>	<b>32</b>	<b>37</b>	<b>38</b>	<b>35</b>	<b>33</b>	<b>35</b>	<b>33</b>	<b>27%</b>	<b>2.4%</b>
<b>Residential</b>	<b>43</b>	<b>43</b>	<b>40</b>	<b>41</b>	<b>38</b>	<b>37</b>	<b>39</b>	<b>35</b>	<b>-19%</b>	<b>-19%</b>
<b>Agriculture/Forestry/Fishing</b>	<b>2.4</b>	<b>2.2</b>	<b>3.2</b>	<b>3.3</b>	<b>3.0</b>	<b>3.2</b>	<b>3.3</b>	<b>3.3</b>	<b>35%</b>	<b>49%</b>

Note: Totals may not add up due to rounding.

Figure 2–9 **Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 1990–2023 and 2005–2023**

**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 2023, the quantity of electricity generated by natural gas-fired units increased by 140% (42 TWh), while the amount generated by coal and refined petroleum products decreased by 77% (72 TWh) and 79% (8.6 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 26 Mt between both 1990 and 2023, and 2005 and 2023.

The efficiency of combustion equipment has also played a role in the GHG emission reductions. Energy efficiency improvements resulted in an approximately 10 Mt reduction in GHG emissions between 1990 and 2023 and a 9.8 Mt reduction between 2005 and 2023.

### **Petroleum Refining (2023 GHG emissions, 14 Mt)**

From 1990 to 2023, GHG emissions from the Petroleum Refining category decreased by 3.2 Mt (18%). This reflects a consolidation of the industry during that period. In 1990, 27 refineries were in operation in Canada with an average crude oil capacity of approximately 11,000 m<sup>3</sup> per day (CER, 2018) whereas in 2023, there were 15 operating refineries with an average capacity of almost 20,000 m<sup>3</sup> per day (CER, 2024). Since 2005, five refineries have permanently closed or converted to terminal facilities with one converting to a biofuel facility: North Atlantic Come-By-Chance (2020), Imperial Oil Dartmouth (2013), Parkland Bowden (2012), Shell Montreal (2010), and Petro-Canada Oakville (2005). These closures contributed to a decrease of 4.4 Mt (24%) in emissions between 2005 and 2023.

### **Oil and Gas Extraction (2023 GHG emissions, 107 Mt)**

Stationary combustion emissions from Oil and Gas Extraction increased by 77 Mt (249%) between 1990 and 2023 and by 44 Mt (70%) between 2005 and 2023. 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 227% increase in the production of non-upgraded crude bitumen and synthetic crude oil from the oil sands industry since 2005 (AER, 2024) and the increased use of more energy-intensive extraction techniques, such as horizontal drilling, hydraulic fracturing and enhanced oil recovery.

In the oil sands industry, crude bitumen extraction occurs through surface mining, in-situ thermal extraction techniques such as steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS), or through primary production methods that are similar to conventional oil production techniques. Thermal extraction processes involve the injection of large volumes of steam, typically produced by combusting natural gas, into the producing formation. Since 2005, total natural gas consumption in the Oil and Gas Extraction category has increased by approximately 97%, and in-situ thermal production has increased by over 435% (AER, 2024). In general, while emission increases from Oil and Gas Extraction may originate from multiple activities, they tend to be consistent with the 541% increase in the production of non-upgraded bitumen through mining or thermal extraction in Canada's oil sands area, particularly in SAGD production. In contrast, since 2005, natural gas production has increased by just 3% (StatCan, n.d.[c]) while conventional oil production, including primary production of crude bitumen in oil sands areas, has increased by only 14% (AER, 2024, StatCan, n.d.[d], n.d.[e]).

Additional information about the Oil and Gas Extraction category is provided in [Table 2–13](#), where emissions are broken down by economic sectors (Natural Gas Production and Processing, Conventional Oil Production and Oil Sands). [Section 2.4.1](#) presents a short discussion of trends in the oil and gas industry by economic sector.

### **Manufacturing Industries and Construction (2023 GHG emissions, 47 Mt)**

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

In 2023, GHG emissions from the Manufacturing Industries and Construction category were 47 Mt, which represents a 25% (15 Mt) decrease from 1990 and a 10% (5.3 Mt) decrease from 2005. The decrease between 2005 and 2023 is driven by Other Manufacturing (-3.2 Mt), Pulp, Paper and Print (-1.6 Mt), Cement (-1.5 Mt), Non-Ferrous Metals (-0.7 Mt), and Iron and Steel (-0.5 Mt), offset by an increase in Chemicals (1.1 Mt), Mining (0.91 Mt), and Construction (0.07 Mt).

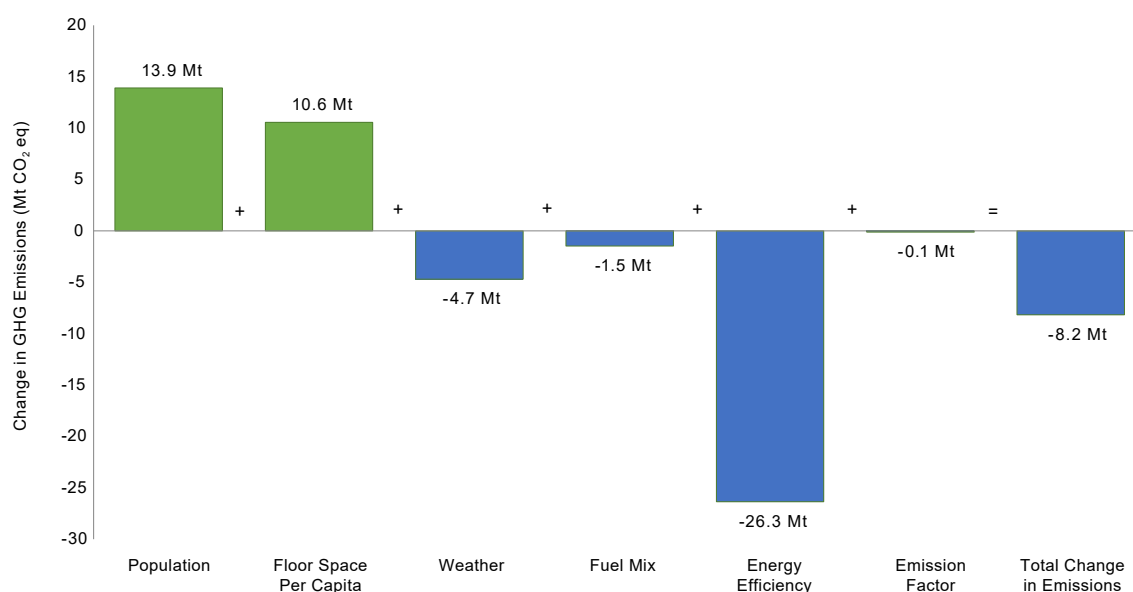
As with Electricity Generation, emission decreases in Manufacturing Industries and Construction largely resulted from decreases in fuel combustion and fuel switching to lower GHG-intensive fuels. In 1990, natural gas made up 89% of the fuel mix in Other Manufacturing, while in 2023 it only made up 70%; replacing the natural gas with wood combustion, which together made up 96% of the fuel mix in 2023. In 1990, heavy fuel oil made up 17% of the fuel mix in the Pulp, Paper and Print subcategory while in 2023, 98% of the fuel mix consisted of less GHG-intensive fuels such as natural gas, spent pulping liquor and wood waste. In contrast, combustion emissions from chemical industries showed an increase in emissions of 1.1 Mt (13%). This is generally consistent with a 39% (CEEDC, n.d.) growth in the production of chemicals between 1990 and 2023.

## Other Sectors (2023 GHG emissions, 71 Mt)

The Other Sectors category includes emissions from the Residential, Commercial and Institutional, and Agriculture and Forestry subcategories. GHG emissions in the Residential and the Commercial and Institutional subcategories come from the combustion of fuels such as natural gas, home heating oil and biomass fuels (non-CO<sub>2</sub> only), primarily to heat residential, commercial and institutional buildings. Emissions in these categories contributed 68 Mt of GHG emissions in 2023, a 1.7% decrease since 1990. Emissions in the Agriculture and Forestry subcategory largely result from the combustion of fuels for activities such as grain drying and heating barns, buildings, or greenhouses. Emissions in this subcategory showed an increase of 0.85 Mt (35%).

Overall, Residential emissions decreased by 8.2 Mt (19%) between 1990 and 2023 and by 8.1 Mt (19%) between 2005 and 2023. In contrast, Commercial and Institutional emissions increased by 7.0 Mt (27%) from 1990 to 2023 and by 0.77 Mt (2.4%) from 2005 to 2023. Energy efficiency improvements, new home construction, increases in population and increases in commercial floor space are the major factors that influenced the changes in energy-related emissions in the Residential and the Commercial and Institutional subcategories (Figure 2–10 and Figure 2–11).

Figure 2–10 **Factors Contributing to the Change in Stationary GHG Emissions from the Residential Category between 1990 and 2023**



**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.

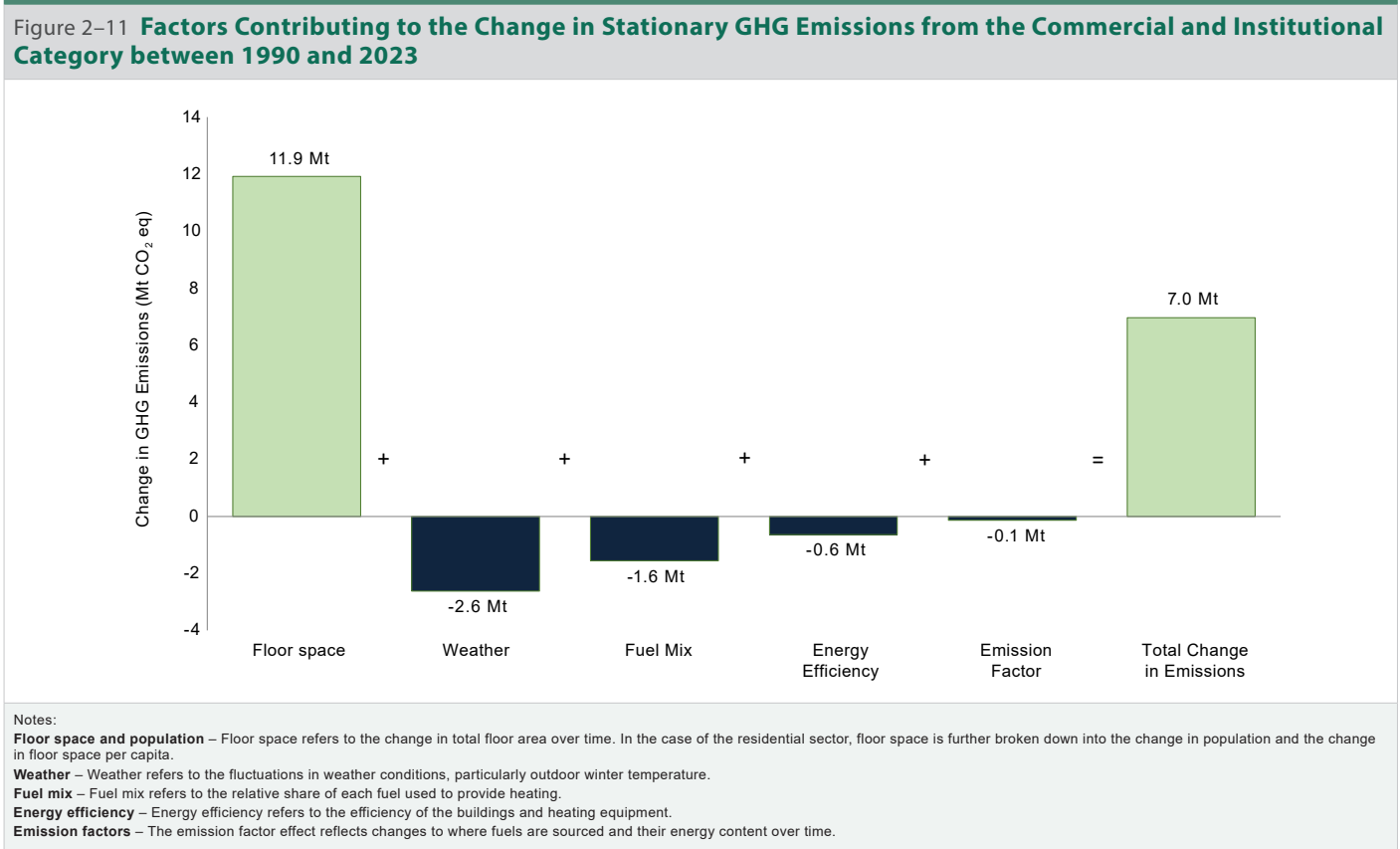
**Energy efficiency** – Energy efficiency refers to the efficiency of the buildings and heating equipment.

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

In the Residential subcategory, population and floor space per capita are the most significant upward drivers of emissions, although their effects have been more than offset by improvements in energy efficiency, which are equivalent to a 26.3 Mt decrease in emissions between 1990 and 2023. Decreasing consumption of light fuel oil in all provinces and territories, especially Quebec and Ontario, between 1990 and 2023 is the largest driver of the 1.5 Mt decrease in the fuel mix contributing to residential emissions in that period.

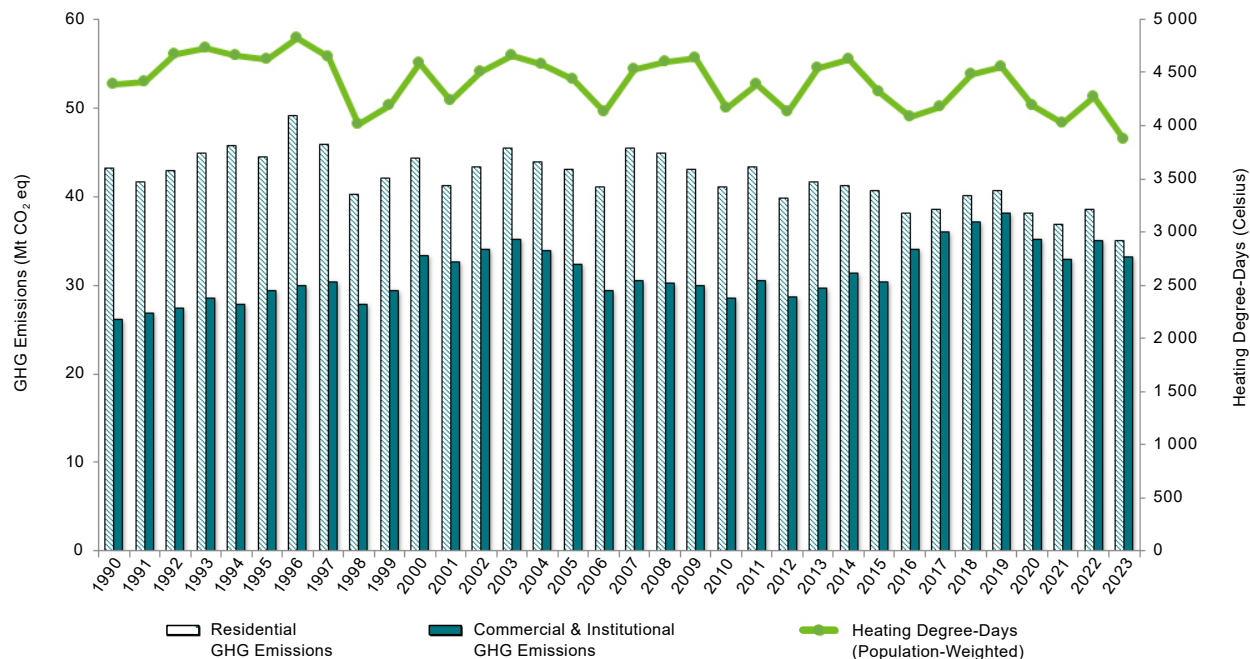
In the long term, floor space was the most significant upward driver of emissions in the Commercial and Institutional subcategory, having increased by 52% since 1990.<sup>8</sup> The resulting 11.9 Mt increase in emissions was partially offset by improvements in the fuel mix and energy efficiency, equivalent to a 1.6 Mt and 0.6 Mt decrease in GHG emissions, respectively (Figure 2–11).

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



8 Lasota, M. 2024. Personal communication (email from Lasota M. to Kay J., Physical Scientist, PIRD, dated November 13, 2024). Economic Analysis Directorate, Environment and Climate Change Canada.

Figure 2–12 **Heating Degree-Days (HDDs) and GHG Emissions from the Residential and the Commercial and Institutional Categories (1990–2023)**



### 2.3.1.2. Transport (2023 GHG emissions, 195 Mt)

Transport is a large and diverse sector, accounting for 195 Mt of GHG emissions or 35% of Canada's Energy sector emissions in 2023. 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 2023, Transport emissions rose by 35% (50 Mt), accounting for a significant portion of Canada's emissions growth. Between 2019 and 2020, Transport emissions decreased by 15% (31 Mt), the first notable year-to-year decrease to occur since 2008–2009, which had a year-to-year decrease of 2.6% (5.1 Mt). Between 2020 and 2023, Transport emissions increased by 9.8% (17 Mt).

Emissions from Transport result primarily from Road Transportation, which includes personal transportation (light-duty gasoline vehicles and trucks) and heavy-duty diesel vehicles, accounting for 62% of Transport emissions in 2023 (Figure 2–13). Other Transportation (Off-Road and Pipelines) is the second-largest category, accounting for 28% of Transport emissions in 2023, 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 2023, the Aviation category increased by 76% (3.6 Mt). The Marine and Railways categories combined contributed approximately 5.0% of the Transport emissions in 2023 and, overall, were stable over the 1990–2023 time series.

Figure 2–13 Trends in Canadian GHG Emissions from Transport (1990–2023)

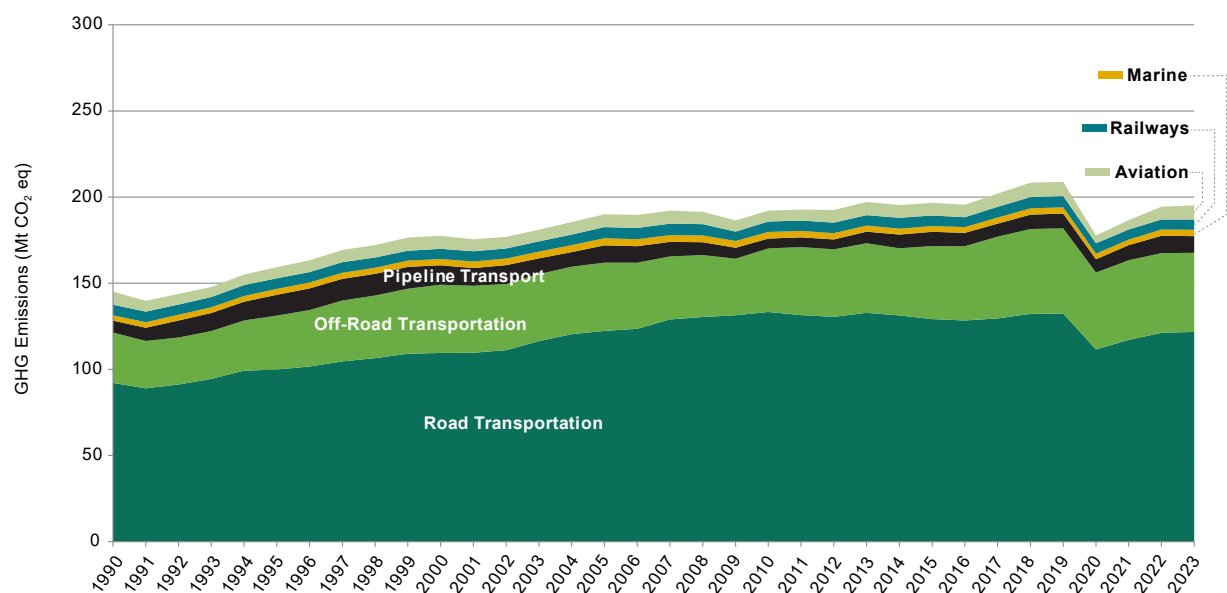


Table 2–5 GHG Emissions from Transport, Selected Years

CRT Code		GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)	
		1990	2005	2018	2019	2020	2021	2022	2023	1990–2023	2005–2023
<b>1.A.3</b>	<b>TRANSPORT</b>	<b>145</b>	<b>190</b>	<b>209</b>	<b>209</b>	<b>178</b>	<b>187</b>	<b>195</b>	<b>195</b>	<b>35%</b>	<b>3%</b>
	<b>Aviation</b>	<b>7.5</b>	<b>7.7</b>	<b>8.7</b>	<b>8.6</b>	<b>4.7</b>	<b>5.6</b>	<b>7.7</b>	<b>8.4</b>	<b>11%</b>	<b>8%</b>
1.A.3.a	Domestic Aviation (Civil)	7.3	7.5	8.4	8.3	4.6	5.4	7.5	8.2	12%	10%
1.A.5.b	Military	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	-15%	-23%
	<b>Road Transportation</b>	<b>92</b>	<b>122</b>	<b>132</b>	<b>132</b>	<b>112</b>	<b>117</b>	<b>121</b>	<b>122</b>	<b>32%</b>	<b>-1%</b>
1.A.3.b.i	Light-Duty Gasoline Vehicles	44	41	32	31	24	25	26	25	-42%	-37%
1.A.3.b.ii	Light-Duty Gasoline Trucks	25	41	54	56	48	50	52	54	118%	31%
1.A.3.b.iii	Heavy-Duty Gasoline Vehicles	4.8	4.6	4.5	4.6	4.2	4.2	3.9	4.1	-15%	-12%
1.A.3.b.iv	Motorcycles	0.2	0.5	0.9	1.0	0.8	0.8	0.8	0.8	286%	72%
1.A.3.b.i	Light-Duty Diesel Vehicles	0.4	0.7	0.5	0.4	0.3	0.3	0.4	0.3	-10%	-50%
1.A.3.b.ii	Light-Duty Diesel Trucks	1.0	0.7	0.8	0.8	0.6	0.8	1.0	0.9	-5%	25%
1.A.3.b.iii	Heavy-Duty Diesel Vehicles	16	34	39	38	33	36	38	36	124%	6%
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	-79%	592%
<b>1.A.3.c</b>	<b>Railways</b>	<b>6.1</b>	<b>6.5</b>	<b>6.5</b>	<b>6.5</b>	<b>6.0</b>	<b>5.9</b>	<b>5.8</b>	<b>5.9</b>	<b>-3%</b>	<b>-9%</b>
	<b>Marine</b>	<b>3.2</b>	<b>4.1</b>	<b>3.7</b>	<b>3.7</b>	<b>3.3</b>	<b>3.2</b>	<b>3.6</b>	<b>3.7</b>	<b>17%</b>	<b>-8%</b>
1.A.3.d	Domestic Navigation	2.3	3.2	3.4	3.3	3.0	2.9	3.3	3.5	52%	9%
1.A.4.c.iii	Fishing	0.9	0.9	0.2	0.2	0.2	0.2	0.2	0.2	-81%	-81%
1.A.5.b	Military Water-Borne Navigation	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	288%	307%
	<b>Other Transportation</b>	<b>36</b>	<b>50</b>	<b>58</b>	<b>58</b>	<b>52</b>	<b>55</b>	<b>56</b>	<b>56</b>	<b>54%</b>	<b>12%</b>
<b>1.A.4.c.ii</b>	<b>Off-Road Agriculture and Forestry</b>	<b>8.7</b>	<b>10</b>	<b>14</b>	<b>14</b>	<b>13</b>	<b>13</b>	<b>13</b>	<b>13</b>	<b>52%</b>	<b>34%</b>
1.A.4.a.ii	Off-Road Commercial and Institutional	4.3	4.5	6.1	6.2	5.6	6.1	6.2	6.3	47%	40%
1.A.2.g.vii	Off-Road Manufacturing, Mining and Construction	12	16	20	20	18	18	19	18	47%	13%
1.A.4.b.ii	Off-Road Residential	0.4	1.2	1.0	1.0	1.0	0.9	0.8	0.8	128%	-32%
1.A.3.e.ii	Off-Road Other Transportation	3.5	7.7	8.0	7.9	7.3	7.5	7.4	7.4	112%	-5%
1.A.3.e.i	Pipeline Transport	6.9	10	8.4	8.5	7.8	8.7	10	9.7	40%	-4%

## Road Transportation (2023 GHG emissions, 122 Mt)

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

The growth trend since 1990 in Road Transportation emissions is largely due to more driving as measured in VKT, which is the net result of changes to annual vehicle kilometre accumulation rates (KAR) and the size of the vehicle fleet. In 2020, total VKT decreased by 17% relative to 2019 levels, driven by reductions to KAR. In 2023, total VKT is 15% higher than 2020 levels but is 4.4% below 2019 levels.

The total vehicle fleet has increased by 56% since 1990 (30% since 2005), most notably for light-duty trucks, which have steadily increased throughout the 1990–2023 time series (Table 2–6). The heavy-duty vehicle fleet steadily increased for most of the time series but has plateaued in recent years. The light-duty car fleet was relatively stable for much of the time series but has noticeably decreased in recent years, driving the decrease observed for the total vehicle fleet for 2021 and later.

Despite decreases to total VKT from 2019 levels, the steady expansion of the overall fleet prior to 2021 resulted in the total VKT for 2023 being 76% and 26% 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 2023, approximately 329 000 fully electric vehicles were in the vehicle fleet, a 48% growth from 2022 (StatCan, n.d.[f]).

Table 2–6 Trends in Vehicle Populations for Canada, Selected Years

Year	Number of Vehicles (000s)			
	Light-Duty Vehicles		Heavy-Duty Vehicles	All Vehicles
	Cars	Trucks		
1990	10 860	4 062	1 085	16 284
2005	10 509	6 925	1 637	19 514
2018	10 199	12 127	1 941	25 007
2019	10 031	12 640	1 937	25 357
2020	9 843	13 114	1 943	25 652
2021	9 888	13 412	1 976	26 095
2022	9 387	13 406	1 932	25 535
2023	9 018	13 601	1 927	25 360
Change since 1990	-17%	235%	78%	56%
Change since 2005	-14%	96%	18%	30%

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.

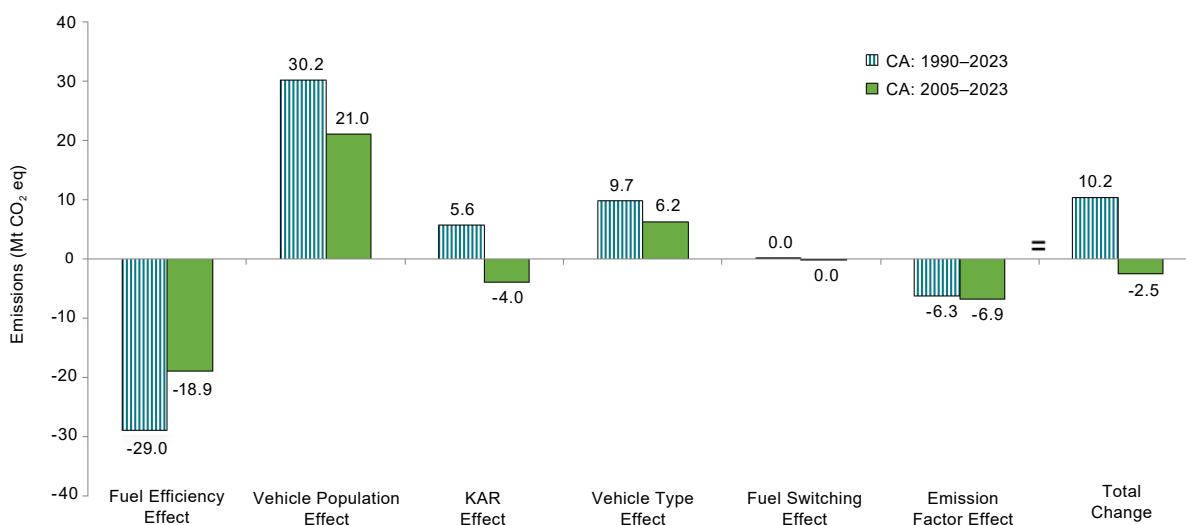
## Light-Duty Gasoline Vehicles (2023 GHG emissions, 25 Mt)

Since 1990, emissions from Light-Duty Gasoline Vehicles (i.e., passenger cars) have steadily decreased and in 2023 were 42% (19 Mt) and 37% (15 Mt) lower than those in 1990 and 2005, respectively. These decreases are largely due to increased fleet-average fuel efficiency, decreased average annual driving rates and reduced sales of passenger cars. As new model year vehicles replace older, less efficient ones, the overall fleet fuel efficiency improves. However, the reduced sales of passenger cars are offset by increased sales of light-duty trucks, which emit significantly more GHGs per kilometre. The implementation of emission control technologies and increased use of biofuels have also contributed to decreased emissions (Figure 2–14).

## Light-Duty Gasoline Trucks (2023 GHG emissions, 54 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 2023 being 118% (29 Mt) and 31% (13 Mt) higher than those in 1990 and 2005, respectively. These increases are largely due to increased sales of light-duty trucks, mitigated somewhat by increased fleet-average fuel efficiency, the implementation of emission control technologies and increased use of biofuels (Figure 2–14). Since 2005, emissions from the light-duty gasoline trucks category have been the top contributor to transportation emissions totals, making up 21% and 27% of that total for 2005 and 2023, respectively.

Figure 2–14 **Factors Contributing to Changes in Light-Duty Vehicle Emissions, 1990–2023 and 2005–2023**



**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, 1990–2023 and 2005–2023.

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

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

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

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

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

**Overall emission factor effect** refers to the change in emissions from emission control technologies on CH<sub>4</sub> and N<sub>2</sub>O emissions as well as the use of biofuels.

## Heavy-Duty Diesel Vehicles (2023 GHG emissions, 36 Mt)

From 1990 to 2011, emissions from Heavy-Duty Diesel Vehicles steadily increased, peaking at 46 Mt in 2011. Since then, emissions from these vehicles have followed a downward trend, largely due to decreased average annual driving rates and reduced growth of the heavy-duty vehicle fleet. In 2023, emissions from these vehicles were estimated to be about 36 Mt, which is 124% (20 Mt) and 5.8% (2.0 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 (2023 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 2023, the Off-Road Manufacturing, Mining and Construction subcategory and the Off-Road Agriculture and Forestry subcategory accounted for 40% and 29% of off-road emissions, respectively. The net emissions for all off-road subcategories have increased by 57% (17 Mt) since 1990 and increased by 16% (6.4 Mt) since 2005. These increases are largely due to increased fleet-average engine power as well as increased total equipment use.

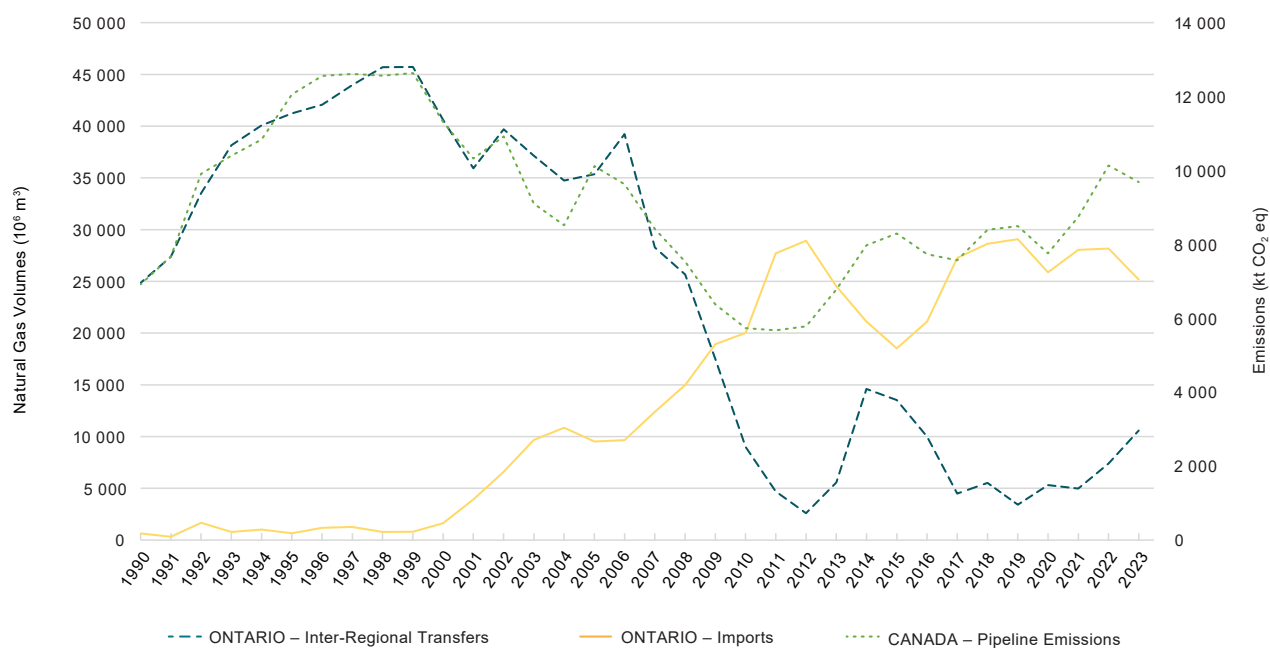
## Other Transportation: Pipeline Transport (2023 GHG emissions, 9.7 Mt)

Pipeline emissions result from the combustion of natural gas at compressor stations used for natural gas transport. In 2023, over 99% of marketable natural gas production occurred in western Canada: Alberta (65%), British Columbia (33%) and Saskatchewan (2.0%). While these provinces account for approximately 65% of marketable natural gas consumption in Canada, Ontario, the most populous province, accounts for approximately 25% of natural gas consumption but produces only 0.03% of natural gas (StatCan, n.d.[c]). The natural gas demand in Ontario, along with the geographical separation from producing regions, necessitates the long-range transport of natural gas through transmission pipelines. For that reason, the source of the natural gas consumed in Ontario has a large impact on pipeline emissions.

Historically, inter-regional transfers of large quantities of Western Canadian natural gas to eastern Canada, especially Ontario, has been the main driver of pipeline emissions. The amount of gas transported from west to east has decreased starting in the early 2000s as western Canadian natural gas was displaced by imports from the United States (StatCan, n.d.[c]) and as more natural gas was consumed in Alberta's oil sands industry. In general, as imports into Ontario increase, inter-regional transfers of gas from western Canada decline, resulting in a decrease in combustion emissions from pipelines (Figure 2–15).

The decrease in emissions from 2022 to 2023 reflects a 4% decrease in natural gas consumption resulting from a 12% decrease in volumes of natural gas transported from Alberta to other provinces and a 3% decrease in exports to the United States.

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

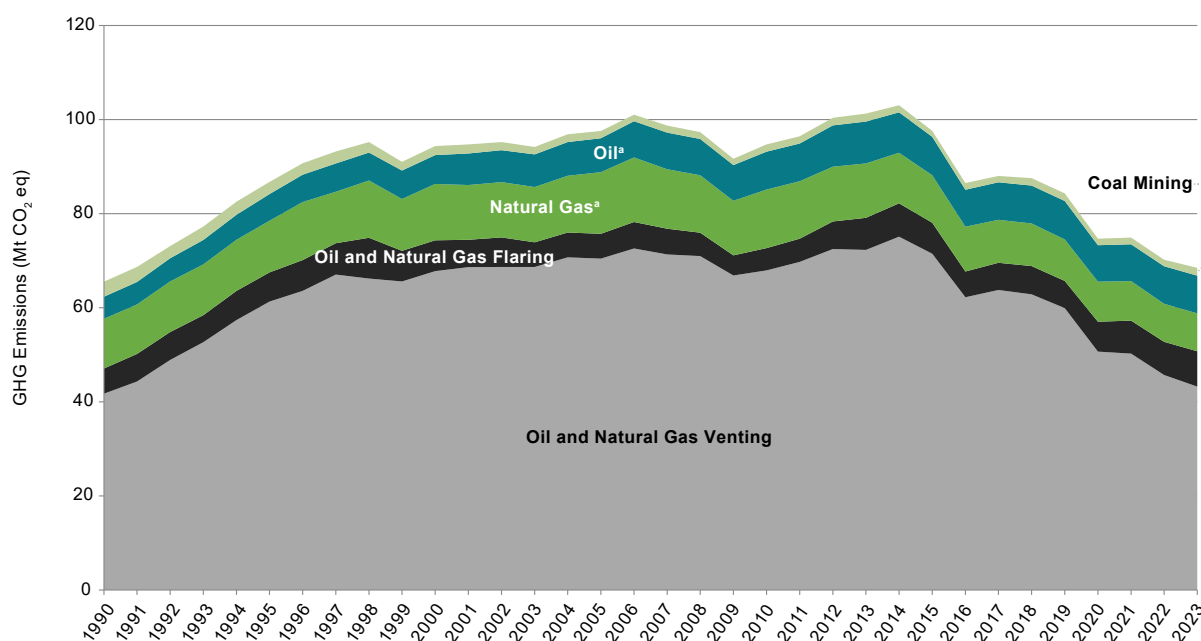


### 2.3.1.3. Fugitive Sources (2023 GHG Emissions, 68 Mt)

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 2.9 Mt (4%) between 1990 (66 Mt) and 2023 (68 Mt) (Table 2–7) with considerably more variation over the time series. Fugitive emissions peaked in 2014 at 103 Mt (Figure 2–16), 57% higher than 1990. Fugitive emissions from Oil and Natural Gas alone increased by 39 Mt (63%) over this period, while releases from Coal Mining decreased by 1.6 Mt (52%), mainly due to mine closures in eastern Canada.

Figure 2–16 Trends in Canadian GHG Emissions from Fugitive Sources (1990–2023)



Note:  
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 <sub>2</sub> eq)								Change (%)	
	1990	2005	2018	2019	2020	2021	2022	2023	1990–2023	2005–2023
<b>FUGITIVE SOURCES<sup>a</sup></b>	<b>66</b>	<b>98</b>	<b>88</b>	<b>84</b>	<b>75</b>	<b>75</b>	<b>70</b>	<b>68</b>	<b>4%</b>	<b>-30%</b>
<b>Coal Mining</b>	<b>3.2</b>	<b>1.5</b>	<b>1.6</b>	<b>1.6</b>	<b>1.4</b>	<b>1.4</b>	<b>1.4</b>	<b>1.6</b>	<b>-48%</b>	<b>6%</b>
<b>Oil and Natural Gas</b>	<b>62</b>	<b>96</b>	<b>86</b>	<b>83</b>	<b>73</b>	<b>73</b>	<b>69</b>	<b>67</b>	<b>7%</b>	<b>-30%</b>
Oil <sup>b</sup>	4.7	7.2	8.1	8.2	7.8	7.8	8.0	8.0	70%	12%
Natural Gas <sup>b</sup>	11	13	9.1	8.8	8.5	8.4	8.1	8.0	-24%	-39%
Venting	42	70	63	60	51	50	46	43	4%	-39%
Flaring	5.4	5.3	6.0	5.8	6.4	7.0	7.0	7.5	41%	43%

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 2023, it accounted for only 19% of total oil and gas fugitive emissions. Since most fugitive emissions originate from conventional oil and natural gas production and processing activities, the increase in crude bitumen production from the oil sands has little impact on fugitive emissions. In contrast, oil sands production has a large impact on combustion emissions (refer to section 2.3.1.1).

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. 2014–2023: declining emissions

Fugitive oil and gas emissions increased steadily from 62 Mt in 1990 to 92 Mt in 2000 (48%). Additionally, over 120,000 oil and gas wells were drilled between 1990 and 2000 (CAPP, 2023). As the number of extraction and processing facilities in the oil and gas industry increases, the number of potential sources of fugitive emissions also grows, driving the increase in emissions. From 2000 to 2014, the oil and gas industry continued to grow substantially, but fugitive emissions did not grow at the same rate, because of the combined effect of improved inspection and maintenance programs, better industry practices, technological improvements and initiatives by provincial regulators. For example, in 1999, the province of Alberta introduced *Directive 060: Upstream Petroleum Industry Flaring, Incinerating, and Venting* to reduce flaring and venting emissions from its oil industry by requiring operators to connect to gas gathering systems under specific conditions (AER, 2014). In 2006, leak detection and repair best management practices were added to Directive 060 to reduce emissions from fugitive equipment leaks. In 2010, British Columbia introduced the *Flaring and Venting Reduction Guideline* (BCOGC, 2015), and in 2012, Saskatchewan adopted *Directive S-10: Saskatchewan Upstream Petroleum Industry Associated Gas Conservation Standards*, both of which have similar goals to Alberta's Directive 060.

Despite these efforts, fugitive oil and gas emissions increased by 9.1 Mt (10%) between 2000 and 2014, peaking in 2014 at 102 Mt. This was mainly due to significant expansion of the industry as the number of operating oil and gas wells increased by over 100% and approximately 270,000 new wells were drilled. These trends indicate that while the various measures had a positive impact on emission reductions, they were not enough to counteract the continued expansion of the industry, as operators required more and more wells to maintain production levels. In fact, between 2000 and 2014 the average production per oil well decreased by about 38% (CAPP, 2023; StatCan, n.d.[d], n.d.[e]) and the average production per natural gas well decreased by 62% in western Canada (CAPP, 2023; StatCan, n.d.[g], n.d.[h]).

From 2014 to 2023, emissions dropped by 35 Mt (34%), mainly due to reductions in venting as more gas was conserved and further measures were adopted to mitigate unintentional leaks. This trend was partly driven by a gradual shift away from conventional heavy oil production in Saskatchewan and Alberta, including Cold Heavy Oil Production with Sand (CHOPS), towards in-situ thermal heavy oil production techniques like SAGD. Gas produced from thermal heavy oil wells is predominantly conserved and consumed onsite to offset the significant energy demands of these operations. Compared to 2014, the number of active conventional heavy oil wells had decreased 36% by 2023, while the number of thermal heavy oil production wells grew by 15%. There was also an overall contraction within the sector as the number of operating wells decreased by 20% and the annual number of wells drilled fell by almost 60%.

Further to existing provincial directives, federal (ECCC, 2018) and equivalent<sup>9</sup> provincial regulations (AB, 2018; BC, 2021; SK, 2020) to reduce CH<sub>4</sub> emissions from oil and gas operations came into effect January 1, 2020. Since the regulations have been in force, natural gas production has increased by 13%, and while the number of operating oil and gas wells remained roughly constant, the number of wells drilled increased by 70%. Improving compliance with the federal and provincial regulations likely offset expected increases that might have otherwise resulted from production growth. It should be noted that vent gas volume reporting requirements in Alberta, British Columbia and Saskatchewan were updated in 2020, resulting in a methodological inconsistency that may have artificially contributed to the decline in emissions over this period. See Annex 3.2, section A3.2.2.1.5 for more details.

9 Under the Canadian Environmental Protection Act, 1999 (CEPA), the Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector), SOR/2018-66 (the "federal methane regulations") were published in the *Canada Gazette*, Part II, vol. 152, no. 1 on April 26, 2018. The federal methane regulations came into force on January 1, 2020, except sections 26, 27 and 37 to 41, which 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).

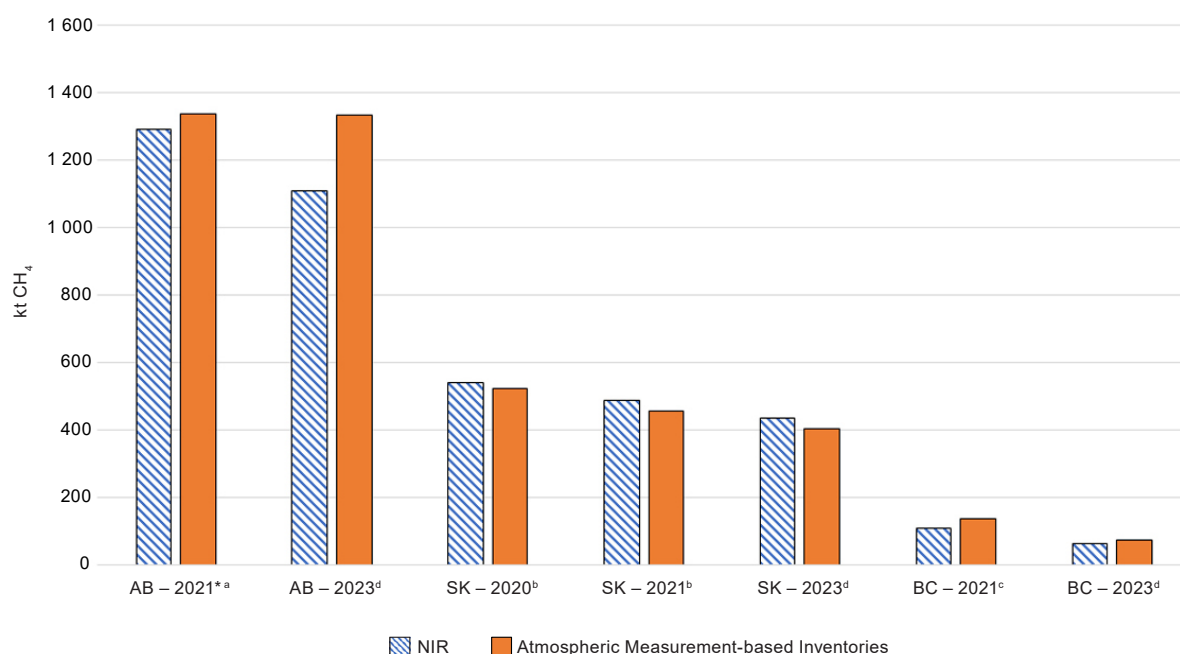
# INTEGRATING TOP-DOWN AND BOTTOM-UP METHANE ESTIMATES FOR THE OIL AND GAS SECTOR

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

Studies in Canada that have used atmospheric measurements to derive “top-down” methane (CH<sub>4</sub>) estimates have typically produced large-scale, regional or facility-level estimates and were not able to resolve emission sources within a facility (e.g., Atherton et al., 2017; Johnson et al., 2017; Zavala-Araiza et al., 2018; Chan et al., 2020; MacKay et al., 2021). Differences in the results from “top-down” and “bottom-up” approaches are unavoidable due to differing methodologies, data sources, level of detail, and other confounding factors. However, recent advances in measurement technology have enabled the development of a protocol to create robust source-resolved atmospheric measurement-based oil and gas methane inventories with defined uncertainties (Johnson et al., 2023). This protocol has been utilized to estimate methane emissions from oil and gas operations in British Columbia (Johnson et al., 2023), Alberta (Conrad et al., 2023a) and Saskatchewan (Conrad et al., 2023b).

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

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



**Notes:**

a. Conrad et al., 2023a. Subject to revision based on learnings from analysis of 2023 and 2024 measurement campaigns

b. Conrad et al., 2023b. Emission estimates updated by EERL to reflect revised strata and previously unsampled strata.

c. Johnson et al., 2023. Emission estimates updated by EERL to reflect revised compressor counts and strata.

d. EERL, 2024

\* subject to revision based on learnings from analysis of 2023 and 2024 measurement campaigns.

#### 2.3.1.4. Trends in CO<sub>2</sub> Transport and Storage

Since 2000, the majority of captured CO<sub>2</sub> transport and storage activities in Canada have been associated with enhanced oil recovery (EOR) operations at Weyburn, Saskatchewan, utilizing captured CO<sub>2</sub> imported from the United States. In 2014, the Weyburn operations also began receiving most of the CO<sub>2</sub> captured at the Boundary Dam coal-fired power plant in Saskatchewan with the remaining amount transported to the Aquistore Project and its Basal Cambrian storage complex for injection directly into long-term storage (LTS).

In 2016, CO<sub>2</sub> capture began in Alberta for the purpose of LTS at a geological site. Shell's Quest project captures CO<sub>2</sub> from the Scotford upgrader and transports it 65 kilometres north to a LTS site. Since 2020, the Alberta CO<sub>2</sub> Trunk line has received CO<sub>2</sub> captured at the Nutrien fertilizer facility and Sturgeon refinery for use in EOR at a site near Clive, Alberta.

In 2023, a total of 4.39 Mt of captured CO<sub>2</sub> was available for LTS and EOR operations, with 3.32 Mt domestically captured and 1.07 Mt imported (Chapter 3, [Table 3–15](#)). Domestically captured CO<sub>2</sub> volumes have increased by over 2800% since 2014 (0.11 Mt) while the cumulative LTS of captured CO<sub>2</sub> has increased by over 2100% since 2015 to 8.26 Mt at 2023 year-end.

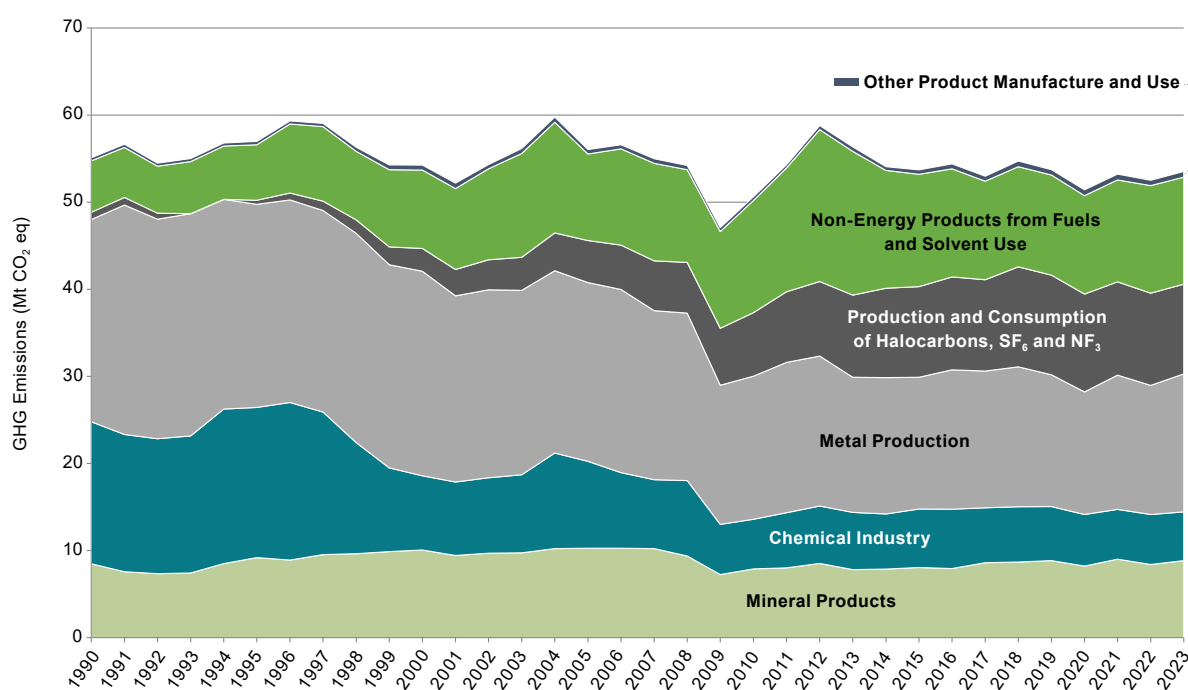
Table A10-3 (Annex 10) presents details of CO<sub>2</sub> capture volumes consistent with the origin of the captured CO<sub>2</sub> (a refinery, upgrading facility and coal-fired power plant) and these volumes are subtracted from emissions reported under Upstream Oil and Gas, and Petroleum Refining, in Alberta, and Public Electricity and Heat Production, in Saskatchewan.

Annex 9 of this report presents emissions from CO<sub>2</sub> transport systems in Canada while Annex 11 presents emissions by provincial/territorial regions. In 2023, CO<sub>2</sub> pipeline fugitives accounted for 36.9 kt of emissions while CO<sub>2</sub> injection sites accounted for 0.04 kt (see Chapter 3, [Table 3–16](#)).

#### 2.3.2. Industrial Processes and Product Use (2023 GHG emissions, 54 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<sub>6</sub> and NF<sub>3</sub>; Non-Energy Products from Fuels and Solvent Use; and Other Product Manufacture and Use. Emissions from the IPPU sector contributed 54 Mt (7.7%) to Canada's 2023 emissions, compared with 56 Mt (7.4%) in 2005, a decrease of approximately 2.5 Mt, or 4.5%. Total emissions in this sector result from activities in several diverse industries. Trends in emissions reflect the combined effects of multiple drivers on various industries.

Figure 2–17 Trends in Canadian GHG Emissions from Industrial Processes and Product Use Sources (1990–2023)



Emission reductions have occurred since 2005 in Iron and Steel Production (CO<sub>2</sub>), Aluminium Production (PFCs), Adipic Acid Production (N<sub>2</sub>O), Magnesium Production and Casting (CO<sub>2</sub> and SF<sub>6</sub>), Nitric Acid Production (N<sub>2</sub>O), and Cement Production (CO<sub>2</sub>). These reductions were mainly offset by increases observed in the Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub> (mostly HFCs) (Figure 2–17 and Table 2–8).

Increases in process emissions from 2022 to 2023 of 1.0 Mt (1.9%) were observed. Some subsectors and categories increased, notably, the Iron and Steel Industry, Cement Production and Aluminium Production; however, these increases

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

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)	
	1990	2005	2018	2019	2020	2021	2022	2023	1990–2023	2005–2023
<b>TOTAL – INDUSTRIAL PROCESSES AND PRODUCT USE</b>	<b>55</b>	<b>56</b>	<b>55</b>	<b>54</b>	<b>51</b>	<b>53</b>	<b>53</b>	<b>54</b>	<b>-3%</b>	<b>-4%</b>
<b>Mineral Products</b>	<b>8.5</b>	<b>10</b>	<b>8.7</b>	<b>8.9</b>	<b>8.2</b>	<b>9.0</b>	<b>8.4</b>	<b>8.8</b>	<b>4%</b>	<b>-14%</b>
Cement Production	5.8	7.6	7.0	7.2	6.7	7.4	6.8	7.3	25%	-4%
Lime Production	1.9	1.8	1.4	1.3	1.2	1.3	1.3	1.2	-33%	-32%
Mineral Product Use	0.80	0.83	0.33	0.32	0.31	0.31	0.31	0.30	-63%	-64%
<b>Chemical Industry</b>	<b>16</b>	<b>10</b>	<b>6.4</b>	<b>6.2</b>	<b>5.9</b>	<b>5.7</b>	<b>5.7</b>	<b>5.6</b>	<b>-66%</b>	<b>-44%</b>
Ammonia Production	2.7	2.7	2.4	2.5	2.3	2.5	2.6	2.4	-12%	-11%
Nitric Acid Production	0.87	1.1	0.24	0.23	0.17	0.19	0.13	0.13	-85%	-88%
Adipic Acid Production	9.2	2.3	-	-	-	-	-	-	-100%	-100%
Petrochemical Production & Carbon Black Production	3.5	3.9	3.7	3.5	3.5	3.0	3.0	3.0	-13%	-22%
<b>Metal Production</b>	<b>23</b>	<b>21</b>	<b>16</b>	<b>15</b>	<b>14</b>	<b>15</b>	<b>15</b>	<b>16</b>	<b>-32%</b>	<b>-23%</b>
Iron and Steel Production	10	11	10.5	9.6	8.1	9.5	9.0	9.5	-9%	-12%
Aluminium Production	10	8.3	5.4	5.2	5.8	5.8	5.7	6.1	-36%	-27%
Magnesium Production and Casting	3.2	1.4	0.14	0.29	0.10	0.14	0.17	0.25	-92%	-83%
<b>Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub></b>	<b>0.82</b>	<b>4.8</b>	<b>11</b>	<b>11</b>	<b>11</b>	<b>11</b>	<b>11</b>	<b>10</b>	<b>1158%</b>	<b>113%</b>
<b>Non-Energy Products from Fuels and Solvent Use</b>	<b>5.9</b>	<b>10</b>	<b>12</b>	<b>12</b>	<b>11</b>	<b>12</b>	<b>12</b>	<b>12</b>	<b>109%</b>	<b>24%</b>
<b>Other Product Manufacture and Use</b>	<b>0.36</b>	<b>0.51</b>	<b>0.65</b>	<b>0.62</b>	<b>0.66</b>	<b>0.66</b>	<b>0.61</b>	<b>0.65</b>	<b>79%</b>	<b>27%</b>

Notes:  
Totals may not add up due to rounding.  
"—" indicates that there were no emissions from the source category.

were partially offset by decreases in Ammonia Production and the Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub>. In 2023, the largest contributions to emissions in the sector originated from Metal Production (16 Mt), followed by Non-Energy Products from Fuels and Solvent Use (12 Mt) and the Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub> (mostly HFCs) (10 Mt) (Table 2–8).

### 2.3.2.1. Mineral Products (2023 GHG Emissions, 8.8 Mt)

Cement Production dominates this subsector, accounting for 83% of emissions from Mineral Products in 2023. Fluctuations over the years largely result from variations in clinker production, especially circa 2009, with some gradual recovery with the opening of a new facility in Quebec in 2017. Emission reductions in this subsector contributed to an overall reduction of 1.4 Mt (14%) from 2005 to 2023.

### 2.3.2.2. Chemical Industry (2023 GHG Emissions, 5.6 Mt)

From 2005 to 2023, an emissions decrease of 4.4 Mt (44%) is observed in the Chemical Industry as a whole. The main driver of emission reductions in this industry was the discontinuation of adipic acid production in 2009; this alone represents a decrease of 2.3 Mt from 2005.<sup>10</sup> N<sub>2</sub>O emissions abatement installations at a nitric acid production facility are mainly responsible for a decrease of 0.94 Mt (88%) in the subsector since 2005. Other changes included a decrease in Petrochemical and Carbon Black Production (0.88 Mt) due to facility closures and feedstock changes in ethylene production, as well as a small decrease (0.29 Mt) in Ammonia Production that is primarily attributed to carbon capture and storage activities (CCS) used for enhanced oil recovery (EOR).

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

### 2.3.2.3. Metal Production (2023 GHG Emissions, 16 Mt)

Emission reductions in the production of magnesium, aluminium, and iron and steel contributed to Metal Production overall reductions of 4.7 Mt (23%) between 2005 and 2023.

The aluminium industry decreased its PFC emissions by 2.7 Mt (80%), largely due to technological improvements. The magnesium production and casting industries also showed a decrease in emissions by 1.2 Mt (83%) as a result of the replacement of SF<sub>6</sub> with alternatives and the closure of plants over the years. Primary magnesium production in Canada ceased in 2008.

From 2005 to 2023, emissions in the iron and steel industry decreased by 1.3 Mt (12%). The main driver behind the decrease in emissions was the 2013 closure of the iron and steel production processes at an integrated mill.

### 2.3.2.4. Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub> (2023 GHG Emissions, 10 Mt)

There is currently no production of HFCs, PFCs, SF<sub>6</sub> or NF<sub>3</sub> in Canada. HFC-23 was generated as a by-product of HCFC-22 production, which ended in 1992. Since then, all emissions in this subsector are associated with the consumption of HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub> only. Emissions from the consumption of HFCs increased by 5.4 Mt (113%) from 2005 to 2023. This can be explained by the replacement of ODSs by HFCs within the refrigeration, air conditioning, and foam blowing agent markets since the Montreal Protocol came into effect. HFC emissions decreased by 1.2 Mt (11%) between 2018 and 2023 due in part to reduced bulk imports. This reduction coincides with the implementation of the *Ozone-depleting Substance and Halocarbon Alternatives Regulations*, which for calendar years 2019 to 2023 limited national net HFC imports (expressed in CO<sub>2</sub> equivalent mass) to 90% of average annual net imports seen from 2011 to 2013 (Government of Canada, 2020). The other sources of emissions (PFCs, SF<sub>6</sub> and NF<sub>3</sub>) in this subsector do not have a significant impact on emissions trends as the next largest source (SF<sub>6</sub>) has emissions of less than 1% of the HFC emissions value.

### 2.3.2.5. Non-Energy Products from Fuels and Solvent Use (2023 GHG Emissions, 12 Mt)

The Non-Energy Products from Fuels and Solvent Use category is one of the largest emission sources in the IPPU sector with its emissions increasing by 2.4 Mt (24%) from 2005 to 2023. The observed change is mostly attributable to the emissions from the feedstock use of butane and waxes, paraffin and unfinished products, which increased by 1.2 Mt (155%) and 0.8 Mt (22%), respectively over the period.

## 2.3.3. Agriculture Sector (2023 GHG Emissions, 55 Mt)

In 2023, emissions from the Agriculture sector accounted for 55 Mt, or 7.9%, of total GHG emissions in Canada, 1 Mt lower than 2005 levels, corresponding to an increase of 13 Mt or 30% since 1990 (Figure 2–18 and Table 2–9). In 2023, the Agriculture sector accounted for 28% of national CH<sub>4</sub> emissions and 76% of national N<sub>2</sub>O emissions, up from 26% and 44% in 1990, respectively.

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

The main economic sectors in Canadian agriculture are livestock and crop production. GHG emissions from the livestock sector include CH<sub>4</sub> emissions from enteric fermentation and emissions of CH<sub>4</sub> and N<sub>2</sub>O from the storage and handling of animal manure. The crop production sector includes N<sub>2</sub>O emissions from the application of inorganic nitrogen fertilizers, crop residue decomposition, animal manure and biosolids applied as fertilizers and crop management practices; CH<sub>4</sub> and N<sub>2</sub>O emissions from the burning of agricultural residues; and CO<sub>2</sub> 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 2023 are 4%, 36% 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 66% of total agricultural emissions in 2023, considerably lower than the proportion in 2005 (81%) (Figure 2–19). As a result of this shift, the proportional contribution of N<sub>2</sub>O (mainly from crop production) to total agricultural emissions has increased steadily since 2005, offset by a decline in CH<sub>4</sub> (from livestock production). Emissions in 2023 are slightly lower than 2005, though the contribution of emissions from crop production has increased relative to the livestock sector. The shift in the industry from grazing cattle production to the annual crop production is also reflected in a decreased carbon sink in agricultural soils observed in a land management change from perennial to annual crops reported in the LULUCF sector (Liang et al. 2020).

Figure 2–18 Trends in Canadian GHG Emissions from Agriculture Sources (1990–2023)

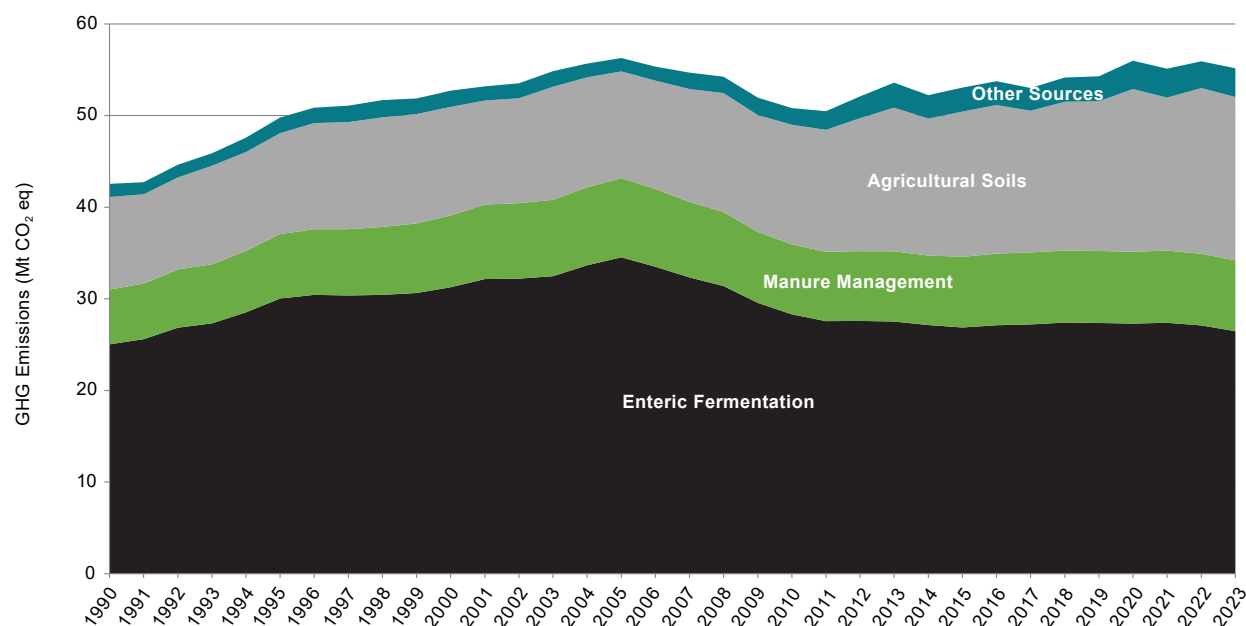


Table 2–9 GHG Emissions from Agriculture, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)	
	1990	2005	2018	2019	2020	2021	2022	2023	1990–2023	2005–2023
<b>AGRICULTURE<sup>a</sup></b>	<b>43</b>	<b>56</b>	<b>54</b>	<b>54</b>	<b>56</b>	<b>55</b>	<b>56</b>	<b>55</b>	<b>30%</b>	<b>-2.0%</b>
<b>By IPCC Category</b>										
Enteric Fermentation	25	35	27	27	27	27	27	26	5.7%	-23%
Manure Management	6.0	8.7	7.9	7.9	7.8	7.9	7.8	7.7	29%	-11%
Agricultural Soils	10	12	16	16	18	17	18	18	76%	53%
Field Burning of Agricultural Residues	0.24	0.045	0.053	0.053	0.057	0.038	0.050	0.046	-80%	2.4%
Liming, Urea Application and Other Carbon-Containing Fertilizers	1.2	1.4	2.6	2.7	3.0	3.1	2.9	3.1	160%	118%
<b>By Production System</b>										
<b>Livestock</b>	<b>33</b>	<b>46</b>	<b>38</b>	<b>38</b>	<b>38</b>	<b>38</b>	<b>37</b>	<b>37</b>	<b>10%</b>	<b>-20%</b>
Dairy Cows	6.1	5.3	5.7	5.8	5.8	5.9	5.9	5.8	-3.8%	10%
Beef Cattle	24	35	27	27	27	27	26	26	9.0%	-27%
Swine	2.0	3.2	3.1	3.1	3.1	3.2	3.1	3.1	54%	-3.8%
Other Livestock <sup>b</sup>	1.4	2.2	1.9	1.9	1.9	1.9	1.9	1.9	34%	-15%
<b>Crop</b>	<b>9.5</b>	<b>11</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>17</b>	<b>19</b>	<b>19</b>	<b>97%</b>	<b>77%</b>
Inorganic Nitrogen Fertilizers <sup>c</sup>	5.6	6.7	11	12	13	13	12	13	139%	101%
Crop Residue Decomposition	2.8	3.2	4.3	4.3	4.5	3.5	4.4	4.2	49%	30%
Other Practices <sup>d</sup>	1.1	0.68	0.71	0.80	0.95	0.94	2.0	1.1	-0.7%	58%

Notes :

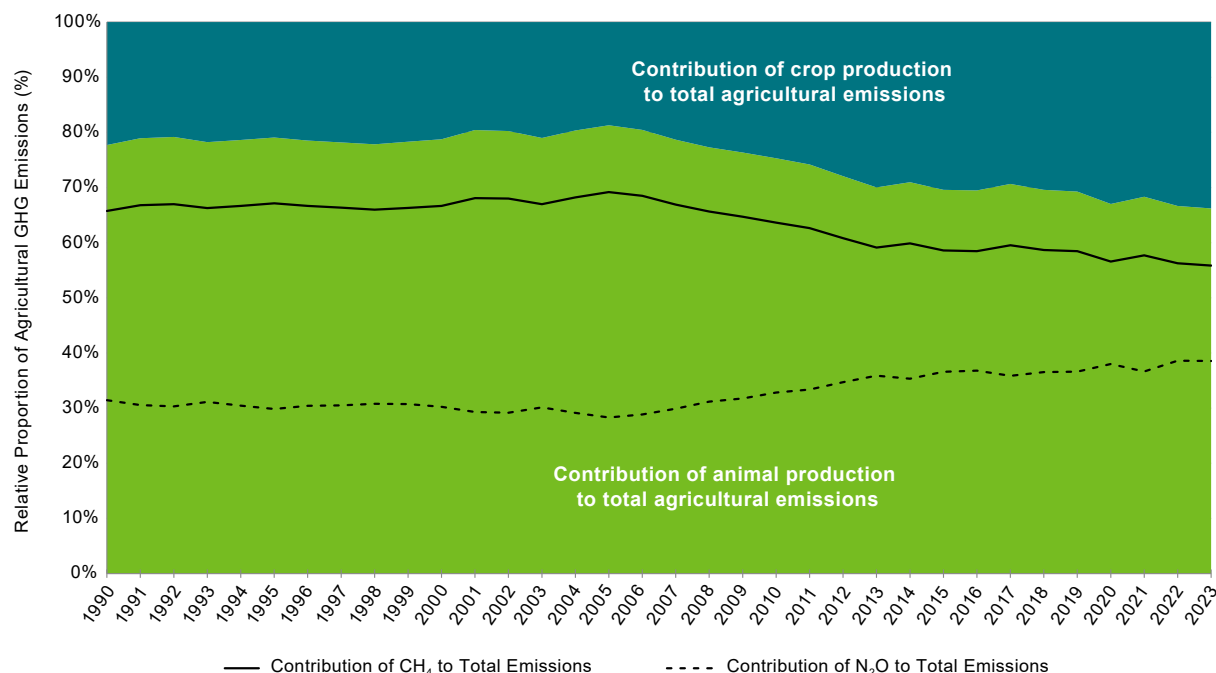
a. Totals may not add up due to rounding.

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

c. Inorganic fertilizers includes emissions of N<sub>2</sub>O from the soil and the CO<sub>2</sub> emissions from the hydrolysis of carbon stored in urea.

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

Figure 2–19 **Proportions of Canadian Agricultural GHG Emissions Emitted as CH<sub>4</sub> and N<sub>2</sub>O, or Attributed to Livestock and Crop Production (1990–2023)**



#### 2.3.3.1. Enteric Fermentation (2023 GHG Emissions, 26 Mt)

Emissions from enteric fermentation originate almost entirely (96%) from Cattle Production in Canada. From 1990 to 2023, emissions increased from 25 Mt to 26 Mt, or 6%. 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 28% 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 11% since 1990, mainly due to a 31% reduction in the dairy cow population from 1990 to 2023 (StatCan, n.d.[i]). However, the average dairy cow today also consumes more feed and produces 57% 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 (2023 GHG emissions, 7.7 Mt)

Emissions from animal manure management systems increased from 6.0 Mt in 1990 to 7.7 Mt in 2023 (or 29%), driven by increases in livestock populations of beef, swine and poultry. The storage of manure results in both CH<sub>4</sub> (14% total agricultural CH<sub>4</sub>) and N<sub>2</sub>O (16% total agricultural N<sub>2</sub>O). The management of beef and poultry manure produces predominantly N<sub>2</sub>O, whereas swine manure produces predominantly CH<sub>4</sub>. Emissions from dairy manure have shifted from mainly N<sub>2</sub>O to mainly CH<sub>4</sub> due to changes in manure storage practices. As a result, CH<sub>4</sub> emissions correspond closely to changes in populations and practices in the swine and dairy sectors, increasing from 2.8 Mt in 1990 to 4.3 Mt (56%) in 2023. N<sub>2</sub>O emissions closely follow the trend in beef populations, increasing from 3.2 Mt in 1990 to 4.3 Mt (33%) in 2005 and subsequently declining to 3.4 Mt (-21%) in 2023. As was the case with enteric fermentation, the increase in beef cattle weights also contributed to the increase in N<sub>2</sub>O emissions from manure.

#### 2.3.3.3. Agricultural Soils (2023 GHG Emissions, 18 Mt)

Emissions from Agricultural Soils originate from the application of inorganic and organic nitrogen fertilizers to annual and perennial cropland and from crop residue decomposition; these emissions can be modified by crop management practices. Emissions increased from 10 Mt in 1990 to 18 Mt in 2023, an increase of 76%, primarily due to an increase in inorganic nitrogen fertilizer use and relative reduction in the proportion of N applied to perennial cropland.

Total emissions from the application of inorganic nitrogen fertilizers increased from 4.8 Mt in 1990 to 10 Mt in 2023, an increase of 118%, 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 2023. 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 (262%) increase in emissions of CO<sub>2</sub> from urea and urea ammonium nitrate.

Emissions from crop residue decomposition ranged from a minimum of 2.3 Mt in 2002 (a drought year) to a maximum of 4.5 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 3.5 Mt in 2021 as a result of severe drought conditions in the prairies that led to a sharp decline in crop production. Emissions rebounded to 4.2 Mt in 2023 as crop production, and therefore crop residue, returned to previous levels resulting in emissions from the loss of native soil carbon due to the lack of carbon input from crop residues to prairie soils in 2021. Though crop production demonstrates high interannual variability, production has tended to increase over the reporting period and, as a result, so have emissions from crop residue.

In 1990, cropland management practices, specifically irrigation and the adoption of conservation tillage, contributed a net 0.13 Mt to total emissions from soils. In 2023, the adoption of conservation tillage (approximately 17 million hectares of cropland since 1990) reduced emissions by 2.2 Mt, while increases in irrigation increased emissions by 1.1 Mt, for a net reduction in emissions of 1.2 Mt.

### 2.3.4. Land Use, Land-Use Change and Forestry Sector (2023 Net GHG Source, 4.2 Mt, Not Included in National Totals)

The LULUCF sector reports anthropogenic GHG fluxes to and from Canada's managed lands, including those associated with land-use change. Emissions of GHGs from sources and removals by sinks are estimated and reported for five categories of managed lands—Forest Land, Cropland, Grassland, Wetlands and Settlements—and for the Harvested Wood Products category, which is closely linked to Forest Land and Forest Conversion. The net LULUCF flux is calculated and presented as the sum of CO<sub>2</sub> and non-CO<sub>2</sub> emissions to the atmosphere and CO<sub>2</sub> removals from the atmosphere.

In 2023, LULUCF was estimated to emit 4.2 Mt to the atmosphere, compared with net emissions of 50 Mt in 1990 and 66 Mt in 2005. National totals are reported to the United Nations Framework Convention on Climate Change (UNFCCC) with and without emissions and removals in the LULUCF sector. The estimated net GHG fluxes in the LULUCF sector when included account for an increase of 8% in 1990, 9% in 2005 and 0.6% in 2023 (Figure 2–6).

The net fluxes reported in the LULUCF sector were positive (emissions) for all years of the time series. Emissions increased over the early part of the time series until 2005 but have demonstrated a generally decreasing trend between 2005 and 2023 (Table 2–10). Over the first half of the time series increasing net CO<sub>2</sub> emissions from the Forest sector were partially attenuated by increasing net CO<sub>2</sub> removals in Cropland and a decrease in emissions from the conversion of forest to other land use. The increasing net emissions by the land sector to the atmosphere reported over the first fifteen years of the reporting period are driven by a sustained expansion of forest harvest in combination with increased insect mortality in the mid-2000s. In recent years, since 2005, the decline and subsequent stabilization of harvest rates has resulted in a reduction in net CO<sub>2</sub> emissions from Forest Land from 2005 to 2023. During this period Cropland removals, though undergoing interannual variability, have not demonstrated a clear trend, with increasing removals resulting from increased annual crop productivity being offset by decreasing removals associated with the loss of perennial land cover and recent increases in rates of agricultural deforestation in some regions. Net fluxes from the LULUCF sector have fluctuated over recent years

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

Sectoral Category	Net GHG Flux (Mt CO <sub>2</sub> eq) <sup>a</sup>									
	1990	2005	2018	2019	2020	2021	2022	2023	Change 1990–2023	Change 2005–2023
<b>LAND USE, LAND-USE CHANGE AND FORESTRY TOTAL</b>	<b>50</b>	<b>66</b>	<b>24</b>	<b>15</b>	<b>25</b>	<b>15</b>	<b>51</b>	<b>4</b>	<b>-46</b>	<b>-62</b>
a. Forest Land	73	140	60	40	40	34	22	24	-49	-110.0
b. Cropland	5.5	-20	-20	-15	-13	-16	25	-22	-28	-1.9
c. Grassland	0.0007	0.0009	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0006	0.0004
d. Wetlands	5.1	2.7	2.5	2.7	2.9	2.8	2.6	2.6	-2.5	-0.09
e. Settlements	4.8	4.7	5.4	5.3	5.3	5.5	5.2	5.0	0.24	0.31
g. Harvested Wood Products	-38	-57	-24	-18	-10	-12	-4.0	-5.1	33	52

Notes:

Totals may not add up due to rounding.

a. Negative sign indicates net removals of CO<sub>2</sub> from the atmosphere.

between lows in emissions of 8.0 Mt and 4.2 Mt in 2014 and 2023 respectively to peaks of 46 Mt and 51 Mt in 2015 and 2022 respectively. The peak in emissions in 2022 resulted from the extensive drought in western Canada that occurred in 2021 as emissions from decomposition of existing soil organic carbon (SOC) significantly exceeded new carbon input to soils (Figure 2–20), however normal yields in 2022 returned soils to a net sink again in 2023.

### 2.3.4.1. Forest Land and Harvested Wood Products (2023 GHG Flux, 18 Mt)

The Forest Land and Harvested Wood Products categories combined include GHG fluxes between the atmosphere and Canada's managed forests and the transfers to the global harvested wood products (HWP) category originating from domestic harvest and subsequent changes in carbon stored as wood products in use. The total net flux from managed forests and resulting HWP amounted to an estimated net emissions of 18 Mt in 2023 (Figure 2–20), which combines net losses of 24 Mt from Forest Land and net gains of 5.1 Mt in HWP from forest harvest.

Net losses reported in Forest Land—after separating GHG fluxes associated with severe natural disturbances from anthropogenic fluxes—increased from 73 Mt in 1990 to 140 Mt in 2005. The predominant anthropogenic trend directly associated with human activities in managed forests is a 34% increase in the carbon removed from forests through harvest and transferred to HWP between 1990 and the peak harvest year, 2004. This trend represented an increase in estimated annual area harvested from 1.0 Mha in 1990 to 1.4 Mha in 2004. Of that annual harvest area 10.4%, 8.9% and 3.9% was harvested as clearcut with slash burning and further, there were an estimated 73 kha, 88 kha and 92 kha of commercial thinning in 1990, 2005 and 2023 respectively. The rest of annual harvest was clear cut leaving residue to decompose in place.

Since 2005, net losses from Forest Land decreased to 24 Mt in 2023 as the area of mature forest has increased, and a greater proportion of past harvest disturbance is switching from a net source to a net sink in combination with increases in harvest that occurs on lands that had been historically harvested. Conventional harvest levels have remained relatively constant in recent years, with 2023 levels still 38% below their peak in 2004. Emissions from slash burning have decreased in recent years reaching their lowest levels throughout the time series. This recent trend of reduced harvest is the combined effect of changing global markets and consumer preferences, as well as growing demand for non-traditional products, e.g., bioproducts and, more recently, due to a significant decline in global demand in traditional paper markets as digital media options replaced many paper products, a trend that was accelerated by the COVID-19 pandemic (NRCan, 2022). Further, the indirect effect of exceptionally high wildfires in several years of the last decade, mainly in western Canada, have impacted the commercially mature forest area in some regions and result in Forest Management agencies re-evaluating rates of harvest.

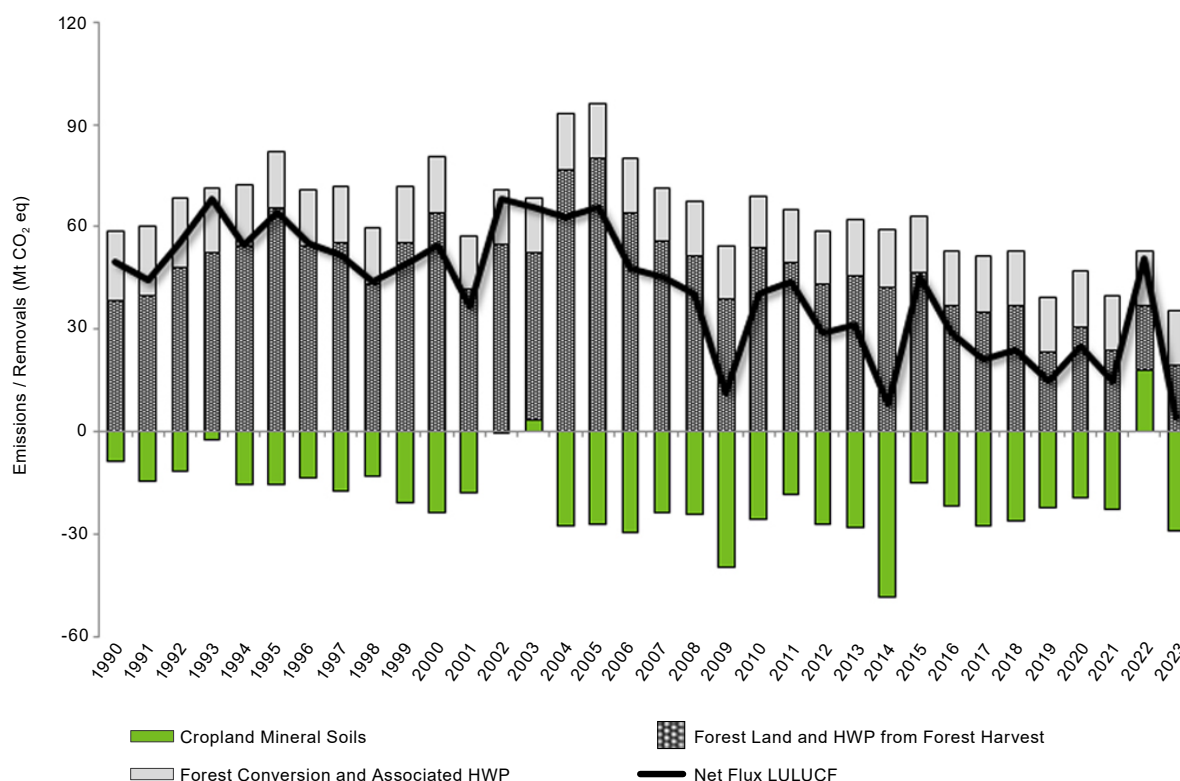
The decrease in net losses nationally from Forest Land is dominated by trends in the Montane Cordillera, Boreal Plains and Boreal East. Severe insect outbreaks in the Montane Cordillera in the early 2000s and subsequent high rates of harvest on impacted forest stands transferred significant amounts of carbon to the HWP pool, reset large areas of previously productive forest to younger age-classes when trees absorb and store less biomass carbon and additional residue from harvest increases decomposition emissions. In addition, forest stands in the Montane Cordillera ecozone were affected by insect infestations that caused low levels of tree mortality over large areas resulting in a generalized increase in emissions of CO<sub>2</sub> from decomposition. Likewise, on the Boreal Plains, sustained harvest transferred carbon out of the forest ecosystem and insect outbreaks and fire combined to reset large areas of previously productive forest to younger age-classes, though impacts were partially offset by increased areas of mature forest in reporting. The combination of reduced net rates of storage of CO<sub>2</sub> in biomass and increased emissions of CO<sub>2</sub> from decomposition resulted in a net increase in losses from forests of these regions—primarily between 1990 and 2005—that was significant enough to influence the national trend. Further, severe wildfires have recently impacted some of these areas reducing the commercially mature forest land base. The trend towards decreasing carbon losses in the Boreal East partially offsets the increasing losses of carbon occurring in other regions, driven by the growth of the area of mature forest over the 1990s and early 2000s which subsequently levels off in recent years, at the same time increased insect disturbance has increased emissions from decomposition. Since 2005, all ecozones have tended towards decreasing carbon losses driven largely by reduced harvest rates. Although emissions and removals associated with severe natural disturbances are differentiated from anthropogenic fluxes, low-level mortality insect disturbances nevertheless influence reported GHG fluxes. Though not reported in the anthropogenic reporting component, the impact of fire on the Canadian managed forest cannot be ignored. Since 2018, wildfires have emitted an average of 290 Mt CO<sub>2</sub> eq per year, impacting forest age-class structure and carbon storage capacity. In 2023, approximately 7.9 Mha of forest areas were burned by wildfires, including large areas of commercially mature stands. These disturbed areas are expected to remain net sources of carbon emissions for several years.

Gains and losses of HWP reflect the net change in long-term storage of carbon in wood harvested in Canada's forests. Annual transfers of carbon to the HWP pool from harvest are balanced against annual losses, either emissions from oxidation (decomposition or combustion) or disposal of products at the end of their useful life, which provides the net change in carbon stored globally as Canadian HWP. Approximately one third of HWP losses (33% in 2023) result from long-lived wood products reaching the end of their useful life and being transferred to the waste stream decades after the wood was harvested. End-of-life disposal and emissions from short-lived products, namely pulp and paper and bioenergy products, accounted for 25% and 39% of annual HWP losses, respectively, in 2023. These same products accounted for 30% and 40% in 1990 and 35% and 40% in 2005. Wood processing waste in 1990 accounted for 15% of annual HWP losses prior to the

now common practice of using wood waste for bioenergy production. Fluctuations in transfers of short-lived wood products generally reflect recent trends in forest harvest rates. As a result of these fluctuations, annual losses from HWP in emissions and disposals have ranged from a low of 130 Mt in 2009 (corresponding to the lowest harvest year), to a peak of 150 Mt in 1995. Net carbon storage increased in the HWP category every year throughout the time series with the exception of 2009 when harvest rates were at their lowest level and losses from the HWP carbon pool exceeded transfers to the category.

In 2005 and 2023, bioenergy transfers and combustion of carbon from Forest Land were 59 Mt and 51 Mt, respectively, for residential and industrial bioenergy. Industrial bioenergy is primarily sourced from waste produced during the processing of wood in the creation of products. In these years, wood processing waste was 4 Mt and 5 Mt with nearly all of it diverted to energy production.

Figure 2–20 LULUCF Sector Net GHG Flux and Major Emission and Removal Components, 1990–2023



#### 2.3.4.1.1. Emissions from Forest Harvesting

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

As is the case with all industries, the scope of activities associated with forest harvesting is broad, spanning multiple sectors of this National Inventory Report (NIR), namely LULUCF, Energy, Industrial Processes and Product Use and Waste. To the extent possible within the current version of data and systems supporting the NIR, the emissions/removals to/from the atmosphere, fluxes between pools and subsequent carbon stock changes for activities associated with forest harvesting are separately reported in Table 2–11.

During the year in which harvest takes place, pre-existing dead organic matter (DOM) and harvest residues decompose and, as a result, carbon dioxide is emitted to the atmosphere; while removals associated with re-growth of the stand are negligible (Table 2–11, Net Emissions from harvested lands, new; Emissions from deforestation for forestry roads, direct). After the initial year of harvest, emissions from decomposition continue; and removals increase over time as the regrowing

Table 2–11 **Emissions, Removals and Carbon Stock Changes Associated with Forest Harvesting Activities, Selected Years**

GHG Source Category	GHG Fluxes and Stocks							
	1990	2005	2018	2019	2020	2021	2022	2023
FOREST LAND								
Net Emissions and Removals, Forest Harvest (Mt CO <sub>2</sub> eq)								
Net emissions from harvested lands	82	94	41	36	34	31	25	22
Net emissions from harvested lands, new <sup>a</sup>	21	33	25	23	22	22	19	19
Net emissions from harvested lands, historic <sup>b</sup>	61	61	16	14	12	9.0	6.0	2.0
Deforestation Forestry Roads	1.1	0.83	0.35	0.35	0.34	0.32	0.31	0.29
Emissions from deforestation for forestry roads, direct	0.32	0.24	0.07	0.08	0.09	0.08	0.08	0.07
Emissions from deforestation for forestry roads, residual	0.76	0.59	0.29	0.27	0.26	0.24	0.23	0.21
HARVESTED WOOD PRODUCTS (HWP)								
Emissions and Fluxes – HWP (Mt CO <sub>2</sub> eq)								
Carbon flux from disposal of HWP commodities <sup>c</sup>	77	87	83	81	84	80	79	78
Industrial Bioenergy Emissions <sup>d</sup>	34	46	39	33	36	38	39	39
Residential Bioenergy Emissions	15	11	13	12	10	9.3	10	9.1
Carbon Stocks and Fluxes (Mt C)								
Carbon transfers from forest to HWP <sup>e</sup>	44	54	43	39	38	38	36	36
Commercial harvest	40	51	39	36	35	35	33	33
Residential firewood harvest	4.1	3.1	3.6	3.2	2.8	2.5	2.7	2.5
Cumulative Stocks in Products	330	510	590	600	600	600	600	600
Solid Wood <sup>f</sup>	280	460	550	560	560	570	570	570
Pulp and paper	45	54	38	37	35	34	32	31
Carbon flux from use and disposal of HWP commodities	35	39	37	34	36	35	35	35
Solid Wood <sup>f</sup>	5.4	9.0	11	11	11	11	11	12
Pulp and paper	11	14	10	10	10	9.3	8.8	8.5
Unused mill residues	5.0	1.0	1.0	0.79	1.8	1.3	1.3	1.3
Industrial Bioenergy	9.3	13	11	9.0	9.9	10	11	11
Residential Bioenergy	4.1	3.1	3.8	3.4	2.9	2.6	2.8	2.6
EMISSIONS REPORTED IN OTHER SECTORS <sup>g</sup>								
Fossil Fuel and Industrial Process Emissions (Mt CO <sub>2</sub> eq)								
Forestry Activities <sup>h</sup>	3.0	2.8	2.5	2.6	2.3	2.5	2.5	2.4
Pulp and Paper Production	15	8.7	7.6	7.9	6.9	7.2	7.4	7.6
Non CO <sub>2</sub> gases from bioenergy production (Mt CO <sub>2</sub> eq)	0.29	0.35	0.3	0.31	0.27	0.28	0.28	0.27
Notes:								
Please refer to NIR methodological annexes (Annex 3) for detailed information about data sources and methods.								
a. Consists of net emissions from harvested forest land from decomposition, minus regrowth in the initial year of harvest. Includes burning of post-harvest residues (i.e., slash), prescribed burning, and reforestation.								
b. Consists of net emissions from decomposition and regrowth from previously harvested stands.								
c. Wood retired to landfills is represented as an instantaneous flux to the atmosphere for reporting purposes.								
d. Includes uncombusted carbon remaining in ash.								
e. 1990-2023 carbon transfers from deforestation for forestry roads to HWP of 2 Mt C (0.14% of total 1990-2023 C transfers) are excluded. Current HWP modelling does not allow emissions associated with specific deforestation activities to be reported separately.								
f. Solid wood includes sawn wood, composite wood (i.e., wood panels) and other industrial solid wood products.								
g. Detailed information can be found in cross-sectional tables published on the Government of Canada's Open Data Portal.								
h. Emissions from on block machinery and wood processing, does not include transport of harvested roundwood to mill.								

forest becomes more productive (Table 2–11, Net emissions from harvested lands, historic; Emissions from deforestation for forestry roads, residual). The current version of Carbon Budget Model of the Canadian Forest Service (CBM-CFS3) does not support emission tracking that differentiates decomposition emissions for pre-existing DOM and new inputs from the harvesting event. Sites with higher DOM stocks prior to harvest (e.g., after insect attack) will have high decomposition emissions regardless of whether harvesting took place.

Fluxes of carbon occur with harvested wood products (HWP) at the production, use, and disposal stages. The production of milled wood products, including pulp and paper, involves machinery with emissions reported in the Energy-Stationary Combustion sector (Table 2–11, Non-CO<sub>2</sub> gases from bioenergy production). Wood is consumed to provide bioenergy for residential (e.g., home heating) and industrial purposes (e.g., heat & power) resulting in emissions (Table 2–11, Residential bioenergy emissions, industrial bioenergy emissions). As long- and short-lived wood products from Canadian wood are retired and disposed of across the globe, the carbon in the products is reported as a flux (Table 2–11, Carbon flux from disposal of HWP products) according to their respective lifespans. These products remain intact for years if disposed of in landfills and become important source of methane reported in the country of disposal (Moreau et al. 2023).

Carbon harvested from the forest remains sequestered in wood products for decades, contributing to a growing global pool of stored carbon (Table 2–11, Cumulative stocks in products). As carbon remains stored in wood products, the managed land that was harvested regenerates, contributing an active carbon sink and a renewable product source. Carbon in the forest was originally removed from the atmosphere through photosynthesis, i.e., the biotic carbon cycle. Therefore, when carbon from the forest re-enters the atmosphere, it does not represent a net gain to CO<sub>2</sub> concentrations in the way that fossil fuels do. Wood-based bioenergy and commodities replace other more emissions-intensive alternatives such as coal, oil, concrete or steel in other economic sectors (e.g., energy, manufacturing, construction, etc.) (Smyth et al. 2017).

Fuel use by harvesting machinery is calculated and reported in the Energy-Transport sector (Table 2–11, Forestry activities). Fuel use associated with the transport of harvested timber off site is, however, unavailable due to the level of aggregation in the Energy-Transport sector.

#### 2.3.4.2. Forest Conversion (2023 GHG Source, 17 Mt)

Forest conversion<sup>11</sup> is not a reporting category per se, since it overlaps with the subcategories of Land Converted to Cropland, Land Converted to Wetlands and Land Converted to Settlements. It also includes carbon transfers to HWP resulting from forest conversion activities since 1990, which can contribute to carbon stocks in wood products globally. Emissions due to forest conversion fell from 25 Mt in 1990 to 17 Mt in 2023.

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

With a current annual conversion rate of 26 kha, Forest Land Converted to Settlements now accounts for the largest share of forest loss, comprising 54% of the total loss in 2023, up from 33% in 1990 and slightly down from 57% in 2005 (Figure 2–21). This increase is mostly driven by an increasing trend in forest conversion for oil and gas infrastructure during the 1990–2006 period and for mining operations and industry around the years 2004–2015. Significantly higher rates of forest conversion for hydro infrastructure around the years 2013 to 2015 have also contributed to this trend. The highest average annual rate of forest conversion to settlements has occurred in the Boreal Plains (12 kha per year) followed by the Boreal Shield East (4.0 kha per year).

Forest clearing for agricultural expansion (Cropland) is the second-largest driver of forest conversion, accounting for 46% of all forest area lost in 2023. Annual rates dropped from 42 kha in 1990 to 12 kha in 2010, predominantly in the Boreal Plains, Subhumid Prairies and Montane Cordillera of western Canada, following a period of active agricultural expansion in previous decades. After 2010, annual rates increased to levels around 22 kha—similar to those observed in mid-1990s—due to more recent agricultural expansion primarily in the Boreal Plains, Subhumid Prairies and Mixedwood Plains (Figure 2–21).

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

The emissions associated with deforestation reflect these trends (see Figure 2–22). Emissions from agricultural expansion were the highest in 1990 at 13.0 Mt, (52% of total deforestation emissions), declined to 6.9 Mt (40%) in 2005 and were higher in 2015 than since the late 1990s. Likewise emissions from hydroelectric development were high in 1990 at 4.2 Mt (17%), and have declined to 1.6 Mt in recent years. Oil and gas resource extraction emissions increased from 1.6 Mt (7%) in 1990 to 3.6 Mt (21%) in 2023, highlighting its growing expansion and impact on forest conversion. Urban and industrial expansion maintained a steady trend with minor fluctuations, averaging 2.1 Mt annually from 1990–2023. This reflects Canada's consistent urban growth despite overall deforestation emissions decreasing since 1990. Similarly, emissions from the deforestation during the construction of transportation lines such as roads and railways remained stable, averaging 0.8 Mt throughout the reporting period. Other resource extraction emissions gradually declined from a peak of 2.6 Mt in 2004 to 1.9 Mt in 2023.

These trends highlight changes in the factors driving land use change over the past 30 years resulting in the overall decline in associated emissions in Canada over the past three decades. The decreasing impacts of agricultural expansion and the reduction in hydroelectric development contribute towards lowers emissions and are partially offset by the increasing role of oil and gas infrastructure on land use change.

<sup>11</sup> Forest conversion emissions are incorporated within sums of emissions of other land-use categories; therefore, the 17 Mt reported in this section is included in the sums associated with the other land-use category totals.

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

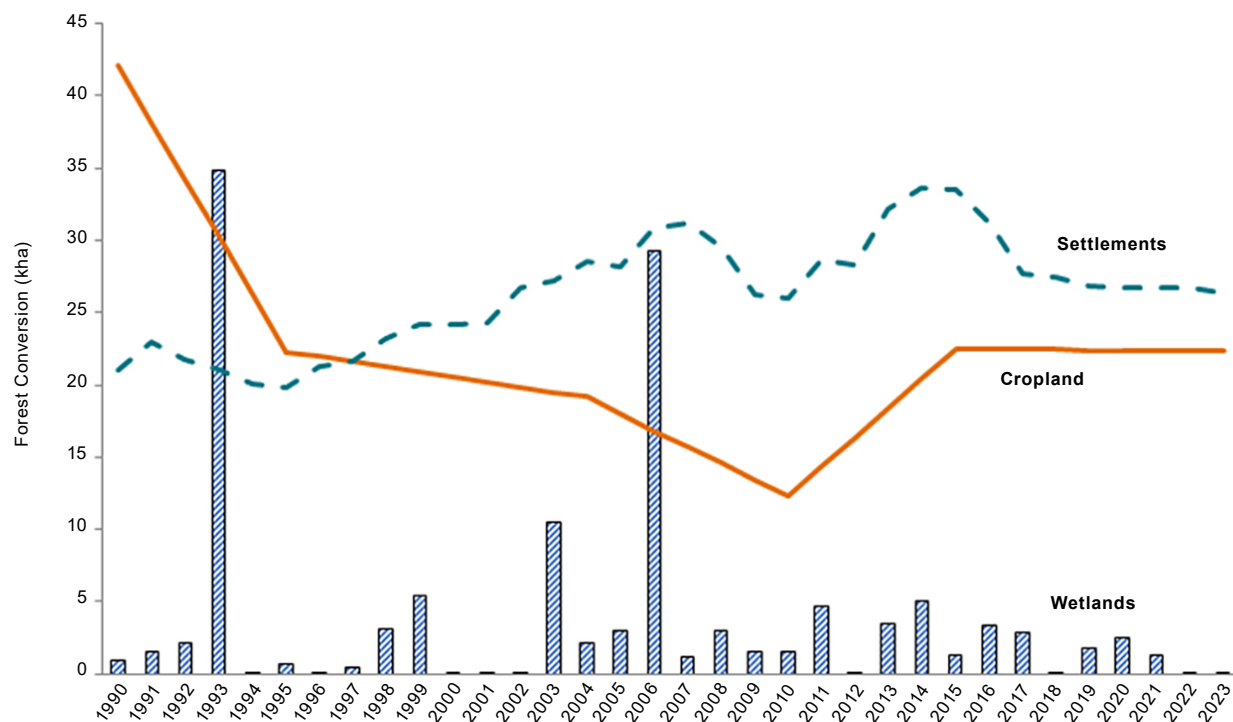
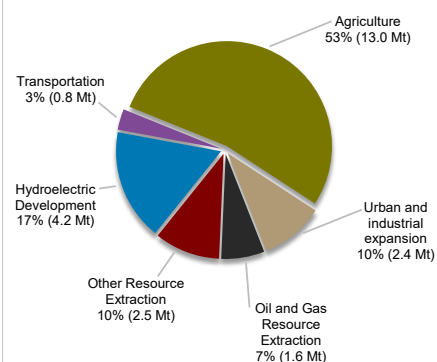
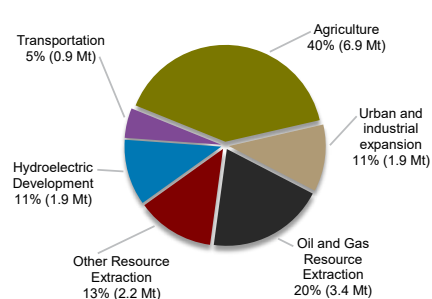
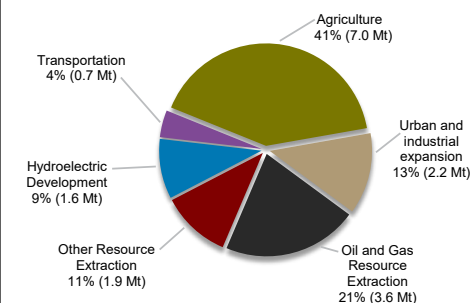


Figure 2–22 Trends in Annual Emissions of Forest Conversion to Cropland, Wetlands and Settlements

(A) 1990 (24.6 Mt CO<sub>2</sub> eq)(B) 2005 (17.2 Mt CO<sub>2</sub> eq)(C) 2023 (17.0 Mt CO<sub>2</sub> eq)

### 2.3.4.3. Cropland (2023 GHG Removals, 22 Mt)

The Cropland category includes the effect of agricultural practices on CO<sub>2</sub> emissions from, and removals by, arable soils as well as the immediate and long-term impacts of forest and grassland conversion to cropland.

Cropland contributed net emissions of 5.5 Mt in 1990, net removals of 20 Mt in 2005 and net removals of 22 Mt in 2023, to the land sector estimates. This land category has net removals ranging from 1.6 to 42 Mt in all years except 1990, 1992, 1993, 2002, 2003, and 2022 where drought conditions in previous years decreased the crop production resulting in net emissions of 5.5, 0.5, 7.7, 7.6, 11 and 25 Mt, respectively. Interannual variability occurs throughout the time series, reflecting weather-related impacts to crop production. In particular, severe drought on the prairies 2021 has resulted in significant emissions from cropland soils in 2022 as decomposition of native SOC was not offset by adequate inputs of fresh residue carbon resulting in net loss of carbon from soils across the prairies for this year. In 2023, the soil sink recovered resulting in net removals again.

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

Since 2005, the decline in net removals that results from a decrease in perennial land cover has largely offset removals resulting from increasing yields and there is subsequently no clear trend. Recent trends are impacted by periodic high crop production and subsequently peak removals in 2009 (-34 Mt) and 2014 (-42 Mt). The decline in emissions from Forest Land Converted to Cropland also contributed to the trend of the increasing removals during the period from 1990 to 2010, but emissions have since increased to mid-1990s levels (see section 2.3.4.2).

#### 2.3.4.3.1. Relationship between Agricultural Emissions and Cropland Carbon

In agricultural ecosystems crop and livestock production compete for the same land, creating trade-offs between the two systems that, in turn, impact GHG emissions and removals as well as soil carbon. Canada reports agricultural emissions in different sectors—Agriculture, LULUCF, and Energy—according to IPCC reporting requirements. Taking an integrated approach to examining emissions from both crop production and livestock helps to better understand trends (Figure 2–23).

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

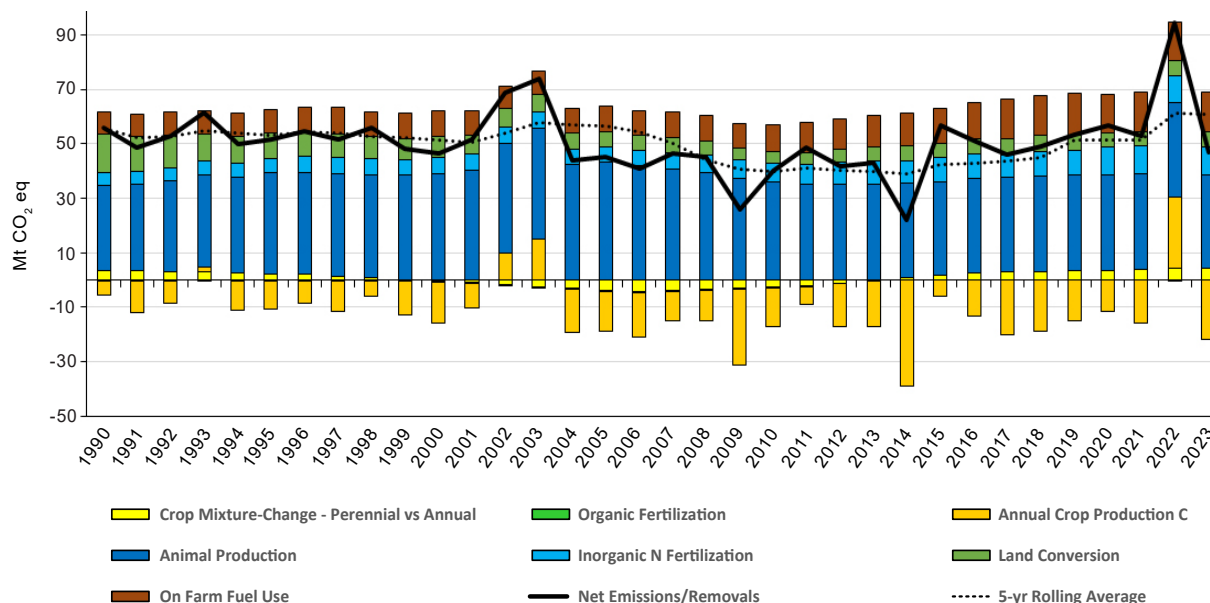
Between 2005 and 2011, cattle populations declined sharply, leading to a 19% reduction in emissions, which have since stabilized at around 35 Mt. During this time and continuing into the present, the conversion of perennial cover to annual crop production has become a net source of CO<sub>2</sub>, reversing the previous carbon removal effect (a change of 8.4 Mt). Emissions from land conversions have also increased by 19%.

In parallel, emissions from inorganic fertilizer use during crop production and agricultural fuel use have continued to rise steadily, increasing by 77% and 52%, respectively since 2005. Carbon storage from increasing yields in annual crop production has not shown a clear trend since 2005, and carbon removals from improved soil management have plateaued.

When assessed together, considering landscape carbon impacts, net emissions from agricultural operations generally have fluctuated around 50 Mt since 1990, looking at a five-year rolling average of emissions. Emissions peaked at 95 Mt in 2022, due to severe drought on the prairies and were at their lowest in 2014 (22 Mt) because of high crop yields boosting the soil sink. Interannual variations in soil carbon fluxes driven by fluctuations in crop yield resulting from weather patterns, make trends more difficult to interpret.

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

Figure 2–23 Integrated Assessment of Emissions and Removals from Agricultural Operations



## Note:

Emissions and removals are grouped here into:

(1) "Animal Production" – Enteric Fermentation and Manure Management

(2) "Organic Fertilization" – direct and indirect emissions from animal manure C and N, biosolids N, and pasture, range and paddock

(3) "Inorganic N fertilization" – direct and indirect emissions

(4) "Change in Perennial/Annual Crop mixture"

(5) "Land Conversion" – forest land to cropland conversion and grassland to cropland conversions

(6) "Annual Crop Production C" – tillage practices, crop residues, field burning of crop residues, cultivation of organic soils, residual emissions, liming, and urea applications (C alone)

(7) "On-Farm Fuel" – emissions from the fuel use by farm vehicles and machinery and stationary combustion on farm

#### 2.3.4.4. Other LULUCF Sources/Sinks (2023 GHG emissions, 7.7 Mt)

Other LULUCF sources/sinks include Wetlands, Settlements and Grassland, which contributed 2.6 Mt, 5.0 Mt and 0.0013 Mt, respectively, to their combined net emissions of 7.7 Mt reported in 2023, down from 9.9 Mt in 1990. The Settlements category includes urban tree growth (annual removals of 4.0 Mt on average throughout the reporting period) and Land Converted to Settlements (annual emissions range between 7.6 Mt in 1995 and 10 Mt in 2013). 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 (2023 GHG Emissions, 23 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from the Waste sector contributed 23 Mt (3.3%) to Canada's total emissions in 2023, comparable to emission levels of 21 Mt in 1990 (3.5% of total emissions) and of 24 Mt (3.1%) in 2005 (Figure 2–24 and Table 2–12). In 2023, landfilling (including municipal solid waste and industrial wood waste landfills) accounted for 20 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<sub>2</sub> emissions from incineration of biomass material) contributed 0.50 Mt, 2.6 Mt and 0.16 Mt, respectively.

Figure 2–24 Trends in Canadian GHG Emissions from Waste (1990–2023)

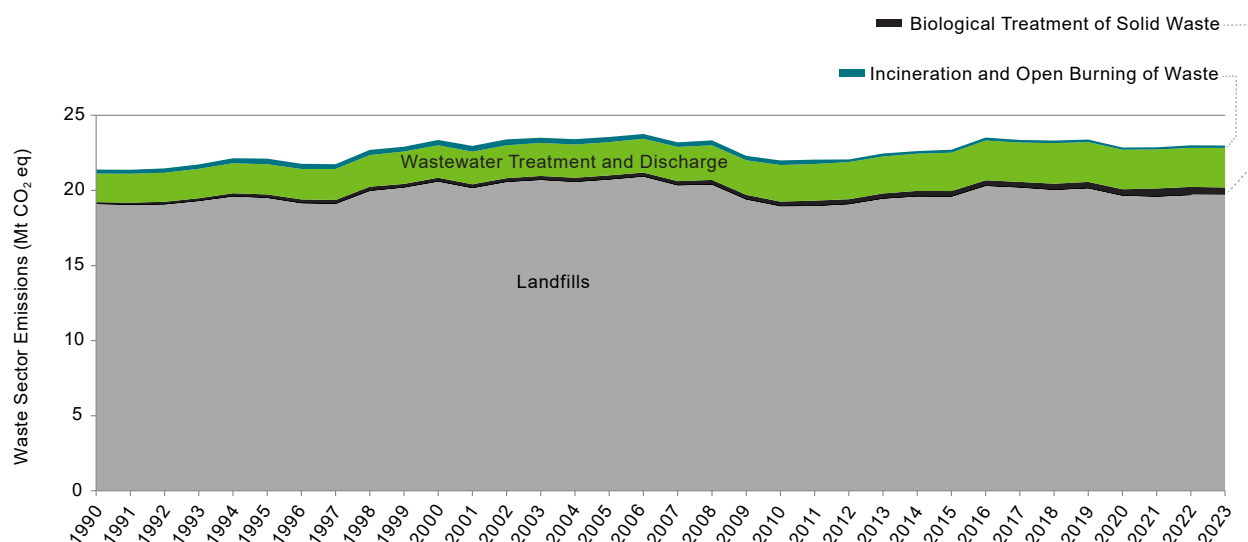


Table 2–12 GHG Emissions from Waste, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)	
	1990	2005	2018	2019	2020	2021	2022	2023	1990–2023	2005–2023
<b>WASTE SECTOR</b>	<b>21</b>	<b>24</b>	<b>23</b>	<b>23</b>	<b>23</b>	<b>23</b>	<b>23</b>	<b>23</b>	<b>7.5%</b>	<b>-2.5%</b>
Landfills	19	21	20	20	20	20	20	20	2.9%	-5.1%
Biological Treatment of Solid Waste	0.08	0.24	0.38	0.38	0.38	0.50	0.50	0.50	518%	106%
Wastewater Treatment and Discharge	1.9	2.2	2.7	2.7	2.6	2.6	2.6	2.6	38%	18%
Incineration and Open Burning of Waste	0.26	0.34	0.17	0.17	0.15	0.15	0.17	0.16	-41%	-55%

Note: Totals may not add up due to rounding.

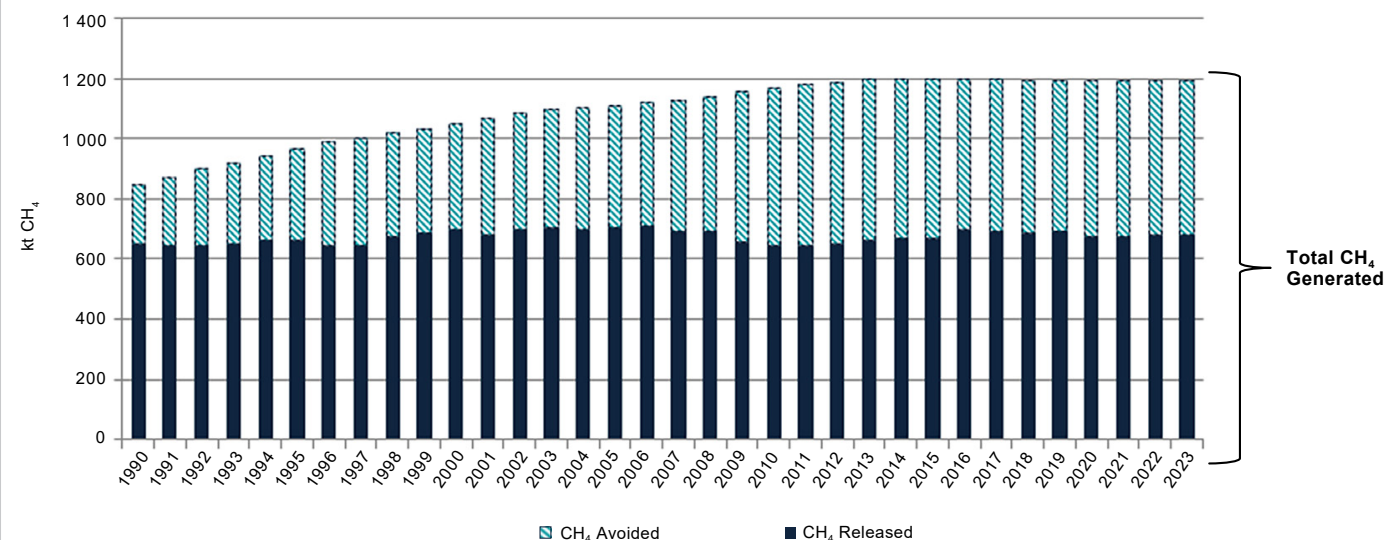
### 2.3.5.1. Landfills (2023 GHG Emissions, 20 Mt)

GHG emissions from landfills are released in landfill gas (LFG) generated by the anaerobic decomposition of buried organic waste. LFG consists mostly of CO<sub>2</sub> and CH<sub>4</sub>, though only the release of CH<sub>4</sub> is reported. The CH<sub>4</sub> 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<sub>4</sub> released from landfill sites is further influenced by the presence of oxidizing landfill covers and the use of LFG capture technologies.

In 2023, emissions from MSW landfills were 19 Mt, while emissions from wood waste landfills were 0.74 Mt. Emissions from MSW landfills increased by 5% from 1990 to 2023 and have decreased by 4% from 2005 to 2023. Emissions from wood waste landfills decreased by 26% from 1990 to 2023 and by 32% from 2005 to 2023.

The amount of CH<sub>4</sub> generated by MSW landfills has 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 2023, 37% of the LFG generated in landfills was recovered through LFG capture technologies or oxidized through cover material, compared with 15% in 1990 (Figure 2–25).

Figure 2–25 Methane Generated, Avoided and Released from MSW Landfills



#### 2.3.5.2. Other Waste Sources (2023 GHG Emissions, 3.3 Mt)

Over the 1990–2023 time period, emissions from the Biological Treatment of Solid Waste (anaerobic digestion and composting), Wastewater Treatment and Discharge (municipal and industrial wastewater treatment), and Incineration and Open Burning subcategories collectively increased by 46% (Figure 2–24 and Table 2–12).

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

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

## 2.4. Emissions by Canadian Economic Sector

In this report, emission estimates are primarily grouped into the activity sectors defined by the IPCC (section 2.3). While this categorization is consistent with the reporting requirements, reallocating emissions into economic sectors is more suitable for the purpose of analyzing trends and policies relative to a particular economic activity (e.g., producing electricity, farming or driving a car). This section reports emissions according to the following Canadian economic sectors: Oil and Gas, Electricity, Transport, Heavy Industry, Buildings, Agriculture, and Waste and others (Table 2–13).

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

Annex 10<sup>12</sup> contains a series of tables which show the distribution of national emissions by Canadian economic sector for the complete time series (1990–2023) and the relationship between economic and IPCC sectors for the latest data year. Similar tables for provinces and territories can be found in Annex 12<sup>13</sup>. 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 Agriculture sector represents all emissions arising from farming activities, including those related to energy combustion for farming equipment as well as those non-CO<sub>2</sub> related to crop and animal production; and finally,
- the Waste and others sector represents emissions that arise from solid and liquid waste, waste incineration, and coal production, light manufacturing, construction and forestry activities.

### 2.4.1. Emissions Trends by Canadian Economic Sector

Overall, GHG emissions trends since 2005 have remained consistent with those described for IPCC sectors, with emission increases in the Oil and Gas (13 Mt or 6.9%) and Agriculture (3.7 Mt or 5.6%) economic sectors being offset by decreases in other sectors, notably Electricity (-67 Mt or -58%), but also Heavy Industry, Waste and others, and Buildings. Since 2005, Transport emissions have generally increased, with an important drop in 2020, bringing 2023 levels similar to 2005 ones.

#### Oil and Gas

In 2023, the Oil and Gas sector produced the largest share of GHG emissions in Canada (30%) (Figure 2–26). Between 1990 and 2023, emissions from this sector increased by 91 Mt (77%). 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 2023, emissions from this sector have generally increased steadily from 117 Mt in 1990, reaching a maximum of 228 Mt in 2014. Most of the increase between 1990 and 2023 is due to considerable expansion in Canada's oil sands. Since 1990, oil sands production has increased by over 800% and emissions have increased by over 73 Mt (~480%). From 2014 to 2019, emissions were relatively stable with some interannual variability due to economic conditions and the 2016 wildfires that impacted oil sands production around Fort McMurray, Alberta. This period was followed by a significant decrease of 14 Mt (6.5%) between 2019 and 2023. This decrease coincides with federal regulations to reduce methane emissions from the upstream oil and gas industry, which came into effect January 1, 2020, and equivalent provincial regulations in Saskatchewan, Alberta and British Columbia. Section 2.3 and the 'Trends in the Oil and Gas Sector' text box discuss the historical drivers of Oil and Gas sector emissions trends in more detail.

#### Transport

Canada's Transport sector is the second-largest contributor to Canada's GHG emissions, accounting for 23% of total emissions in 2023 (Figure 2–26). Between 1990 and 2023, emissions rose by 39 Mt (33%). Since 1990, emissions from this sector have increased gradually, apart from a significant decrease between 2019 and 2020 largely due to fewer kilometers driven during the first year of the COVID-19 pandemic. Transport emissions in 2023 are slightly above 2005 levels (0.37 Mt or 0.2% since 2005). Section 2.3 discusses the main drivers of historical emissions trends associated with passenger and freight transport.

#### Electricity

In 2023, the Electricity sector (excluding industrial and commercial cogeneration) contributed 7.0% to total Canadian emissions (Figure 2–26). Between 1990 and 2023, emissions decreased by 46 Mt (48%). 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 67 Mt or 58% since 2005, despite the 8% increase in demand. Section 2.3 discusses the main historical drivers of emissions trends associated with electricity generation.

12 Available on the Government of Canada Open Data Portal at <http://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b>.

13 Ibid.

## Heavy Industry

Emissions from this sector were responsible for 16% of total Canadian total emissions in 1990, falling to 11% in 2023 (Figure 2–26). The Heavy Industry sector experienced some fluctuations and overall decreases in emissions over the reporting period, and similar to other sectors of the economy, a notable decrease in the 2008–2009 recessionary period. The emissions decreased by 19 Mt (19%) since 1990 and 9.5 Mt (11%) since 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.

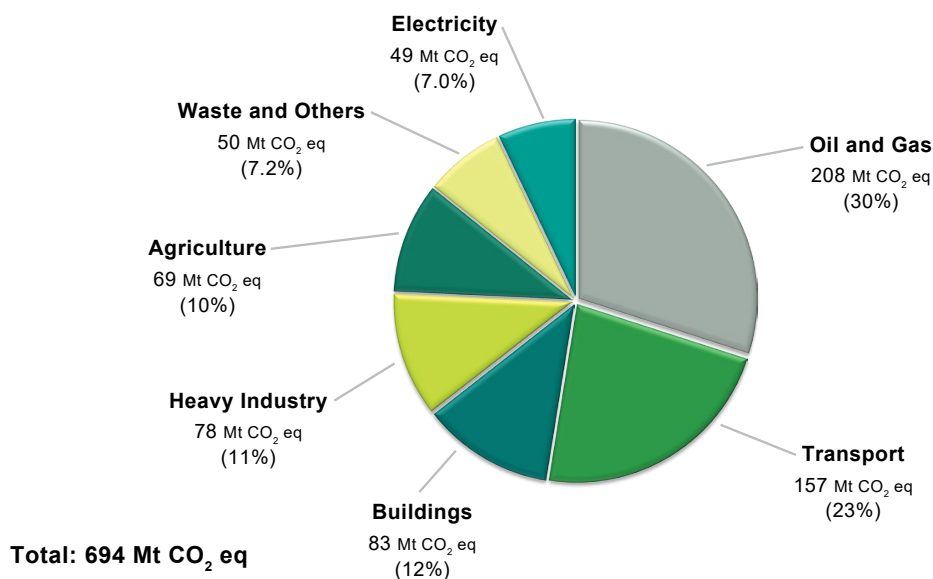
## Buildings

In 2023, the Buildings sector contributed 12% to total Canadian emissions (Figure 2–26). Emissions from residential fuel combustion has decreased 5.7 Mt (13%) since 1990, which is offset by a 17 Mt (61%) increase in emissions from the service industry. Since 2005, the Buildings sector emissions decreased by 2.0 Mt or 2.3%. GHG emissions from the Buildings sector have increased with population growth and commercial development, fluctuated throughout the time series but, have remained relatively stable since 2005.

## Agriculture and Waste and Others

Emissions from the Agriculture sector continued a gradual upward trend throughout the reporting period, rising from 51 Mt in 1990 to 66 Mt in 2005, and 69 Mt in 2023 (Figure 2–26). Emissions from the Waste and others sector decreased by 7.3 Mt (13%) since 1990 and 3.9 Mt (7.2%) since 2005. Overall, Waste emissions fluctuated and slightly increased over the time series, from 21 Mt in 1990 to 23 Mt in 2023. Section 2.3 discusses the main historical drivers of emissions trends associated with Agriculture and Waste.

Figure 2–26 **Breakdown of Canada's GHG Emissions by Economic Sector (2023)**



## TRENDS IN THE OIL AND GAS SECTOR

Emissions in the Canadian Oil and Gas (O&G) economic sector include flaring, venting, unintentional leaks, industrial processes and all combustion-related emissions (stationary combustion, off-road transportation, utility and industrial generation of electricity and steam), excluding captured CO<sub>2</sub>, to provide a complete emission profile of the industry.

In 2023, the largest contributor to O&G emissions was the Oil Sands category (89 Mt, or 43%), followed by Natural Gas Production and Processing (52 Mt, or 25%), Conventional Oil Production (38 Mt, or 18%) and Petroleum Refining (17 Mt, or 8%). The primary drivers of emissions within the O&G sector are production growth and emission intensity (defined as the average amount of GHG emissions generated per barrel of oil equivalent).

### Production Growth

From 1990 to 2023, the production of total crude oil increased by 199%. The increase was driven almost entirely by Canada's oil sands operations (mining, thermal in-situ extraction and crude bitumen/heavy oil upgrading) with total oil sands output (non-upgraded bitumen and synthetic crude oil production) increasing by over 800% since 1990, accounting for 83% of total crude oil production growth. In contrast, conventional crude oil production (including primary extraction in designated oil sands areas) increased by 41% over the same period. Consistent with the production increases, emissions from Conventional Oil Production increased by 6 Mt (about 20%), while emissions from oil sands increased by 73 Mt (about 480%).

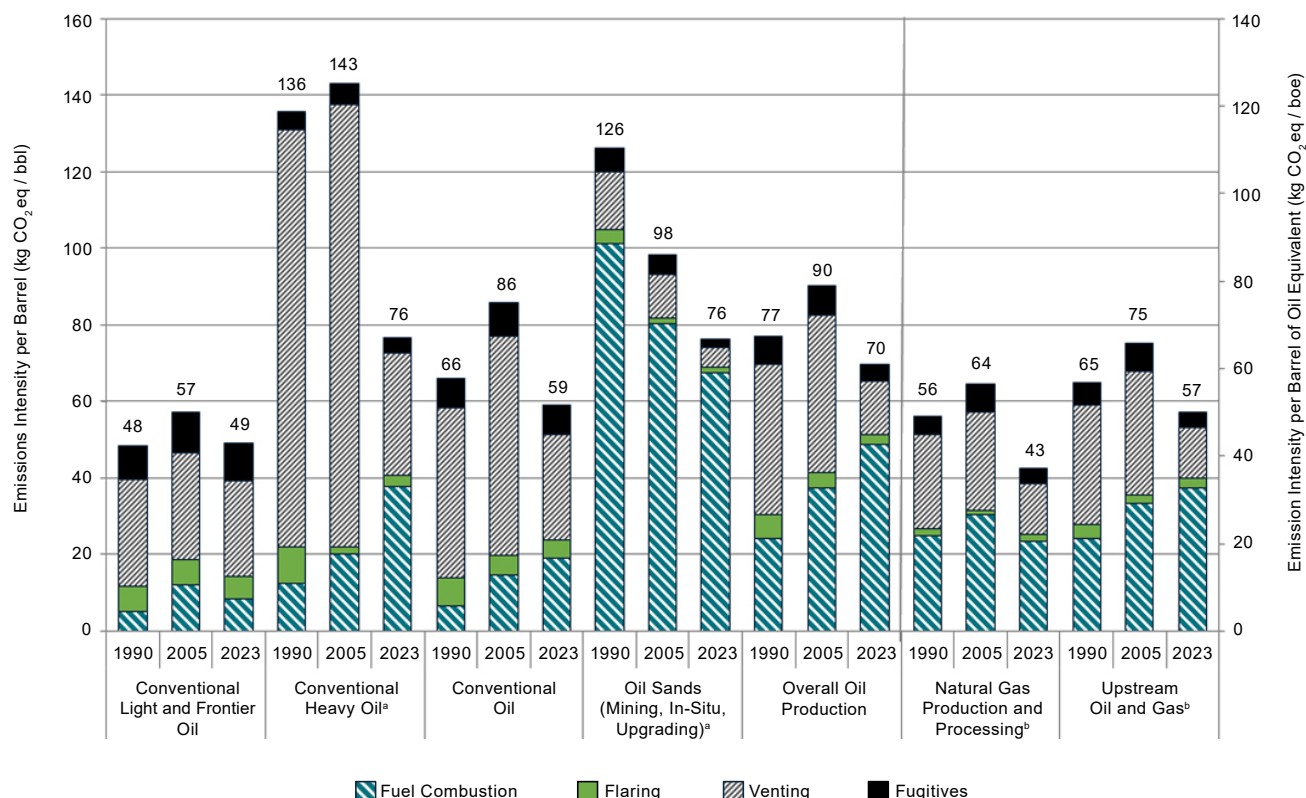
Emissions from Natural Gas Production and Processing have increased by 14 Mt (37%) since 1990, consistent with a 61% increase in gross production volumes. Most of this growth has occurred in northeastern British Columbia, which has accounted for 74% of the national production growth.

### Emission Intensity

The emission intensity of overall oil production in Canada decreased by 8% between 1990 and 2023, from 77 to 70 kg CO<sub>2</sub> eq per barrel (Figure 2–B) with the most notable decrease of 22% occurring since 2015 where intensity was 89 kg CO<sub>2</sub> eq per barrel. Contributors to this trend include decreasing reserves of easily removable crude oil, along with increasing reliance on reserves requiring more energy- and GHG-intensive extraction methods. These include more difficult-to-extract crude oil and crude bitumen, including those extracted using enhanced oil recovery operations such as steam-assisted gravity drainage (SAGD). The increased use of horizontal wells and multi-stage fracturing techniques also increases emissions and the amount of energy required for drilling and well-completion activities. Fuel combustion emissions have increased by over 100% per barrel of oil extracted (24 kg CO<sub>2</sub> eq per bbl in 1990 to 49 kg CO<sub>2</sub> eq per bbl in 2023), which is indicative of increased oil sands production that requires large quantities of steam, generally produced from combusting natural gas.

The rising quantity of petroleum extracted from Canada's oil sands has had the largest impact on increasing the emission intensity of overall oil production. However, the intensity of oil sands operations themselves has declined steadily from 126 kg CO<sub>2</sub> eq per barrel in 1990 to 76 kg CO<sub>2</sub> eq per barrel in 2023. 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 190% while SCO production increased by only 45%. The additional energy required to process the crude bitumen (and resulting emissions) is transferred downstream, mainly to export markets where the bitumen is processed at petroleum refineries. Since 2015, almost 9 Mt of CO<sub>2</sub> emissions from the Scotford Upgrader have been captured and transported to an underground storage site, contributing to the reduction in oil sands emissions intensity.

Figure 2-B Emissions Intensity by Source Type for Oil and Gas (1990, 2005 and 2023)



## 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.

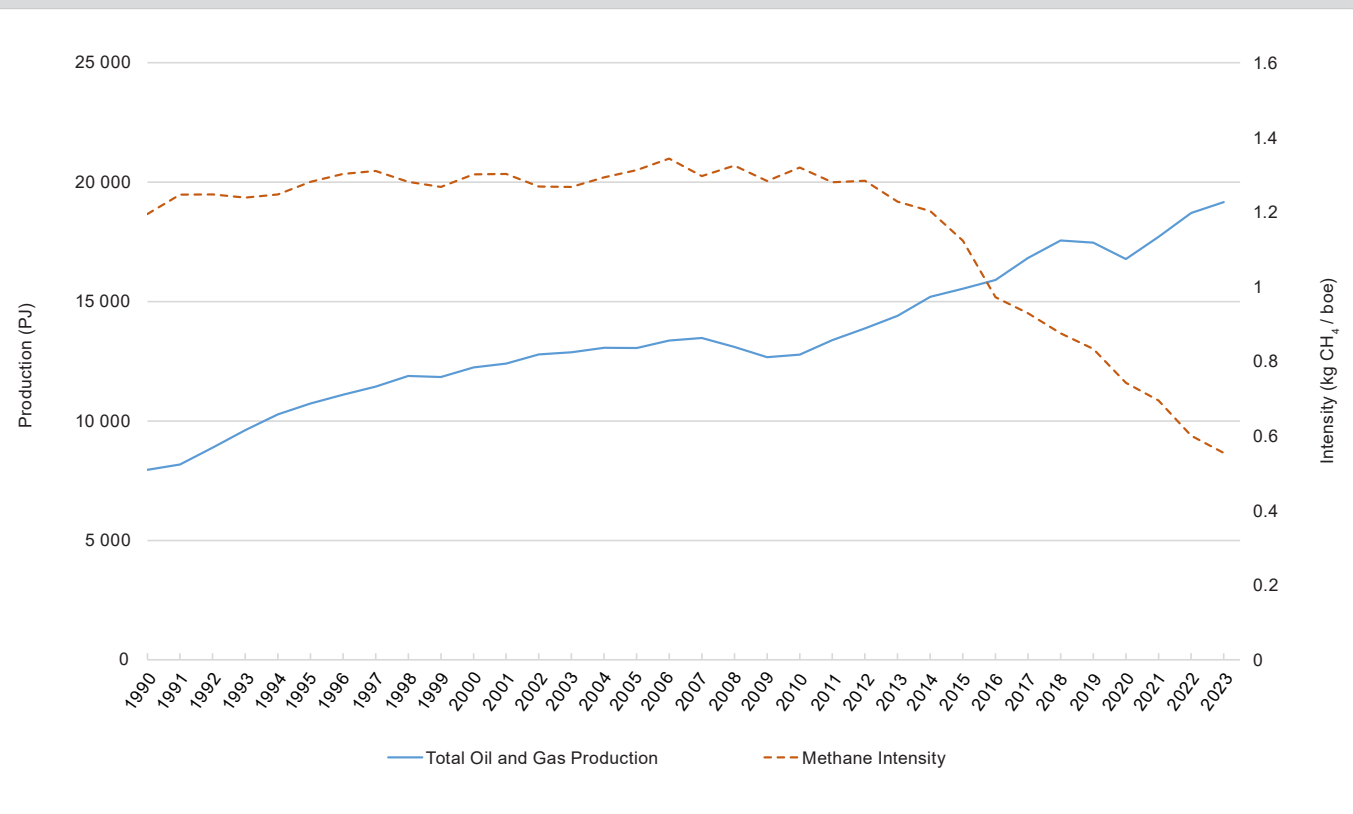
b. Calculated on a barrel of oil equivalent (boe) basis by converting production volumes to energy basis and then dividing by energy content of light crude oil (6.1215 GJ/bbl).  
[1 barrel (bbl) = 0.159 m<sup>3</sup>]

Production data sources = Natural Gas: StatCan (1990–); Crude Oil: NB NRED (2024), SK MER (1990–2008, 2009–2011, 2012–), StatCan (n.d.[d], n.d.[h]); Oil Sands: AER (2024), Cenovus (2024).

In contrast to combustion emissions, venting, flaring and fugitive emissions per barrel of oil extracted have decreased by 65%, 57% and 43%, respectively, since 1990. These reductions are due to increased oil sands production, which produces much fewer fugitive emissions per barrel than conventional oil production, and initiatives such as Alberta's Directive 60 (AER, 2014), British Columbia's Flaring and Venting Reduction Guideline (BCOGC, 2015), Saskatchewan's Directive S-10, and the Canadian Association of Petroleum Producers (CAPP) Best Management Practice for Fugitive Emissions (CAPP, 2007). More recently, the federal regulations to reduce methane from upstream oil and gas (ECCC, 2018) and equivalent provincial regulations in Alberta (AB, 2018; ECCC, 2020a), British Columbia (BC, 2021; ECCC, 2020b), and Saskatchewan (SK, 2020; ECCC, 2020c), which came into effect January 1, 2020, have also had an impact.

These factors have collectively contributed to a 57% decrease in the methane intensity of total oil and gas production (Figure 2-C) since 2012. Over that same period, total Canadian oil and gas production increased by 38%. In fact, since 2012, efforts in all three major oil and gas producing provinces (Alberta, British Columbia and Saskatchewan) have resulted in decreases in methane emissions intensity. In Alberta, methane intensity decreased by 57% while production increased by 44%. Similarly, in British Columbia, the intensity decreased by 78% at the same time as a 91% increase in production. In Saskatchewan, both methane intensity (-42%) and production (-8%) have decreased since 2012. This shows that efforts by industry and regulators have had positive impacts on emissions intensity, which puts downward pressure on emission levels while competing against the upward pressure of production increases.

Figure 2-C **Methane (CH<sub>4</sub>) Emission Intensity Versus Total Oil and Gas Production, Canada**



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

Table 2–13 Trends in GHG Emissions by Canadian Economic Sector

Economic Sector	GHG Emissions (Mt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>NATIONAL TOTAL</b>	<b>606</b>	<b>759</b>	<b>747</b>	<b>747</b>	<b>682</b>	<b>694</b>	<b>700</b>	<b>694</b>
<b>Oil and Gas</b>	<b>117</b>	<b>194</b>	<b>223</b>	<b>222</b>	<b>204</b>	<b>211</b>	<b>209</b>	<b>208</b>
<b>Upstream Oil and Gas</b>	<b>97</b>	<b>172</b>	<b>206</b>	<b>203</b>	<b>187</b>	<b>193</b>	<b>191</b>	<b>190</b>
Natural Gas Production and Processing	38	75	62	60	58	59	54	52
Conventional Oil Production	32	48	51	49	39	39	38	38
Conventional Light Oil Production	19	22	31	29	23	22	21	21
Conventional Heavy Oil Production	13	25	19	17	14	16	16	16
Frontier Oil Production	0.26	1.7	1.8	1.8	1.6	1.4	1.3	1.3
Oil Sands (Mining, In-situ, Upgrading)	15	37	83	84	81	86	87	89
Mining and Extraction	2.9	6.8	16	17	16	17	17	17
In-situ	4.6	13	44	43	41	45	46	47
Upgrading	7.8	17	23	24	24	24	24	24
Oil, Natural Gas and CO <sub>2</sub> Transmission	12	12	10	10	9	10	11	11
<b>Downstream Oil and Gas</b>	<b>20</b>	<b>22</b>	<b>18</b>	<b>20</b>	<b>17</b>	<b>18</b>	<b>18</b>	<b>18</b>
Petroleum Refining	18	20	17	19	16	17	17	17
Natural Gas Distribution	1.6	1.7	0.82	1.0	1.0	1.0	0.94	0.94
<b>Electricity</b>	<b>94</b>	<b>116</b>	<b>63</b>	<b>62</b>	<b>54</b>	<b>52</b>	<b>49</b>	<b>49</b>
<b>Transport</b>	<b>118</b>	<b>156</b>	<b>169</b>	<b>169</b>	<b>142</b>	<b>149</b>	<b>155</b>	<b>157</b>
<b>Passenger Transport</b>	<b>80</b>	<b>95</b>	<b>102</b>	<b>103</b>	<b>83</b>	<b>86</b>	<b>92</b>	<b>94</b>
Cars, Trucks and Motorcycles	71	85	90	91	75	78	81	82
Bus, Rail and Aviation	8.8	10	12	12	7.6	8.1	11	12
<b>Freight Transport</b>	<b>30</b>	<b>48</b>	<b>52</b>	<b>51</b>	<b>45</b>	<b>48</b>	<b>49</b>	<b>48</b>
Heavy-Duty Trucks, Rail	25	42	47	46	41	43	44	43
Aviation and Marine	4.8	5.4	4.9	4.8	4.6	5.3	4.8	5.0
<b>Other: Recreational, Commercial and Residential</b>	<b>8.2</b>	<b>14</b>	<b>15</b>	<b>15</b>	<b>14</b>	<b>15</b>	<b>15</b>	<b>15</b>
<b>Heavy Industry</b>	<b>97</b>	<b>88</b>	<b>80</b>	<b>79</b>	<b>75</b>	<b>78</b>	<b>78</b>	<b>78</b>
<b>Mining</b>	<b>7.2</b>	<b>8.1</b>	<b>11</b>	<b>11</b>	<b>10</b>	<b>11</b>	<b>11</b>	<b>9.3</b>
<b>Smelting and Refining (Non-Ferrous Metals)</b>	<b>17</b>	<b>14</b>	<b>10</b>	<b>10</b>	<b>10</b>	<b>9.9</b>	<b>10</b>	<b>10</b>
<b>Pulp and Paper</b>	<b>15</b>	<b>9.0</b>	<b>7.9</b>	<b>8.2</b>	<b>7.2</b>	<b>7.4</b>	<b>7.6</b>	<b>7.8</b>
<b>Iron and Steel</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>15</b>	<b>13</b>	<b>15</b>	<b>14</b>	<b>14</b>
<b>Cement</b>	<b>10</b>	<b>13</b>	<b>11</b>	<b>11</b>	<b>10</b>	<b>11</b>	<b>10</b>	<b>11</b>
<b>Lime and Gypsum</b>	<b>2.9</b>	<b>3.5</b>	<b>2.4</b>	<b>2.3</b>	<b>2.2</b>	<b>2.2</b>	<b>2.5</b>	<b>2.2</b>
<b>Chemicals and Fertilizers</b>	<b>28</b>	<b>24</b>	<b>21</b>	<b>22</b>	<b>23</b>	<b>22</b>	<b>23</b>	<b>23</b>
<b>Buildings</b>	<b>72</b>	<b>85</b>	<b>92</b>	<b>94</b>	<b>88</b>	<b>85</b>	<b>88</b>	<b>83</b>
<b>Service Industry</b>	<b>28</b>	<b>40</b>	<b>49</b>	<b>50</b>	<b>47</b>	<b>45</b>	<b>46</b>	<b>44</b>
<b>Residential</b>	<b>44</b>	<b>45</b>	<b>43</b>	<b>44</b>	<b>41</b>	<b>40</b>	<b>42</b>	<b>38</b>
<b>Agriculture</b>	<b>51</b>	<b>66</b>	<b>69</b>	<b>69</b>	<b>70</b>	<b>69</b>	<b>70</b>	<b>69</b>
<b>On-Farm Fuel Use</b>	<b>8.2</b>	<b>9.4</b>	<b>15</b>	<b>15</b>	<b>14</b>	<b>14</b>	<b>14</b>	<b>14</b>
<b>Crop Production</b>	<b>9.5</b>	<b>11</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>17</b>	<b>19</b>	<b>19</b>
<b>Animal Production</b>	<b>33</b>	<b>46</b>	<b>38</b>	<b>38</b>	<b>38</b>	<b>38</b>	<b>37</b>	<b>37</b>
<b>Waste and Others</b>	<b>57</b>	<b>54</b>	<b>52</b>	<b>52</b>	<b>48</b>	<b>49</b>	<b>50</b>	<b>50</b>
<b>Waste</b>	<b>21</b>	<b>24</b>	<b>23</b>	<b>23</b>	<b>23</b>	<b>23</b>	<b>23</b>	<b>23</b>
<b>Coal Production</b>	<b>4.6</b>	<b>3.0</b>	<b>3.2</b>	<b>3.5</b>	<b>3.0</b>	<b>3.1</b>	<b>3.2</b>	<b>3.6</b>
<b>Light Manufacturing, Construction and Forest Resources</b>	<b>31</b>	<b>27</b>	<b>25</b>	<b>25</b>	<b>22</b>	<b>23</b>	<b>24</b>	<b>24</b>

## 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.

# CHAPTER 3

## ENERGY (CRT SECTOR 1)

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### 3.1. Overview

In 2023, the Energy sector contributed 562 Mt (81%) to Canada's total greenhouse gas (GHG) emissions (Figure 3–1 and Table 3–1). This includes carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) emissions from: all fuel combustion activities, fugitive sources, and CO<sub>2</sub> leakage from carbon capture, transport, use and storage (CCTUS) activities.<sup>1</sup>

The combustion of fossil and biomass fuels generated 494 Mt (88%) of the Energy sector's GHG emissions while the remaining 69 Mt (12%) are fugitive emissions from fossil fuel industries and CCTUS. Fuel combustion emissions are split into the five categories shown in Figure 3–1: Energy Industries, Manufacturing Industries and Construction, Transport, Other Sectors, and Others. Specific details are presented in their respective sections, refer to sections 3.2.4 to 3.2.8.

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

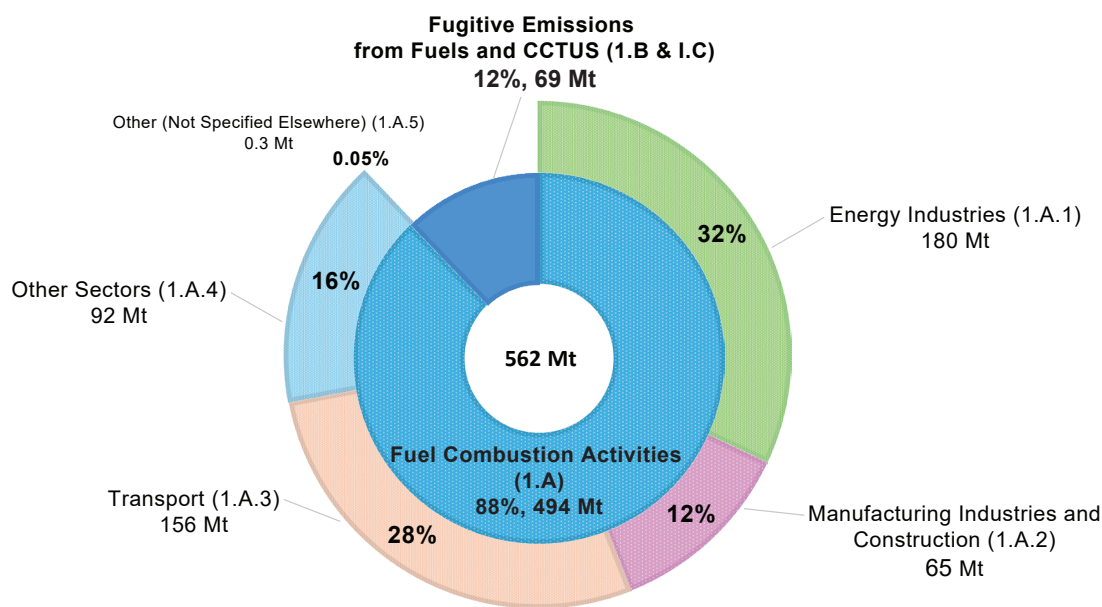
Currently, captured CO<sub>2</sub> from industrial operations is transported and used for enhanced oil recovery (EOR) or injected into long-term storage (LTS). Section 3.4 has details of the capture volumes and emissions associated with CCTUS.

Table 3–1 Overview of GHG Emissions from the Energy Sector, Selected Years								
GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>ENERGY SECTOR</b>	<b>487 000</b>	<b>623 000</b>	<b>615 000</b>	<b>616 000</b>	<b>552 000</b>	<b>562 000</b>	<b>568 000</b>	<b>562 000</b>
<b>Fuel Combustion Activities (1.A)</b>	<b>422 000</b>	<b>525 000</b>	<b>527 000</b>	<b>532 000</b>	<b>477 000</b>	<b>487 000</b>	<b>498 000</b>	<b>494 000</b>
Energy Industries (1.A.1)	143 000	205 000	190 000	191 000	178 000	181 000	179 000	180 000
Manufacturing Industries and Construction (1.A.2)	74 700	68 400	68 300	69 300	62 800	64 900	65 800	65 000
Transport (1.A.3)	118 000	157 000	167 000	167 000	140 000	147 000	155 000	156 000
Other Sectors (1.A.4)	86 000	94 200	102 000	104 000	96 400	93 600	97 300	91 900
Other (Not Specified Elsewhere) (1.A.5)	260	290	360	370	290	330	310	310
<b>Fugitive Emissions from Fuels (1.B)</b>	<b>66 000</b>	<b>98 000</b>	<b>88 000</b>	<b>84 000</b>	<b>75 000</b>	<b>75 000</b>	<b>70 000</b>	<b>68 000</b>
<b>CO<sub>2</sub> Transport and Storage (1.C)</b>	<b>NO</b>	<b>0.1</b>	<b>0.3</b>	<b>58</b>	<b>109</b>	<b>31</b>	<b>36</b>	<b>37</b>

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

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

Figure 3–1 2023 Energy Sector Emission Contribution by Category



### 3.1.1. Recalculations

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

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2017	2018	2019	2020	2021	2022
<b>ENERGY SECTOR (1)</b>								
Previous Submission (2024 NIR)	489 000	626 000	613 000	622 000	622 000	558 000	569 000	577 000
Current Submission (2025 NIR)	487 000	623 000	608 000	615 000	616 000	552 000	562 000	568 000
Change in Emissions	-1 690	-2 780	-4 940	-6 650	-5 990	-5 680	-6 410	-8 680
	-0.35%	-0.44%	-0.81%	-1.1%	-0.96%	-1.0%	-1.1%	-1.5%
<b>FUEL COMBUSTION (1.A)</b>								
Previous Submission (2024 NIR)	423 000	529 000	524 000	532 000	536 000	481 000	492 000	502 000
Current Submission (2025 NIR)	422 000	525 000	520 000	527 000	532 000	477 000	487 000	498 000
Change in Emissions	-1 080	-3 470	-3 590	-5 070	-4 300	-3 850	-4 220	-3 760
	-0.26%	-0.66%	-0.69%	-0.95%	-0.80%	-0.80%	-0.86%	-0.75%
<b>FUGITIVE (1.B) AND CO<sub>2</sub> TRANSPORT &amp; STORAGE (1.C)</b>								
Previous Submission (2024 NIR)	66 000	97 000	89 000	89 000	86 000	77 000	77 000	75 000
Current Submission (2025 NIR)	66 000	98 000	88 000	88 000	84 000	75 000	75 000	70 000
Change in Emissions	-610	690	-1 400	-1 600	-1 700	-1 800	-2 200	-4 900
	-0.92%	0.71%	-1.5%	-1.8%	-2.0%	-2.4%	-2.8%	-6.6%

Note: Totals may not add up due to rounding.

Overall, recalculations resulted in a downward revision of 8.68 Mt compared to the 2024 UNFCCC submitted value for 2022. Recalculations are grouped as follows:

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

- Revisions to fuel consumption data in the *Report on Energy Supply and Demand in Canada* (RES<sub>D</sub>) (Statistics Canada, n.d.) generally result in recalculations to multiple fuel combustion categories and subcategories. Revised 2022 RES<sub>D</sub> data have been incorporated (as per standard practice) as an update to the 2022 preliminary data<sup>2</sup> along with corrections to some historical data utilized in last year's national inventory submission to the UNFCCC. Revisions to the RES<sub>D</sub> consist of:
  - 2019 to 2022 butane data
  - 2020 to 2022 diesel fuel oil data
  - 2010 to 2022 heavy fuel oil data
  - 2011 to 2022 natural gas data
  - 1990 to 2022 petroleum coke data
  - 2005 to 2022 propane data
  - 2005 to 2022 still gas data
- Revisions of non-RES<sub>D</sub> data consist of:
  - 1990 to 2022 quantity of liquid fuels combusted by marine vessels
  - 1990 to 2022 quantity of off-road vehicles/equipment in operation
  - 2022 aircraft movement statistics
  - 1990 to 2022 volumes of flared gas subtracted from stationary combustion to avoid double counting
  - 2007 to 2022 quantity of landfill gas combusted
  - 1990 to 2022 quantity of sludge gas combusted

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

- a method of estimating emissions for digester gas from centralized industrial and municipal anaerobic digesters used for energy purposes (refer to section A3.6.2.2 for a detailed description of the method);
- methodological updates to mixed waste fuel used in the cement industry (refer to section A3.1.4.1.3 for a detailed description of the method);
- methodological updates to fugitive emissions from the natural gas transmission, storage, and distribution sectors (refer to sections A3.2.2.2 and A3.2.2.4 for detailed descriptions);
- improvements to modeling parameters used to estimate emissions from pneumatic equipment in the British Columbia UOG sector (refer to section A3.2.2.1.3 for a detailed description of the method);
- improvements to the methodology for estimating formation CO<sub>2</sub> emissions in British Columbia (refer to section A3.2.2.1.1 for a description of the method);
- methodological updates to modelled road vehicle population estimates (refer to section A3.1.4.2 for more details); and
- methodological updates to estimate fuel combusted by locomotives (refer to section A3.1.4.2 for more details).

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

- CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emission factors for petroleum coke stationary fuel combustion;
- CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emission factors for residential firewood stationary fuel combustion appliances;
- CO<sub>2</sub> emission factors for mixed waste fuel stationary fuel combustion; and
- CO<sub>2</sub> and CH<sub>4</sub> emission factors for producer-consumed natural gas stationary fuel combustion in Alberta and Saskatchewan.

<sup>2</sup> Statistics Canada annually publishes a revised, final version of the previous year's (preliminary) energy data. Currently, energy data for 2023 are preliminary and are subject to revision in 2025.

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

- Reallocation of GHG emissions from CRT category 1.A.2.a Iron and Steel to 2.C.1.b Pig Iron for the use of natural gas in blast furnaces.

Other improvements impacted the UOG sector, including an update to model parameters for fugitive equipment leaks in Alberta (described in section A3.2.2.1.3), and finally, the procedure for reconciling compressor seal emissions with reported venting emissions in Saskatchewan was updated for the period from 2020 to 2022, as described in section 3.3.2.5.

## MEMO ITEMS AND EMISSION ALLOCATION

- Only the CH<sub>4</sub> and N<sub>2</sub>O emissions from the combustion of biomass and biofuels are included while their CO<sub>2</sub> emissions appear as a memo item in UNFCCC inventory reporting tables.
- GHGs from international aviation and international navigation activities are also reported as a memo item.
- Off-road emissions from vehicles and machinery, including fishing vessels, appear in the separate and distinct mobile subcategories where they occur within the Manufacturing Industries and Construction (1.A.2) or Other Sectors (1.A.4). Military aviation and navigation are reported under the Other (1.A.5) subcategory.
  - Allocation of emissions in this chapter is consistent with the Intergovernmental Panel on Climate Change (IPCC) and UNFCCC reporting table categorization, and differs from the emissions allocation presented in [Chapter 2](#), Annex 9 and Annex 11, where emissions from off-road transportation, fishing, military aviation and military navigation are included under general transport.
- In Canada peat is produced, exported, and used for horticultural purposes only. Peat is not used as a fuel to support combustion activities. Information on peat is presented in the Land Use, Land-Use Change, and Forestry (LULUCF) sector (Chapter 6, section 6.1) and the fuel used to harvest and produce peat is included in the Agriculture/Forestry/Fishing subcategory within Other Sectors (1.A.4).

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

Emission sources in the Fuel Combustion Activities category include all GHG emissions from the combustion of fossil and biomass fuels, excluding the CO<sub>2</sub> emissions from biomass fuels such as residential fuel wood and biodiesel. Instead, CO<sub>2</sub> from biomass combustion appears in the memo item section of the CRT. Major categories include Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors. Annex 3.1, Methodology and Data for Estimating Emissions from Fossil Fuel Combustion, presents the methods used to calculate emissions from fuel combustion. The estimation methods are consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) Tier 2 and Tier 3 approaches, with country-specific emission factors and parameters.

In 2023, about 494 Mt (71%) of Canada's GHG emissions were from the combustion of fossil and biomass fuels ([Table 3–1](#)). Overall, GHG emissions from Fuel Combustion activities have increased by 17% since 1990. Between 1990 and 2023, emissions from the Energy Industries (1.A.1) category increased by 26% (37.5 Mt), the Manufacturing Industries and Construction (1.A.2) category decreased by 13% (-9.71 Mt), the Transport (1.A.3) category increased by 32% (38.2 Mt), and the Other Sectors (1.A.4) category increased by 6.9% (5.94 Mt) (see [Figure 3–2](#)).

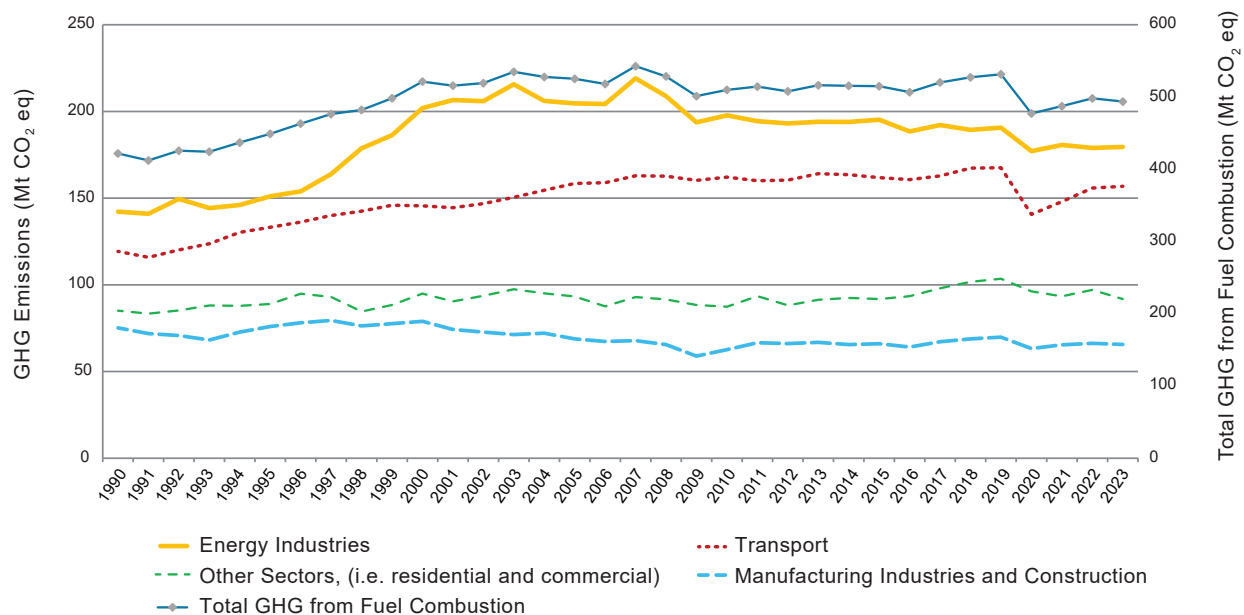
#### 3.2.1. Comparison of the Sectoral Approach with the Reference Approach

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

Figure 3–2 GHG Emissions from Fuel Combustion Activities



### 3.2.2.1. International Aviation (CRT Category 1.D.1.a)

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

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

Table 3–3 GHG Emissions from Domestic and International Aviation

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
International Aviation	5 800	10 100	15 000	15 200	6 580	6 610	11 400	13 600
Domestic & Military Aviation	7 510	7 710	8 660	8 580	4 750	5 600	7 660	8 360
<b>Total</b>	<b>13 300</b>	<b>17 800</b>	<b>23 700</b>	<b>23 700</b>	<b>11 300</b>	<b>12 200</b>	<b>19 100</b>	<b>21 900</b>

Note: Totals may not add up due to rounding.

### 3.2.2.2. International Navigation (CRT Category 1.D.1.b)

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

Similar to the Aviation subcategory, due to different approaches, careful consideration should be taken when comparing fuel consumption (in energy terms) in this subcategory to those of the RESD and IEA. The method employed in the national inventory uses detailed domestic and international movements based on a vessel's port of origin and destination. The fuel consumption values reported to the IEA by Canada are based on vessel flag (domestic or foreign). Furthermore, due to design and operating procedures of marine vessels, it is common for vessels to store significant amounts of fuel onboard. This means that it is possible for vessels to navigate in Canadian waters without purchasing fuel from a Canadian supplier. Since the RESD contains only domestic fuel transactions, it is possible to have more fuel consumed in the marine sector than the amounts reported for Canada.

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
International Navigation	5 120	6 220	3 930	4 340	3 640	3 670	3 570	3 500
Domestic, Fishing & Military Navigation	3 190	4 080	3 650	3 660	3 260	3 210	3 590	3 740
<b>Total</b>	<b>8 310</b>	<b>10 300</b>	<b>7 590</b>	<b>8 000</b>	<b>6 890</b>	<b>6 890</b>	<b>7 170</b>	<b>7 230</b>

Note: Totals may not add up due to rounding.

### 3.2.3. Feedstocks and Non-Energy Use of Fuels

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

### 3.2.4. Energy Industries (CRT Category 1.A.1)

#### 3.2.4.1. Category Description

The Energy Industries category has three subcategories: Public Electricity and Heat Generation, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries.

In 2023, the Energy Industries category accounted for 180 Mt (26%) of Canada's total GHG emissions, with a 26% (37.5 Mt) increase in total GHG emissions since 1990. The Public Electricity and Heat Generation subcategory accounted for 32% (58.2 Mt) of the GHG emissions from Energy Industries, while the Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries subcategories contributed 7.9% (14.2 Mt) and 60% (108 Mt), respectively (Table 3–5). Chapter 2, Emissions Trends, has further discussion of trends in emissions from the Energy Industries category.

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>ENERGY INDUSTRIES TOTAL (1.A.1)</b>	<b>143 000</b>	<b>205 000</b>	<b>190 000</b>	<b>191 000</b>	<b>178 000</b>	<b>181 000</b>	<b>179 000</b>	<b>180 000</b>
Public Electricity and Heat Generation	94 100	123 000	70 900	69 600	62 300	61 600	58 100	58 200
Petroleum Refining	17 400	18 500	13 300	15 300	13 500	14 100	14 600	14 200
Manufacture of Solid Fuels and Other Energy Industries <sup>a</sup>	31 200	63 500	106 000	106 000	102 000	106 000	107 000	108 000

Notes:  
Totals may not add up due to rounding.

a. In accordance with the UNFCCC Common Reporting Tables, Manufacture of Solid Fuels and Other Energy Industries includes stationary combustion emissions from coal mines. However, in Annex 10 and Annex 12, these emissions are included in the Coal Production category.

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

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

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

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

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

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

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

The Petroleum Refining subcategory includes fuel combustion emissions from the production of petroleum products from a raw feedstock. Conventional or synthetic crude oil is refined into petroleum products such as heavy fuel oil, residential fuel oil, aircraft fuel, gasoline, and diesel by distillation and other processes. These processes use heat from combusting either internally generated fuels (such as still gas and petroleum coke) or purchased fuels (such as natural gas). Following IPCC guidance (IPCC, 2019), emissions from the controlled burn-off of catalyst coke during catalyst regeneration processes are reported under 1.A.1.b. The Fugitive Emissions from Fuels category (section 3.3) includes CO<sub>2</sub> generated by refineries during the production of hydrogen by steam reforming of natural gas, as well as fugitive emissions from all other operations.

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

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

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

### 3.2.4.2. Methodological Issues

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

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

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

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

The RESD aggregates fuel-use data for industrial wood wastes and spent pulping liquors combusted for energy purposes into one national total. Reallocating emissions of CH<sub>4</sub> and N<sub>2</sub>O from the combustion of biomass to their respective categories uses the RESD feeder survey data. CO<sub>2</sub> emissions from biomass combustion are not included in totals but rather reported separately in the UNFCCC CRT as a memo item.

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

Calculated emissions for this subcategory use all fuel attributed to the petroleum refining industry, including all petroleum products reported as producer-consumed/own consumption as well as natural gas purchased for fuel-use. The fuel-use data in the RESD include volumes of flared fuels; however, 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 section A3.2.2.8, for more details.

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

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

Fossil fuel producers often combust unprocessed, non-marketable, natural gas. This fuel has a higher CO<sub>2</sub> emission factor than marketable natural gas (see section A6.1.1), since it contains a larger percentage of complex hydrocarbons, resulting in higher carbon content. Likewise, the energy content of non-marketable natural gas is higher than that of marketable natural gas.

### 3.2.4.3. Uncertainty Assessment and Time-Series Consistency

The estimated uncertainty range for the Energy Industries category is  $\pm 3\%$  for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O combined and  $\pm 2\%$  for CO<sub>2</sub> alone.

Uncertainties for the Energy Industries category depend on data collection methods and the representativeness of a specific fuel's emission factor. Data collection for taxation purposes means commercial fuel volumes and properties are generally accurate, with greater uncertainty surrounding both the reported quantities and the properties of non-marketable fuels (e.g., own use of natural gas from producing wells and still gas consumption by refineries). For example, in the Petroleum Refining subcategory, the CO<sub>2</sub> 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<sub>2</sub> factors for commercial fuels. Coal CO<sub>2</sub> emission factors were developed using statistical methods and 95% confidence intervals.

The estimated uncertainty for CH<sub>4</sub> ( $\pm 110\%$ ) and N<sub>2</sub>O ( $\pm 275\%$ ) 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<sub>4</sub> and N<sub>2</sub>O 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.

<sup>3</sup> The RESD "input data" is sourced from the surveys that feed the RESD. (The RESD aggregates and summarizes the data from these surveys.)

Approximately 30% of the emissions from the Manufacture of Solid Fuels and Other Energy Industries subcategory are associated with the consumption of non-marketable natural gas for natural gas production and processing, conventional crude oil production, and in-situ bitumen extraction. The uncertainty estimates for emissions from the combustion of this fuel is influenced by the CO<sub>2</sub> (-1.4 to +2.0% for Alberta; ±6% for all other provinces) and CH<sub>4</sub> (0% to +240%) emission factor uncertainties for the consumption of unprocessed natural gas. Emissions estimates, for the oil and gas industry, use provincially-weighted natural gas emission factors because plant-level information on the composition of unprocessed natural gas (which will vary from plant to plant) is unavailable.

#### 3.2.4.4. QA/QC and Verification

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

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

As described in Chapter 1 section 1.4.4, Canada's Greenhouse Gas Reporting Program (GHGRP) has collected GHG emission data from facilities that released emissions of 10 kt CO<sub>2</sub> eq or more starting in 2017, and from those that released emissions of 50 kt CO<sub>2</sub> eq or more between 2004 and 2016. Where coverage of a specific sector is complete, or close to complete, the GHGRP data allows for a comparison between industry-reported values and Canadian inventory emission estimates. This is possible for the Petroleum Refining and Public Electricity subcategories, and oil sands mining and upgrading, due to near complete coverage of these industries.

#### 3.2.4.5. Recalculations

Several improvements and activity data revisions have contributed to increased data accuracy and comparability, as well as consistency with the 2006 IPCC Guidelines and MPGs. Recalculations for 2022 resulted in a downward revision of 0.83 Mt CO<sub>2</sub> eq for the Energy Industry category compared to the previous submission, due to:

- revised RESD data, including updates to butane, diesel, natural gas, still gas, petroleum coke, and propane resulted in recalculations between 1990 and 2022 (emissions change ranged from -3.4 Mt in 2016 to +1.2 Mt in 1996 and 2022 saw a 0.85 Mt increase);
- revised CO<sub>2</sub> and CH<sub>4</sub> emission factors for producer-consumed natural gas in Alberta and Saskatchewan resulted in recalculation from 2020 to 2022 (emissions change ranged from +0.01 Mt in 2020 to +0.02 Mt in 2022); and
- revised CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emission factors for petroleum coke resulted in recalculations between 1990 and 2022 (emissions change ranged from -2.5 Mt in 2004 to -1.1 Mt in 1991).

#### 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. Discussions of recalculations resulting from improvements to the energy balance are found in their respective sections or in the general overview section of this chapter.

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

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

Canada is focused on developing country-specific emission factors with improvements that prioritize fuels having the largest GHG contribution. In recent years, new test results and studies have provided the basis for updates to the CO<sub>2</sub> emission factors and heating values for coal, gasoline, diesel, and marketable and non-marketable natural gas. Section A6.1 of this report presents the results of these improvement activities. Canada will continue to assess and identify additional fuels for improvement.

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

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

### 3.2.5.1. Category Description

This category is composed of emissions from the combustion of purchased fossil fuels by all mining, manufacturing and construction industries. The following subsections present the six UNFCCC assigned subcategories under the Manufacturing Industries and Construction category.

In 2023, the Manufacturing Industries and Construction category accounted for 65.0 Mt (9.4%) of Canada's total GHG emissions, with a 13% (9.71 Mt) decrease in overall emissions since 1990 (refer to Table 3–6 for more details). Within the Manufacturing Industries and Construction category, 37.5 Mt (58%) of the GHG emissions are from the Other subcategory, which is made up of mining, construction, off-road (associated with the manufacturing, mining and construction) along with other manufacturing activities. This subcategory is followed by, in order of decreasing contributions, Chemicals (9.31 Mt, 14%), Pulp, Paper and Print (6.98 Mt, 11%), Iron and Steel (4.57 Mt, 7.0%), Non-metallic Minerals (3.54 Mt, 5.4%), and Non-ferrous Metals (3.08 Mt, 4.7%) subcategories. GHG emissions from Food Processing, Beverages and Tobacco are included in the Other Manufacturing subcategory due to a lack of disaggregated fuel-use data.

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

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>MANUFACTURING INDUSTRIES AND CONSTRUCTION TOTAL (1.A.2)</b>	<b>74 700</b>	<b>68 400</b>	<b>68 300</b>	<b>69 300</b>	<b>62 800</b>	<b>64 900</b>	<b>65 800</b>	<b>65 000</b>
Iron and Steel	4 940	5 020	5 210	5 010	4 290	4 820	4 520	4 570
Non-ferrous Metals	3 530	3 800	2 950	3 430	3 240	3 010	3 170	3 080
Chemicals	8 260	8 240	9 350	9 640	9 570	9 430	9 250	9 310
Pulp, Paper and Print	14 460	8 580	7 070	7 100	6 410	6 730	6 810	6 980
Food Processing, Beverages and Tobacco <sup>a</sup>	IE	IE	IE	IE	IE	IE	IE	IE
Non-metallic Minerals	3 940	5 050	4 210	4 170	3 680	3 540	3 630	3 540
Other	39 600	37 700	39 500	39 900	35 600	37 400	38 400	37 500
Mining (excluding fuels) and Quarrying <sup>b</sup>	4 160	3 980	5 460	5 440	4 760	5 310	5 290	4 890
Construction	1 880	1 440	1 380	1 440	1 410	1 420	1 560	1 510
Off-road Manufacturing, Mining and Construction	12 400	16 200	20 000	20 300	17 500	18 500	18 600	18 200
Other Manufacturing	21 200	16 100	12 700	12 800	11 900	12 100	12 900	12 900

**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 Tables, combustion emissions from coal mines are excluded from Mining (excluding fuels) and Quarrying. However, in Annex 9 and Annex 11, these emissions are included in the Mining category.

### 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 section A3.1.4, which is consistent with IPCC Tier 2 and Tier 3 approaches. GHG emissions generated from the use of transportation fuels (e.g., diesel and gasoline) appear under Off-Road Vehicles and Other Machinery (1.A.2.g.vii) of the Manufacturing Industries and Construction category.

The RESD aggregates fuel-use data for industrial wood wastes and spent pulping liquors combusted for energy purposes into one national total. The reallocation of CH<sub>4</sub> and N<sub>2</sub>O emissions from the combustion of biomass to their respective categories relies on RESD feeder survey data. CO<sub>2</sub> emissions from biomass combustion are not included in totals but appear separately in the UNFCCC CRT as a memo item.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

### 3.2.5.3. Uncertainty Assessment and Time-Series Consistency

The estimated uncertainty for the Manufacturing Industries and Construction category is  $\pm 1\%$  for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O combined.

The underlying fuel quantities and CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O 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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions. Any mathematical and reference errors found during QC checks were corrected prior to publication. The data, methodologies and changes related to QC activities are documented and archived.

### 3.2.5.5. Recalculations

There are revised emissions estimates for all years, with estimates for 2022 revised downwards by 1.2 Mt CO<sub>2</sub> eq over the previous submission because of:

- revised RESD data, including coal, diesel, heavy fuel oil, kerosene & stove oil, light fuel oil, natural gas, petroleum coke, and propane, which affected 1990 to 2022 (emissions change ranged from -0.8 Mt in 2018 to +0.01 Mt in 1990 and 2022 saw a 0.6 Mt decrease);
- revised mixed waste fuel data and CO<sub>2</sub> emission factors resulted in recalculations between 2001 and 2022 (emissions change ranging from -0.1 Mt in 2018 to +0.1 Mt in 2017);
- reallocation of natural gas data from CRT category 1.A.2.a Iron and Steel to 2.C.1.b Pig Iron resulted in recalculations between 1990 and 2022 (emissions change ranging from -1.2 Mt in 2018 to -0.01 Mt in 1990);
- revised CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emission factors for petroleum coke resulted in recalculations between 1990 and 2022 (emissions change ranged from -0.5 Mt in 2006 to -0.01 Mt in 1998); and
- revised off-road activity data between 1990 and 2022 because of revisions to off-road vehicles/equipment in operation and revisions to RESD data.

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

Planned updates to off-road emissions modelling inputs are discussed in section 3.2.6.6, Planned Improvements.

### 3.2.6. Transport (CRT Category 1.A.3)

In 2023, transport-related GHG emissions total 156 Mt, accounting for about 23% 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 29.1 Mt (118%) for LDGTs and 20.1 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 19.4 Mt (43%) since 1990. Since 1990, emissions from the Transport category have increased 38.2 Mt (33%) and have contributed to the equivalent of 44% of the total overall growth in emissions observed in Canada.

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>TRANSPORT</b>	<b>118 000</b>	<b>157 000</b>	<b>167 000</b>	<b>167 000</b>	<b>140 000</b>	<b>147 000</b>	<b>155 000</b>	<b>156 000</b>
Domestic Aviation <sup>a</sup>	7 270	7 450	8 410	8 340	4 560	5 400	7 460	8 170
Road Transportation	92 100	122 000	132 000	132 000	112 000	117 000	121 000	122 000
Light-Duty Gasoline Vehicles	44 200	40 600	32 000	31 300	24 500	25 300	25 700	25 400
Light-Duty Gasoline Trucks	24 700	40 900	54 300	56 000	47 800	49 500	51 700	53 700
Heavy-Duty Gasoline Vehicles	4 790	4 620	4 540	4 600	4 240	4 220	3 930	4 080
Motorcycles	204	459	931	964	760	812	763	788
Light-Duty Diesel Vehicles	367	665	456	424	311	333	362	330
Light-Duty Diesel Trucks	988	748	764	789	640	770	980	936
Heavy-Duty Diesel Vehicles	16 200	34 300	39 200	38 200	33 200	35 900	37 700	36 300
Propane and Natural Gas Vehicles	761	23	108	140	150	157	173	161
Railways	6 100	6 510	6 460	6 510	6 020	5 860	5 810	5 940
Domestic Navigation <sup>a, b</sup>	2 280	3 180	3 350	3 350	2 970	2 890	3 300	3 460
Other Transportation <sup>c</sup>	10 400	17 900	16 400	16 400	15 100	16 200	17 600	17 000
Off-Road	3 470	7 740	7 960	7 910	7 330	7 480	7 430	7 360
Pipeline Transport	6 920	10 100	8 400	8 500	7 760	8 740	10 100	9 690

Notes:  
 Totals may not add up due to rounding.  
 a. Excludes emissions from military equipment, reported in the Other (Not Specified Elsewhere) (CRTF Category 1.A.5) categories.  
 b. Excludes emissions from 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. Category Description

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

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

### 3.2.6.2. Methodological Issues

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

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

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

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

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

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

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

The procedure used to estimate GHG emissions from the Railways subcategory adheres to an IPCC Tier 2 methodology for CO<sub>2</sub> emissions and an IPCC Tier 1 methodology for CH<sub>4</sub> and N<sub>2</sub>O emissions (IPCC, 2006). Fuel combustion data from the Railway Association of Canada (RAC) are reconciled with RESD data reported under railways. The resulting fuel combustion estimates are then multiplied by country-specific emission factors. Amounts of RESD data reported under railways that were determined to not be used in locomotives, because of reconciling with RAC data, were distributed amongst select road transportation and off-road subcategories.

Total emissions from steam train operations are considered insignificant and are not included in the inventory. An assessment of Canadian operations found that they collectively produce about 0.5 kt CO<sub>2</sub> eq, below specified MPGs reporting requirements of 0.05% of total emissions, and less than the 500 kt threshold.

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

This subcategory includes all GHG emissions from domestic marine transport. Emissions arising from fuel used for international voyages are reported separately under Memo Items – International Bunkers (CRT Category 1.D.1.b). Emissions from fuel consumed by fishing vessels are reported under Agriculture/Forestry/Fishing – CRT Category 1.A.4.c. Emissions from fuel consumed by military vessels are reported under Other (Not specified elsewhere) – Mobile subcategory (CRT category 1.A.5.b).

The methodology complies with an IPCC Tier 2 approach for CO<sub>2</sub> emissions and an IPCC Tier 1 approach for CH<sub>4</sub>, and N<sub>2</sub>O emissions (IPCC 2006). Fuel consumption data from the RESD are reconciled with the fuel consumption data from the MEIT and the results are multiplied by country-specific or IPCC default emission factors.

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

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

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

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

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

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

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

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

## 3.2.6.3. Uncertainty Assessment and Time-Series Consistency

### Transport

The overall uncertainty of the 2023 estimates for the Transport category (not including pipelines) was estimated to be  $\pm 1.1\%$  for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O combined.

### Emissions from Domestic Aviation

The uncertainty associated with overall emissions from domestic aviation was estimated to be  $\pm 5.4\%$ . The Domestic Aviation subcategory only contributed approximately 5% to total Transport GHG emissions in 2023 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  $\pm 1.7\%$ , driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO<sub>2</sub> emissions. Conversely, the high uncertainties associated with CH<sub>4</sub> and N<sub>2</sub>O emissions, as well as biofuel activity data, did not significantly influence the analysis because of their comparatively minor contributions to the inventory.

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

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

## Emissions from Railways

The uncertainty associated with emissions from rail transport was estimated to be  $\pm 19\%$ . The greatest influence was exerted by the high  $\text{N}_2\text{O}$  emission factor uncertainty ( $-50\%$  to  $+200\%$ ), whereas the relatively low uncertainties in diesel fuel activity data and  $\text{CO}_2$  emission factors contributed very little. Notably, railway emissions only accounted for approximately 4% of total Transport GHG emissions in 2022 and therefore did not significantly influence the overall uncertainty results.

## Emissions from Domestic Navigation

The uncertainty associated with emissions from the Domestic Navigation category was estimated to be  $\pm 2.7\%$ . The high  $\text{N}_2\text{O}$  emission factor uncertainty ( $-40\%$  to  $+140\%$ ) represented the largest contribution to uncertainty, while  $\text{CO}_2$  emission factor uncertainties were insignificant. Since domestic navigation emissions only made up 2% of the Transport category GHG inventory in 2023, they did not substantially alter the overall uncertainty results.

## Emissions from Pipeline Transport

In general, the  $\text{CH}_4$  emission uncertainty for pipeline transport ranges from  $\pm 15\%$ . Table A2–1 and Table A2–2 show specific uncertainties from pipelines, by GHGs.

## Emissions from Off-Road

The uncertainty associated with all off-road sources was estimated to be  $\pm 1.7\%$ , driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related  $\text{CO}_2$  emissions.

### 3.2.6.4. QA/QC and Verification

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

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

### 3.2.6.5. Recalculations

Transportation estimates were revised for the 1990–2022 period as follows.

- **RESD fuel:** Revisions include updating preliminary 2022 RESD data for all fuels as well as updating heavy fuel oil volumes for the 2010–2021 period and updating diesel fuel oil volumes for the 2020–2021 period. These revisions only had a notable impact on emissions associated with Domestic Navigation and International Navigation for reporting years 2010 and later.
- **MEIT data:** Marine vessel activity data from the Marine Emissions Inventory Tool (MEIT) were updated, contributing to revisions associated with all forms of water-borne navigation for all reporting years. With Domestic Navigation, Fishing, and Military Water-Borne Navigation combined, updates were significant for reporting years 2019 and later.
- **Off-road vehicle/equipment population data:** Off-Road vehicles/equipment estimated to be in operation were updated for all reporting years. These updates had a minor impact on off-road emissions totals as well as the distribution of activity data and emissions amongst off-road subcategories and select subcategories associated with road vehicles.
- **Methodological update to fuel combusted by locomotives:** This update consisted of using activity data provided by the Railway Association of Canada to determine proportions of RESD data reported under railways as being used in locomotives. Excess RESD data reported under railways was attributed to select subcategories associated with road vehicles and off-road vehicles/equipment that are likely used by railway companies. This update contributed to minor increases to emissions estimates for road vehicles and off-road vehicles/equipment but resulted in significant decreases to railway emissions estimates, ranging from 0% to 16% across the 1990–2022 time series.

- **Methodological update to modelled road vehicle populations:** This update consisted of using the latest vehicle registration data published by StatCan to inform emissions estimation for Road Transportation. This update had a negligible impact on reported Road Transportation emissions totals but had a notable impact on the distribution of activity data and emissions amongst its subcategories as well as select subcategories associated with off-road vehicles/equipment. The impacts of this update were most notable for Light-Duty Gasoline Vehicles and Other Transportation – Off-Road.

### 3.2.6.6. Planned Improvements

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

## 3.2.7. Other Sectors (CRT Category 1.A.4)

### 3.2.7.1. Category Description

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

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<sub>2</sub> as well as technology-dependent CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> and N<sub>2</sub>O emissions are included in the subcategory estimates, with CO<sub>2</sub> emissions reported separately in the CRT as memo items and not included in Energy sector totals.

In 2023, the Other Sectors category contributed 91.9 Mt (13%) of Canada's total GHG emissions, with an overall growth of about 6.9% (5.94 Mt) since 1990. Within the Other Sectors category, the Commercial/Institutional subcategory contributed 39.5 Mt (43%), the Residential subcategory contributed 35.8 Mt (39%), and the Agriculture/Forestry/Fishing subcategory contributed 16.6 Mt (18%). Since 1990, GHG emissions have grown by 29% (8.98 Mt) in the Commercial/Institutional subcategory and 38% (4.65 Mt) in the Agriculture/Forestry/Fishing subcategory, while GHG emissions in the Residential subcategory have declined by about 18% (7.68 Mt). Refer to [Table 3–8](#) for additional details. [Chapter 2](#) has further discussion of trends for the Other Sectors category.

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>OTHER SECTORS TOTAL (1.A.4)</b>	<b>86 000</b>	<b>94 200</b>	<b>102 000</b>	<b>104 000</b>	<b>96 400</b>	<b>93 600</b>	<b>97 300</b>	<b>91 900</b>
Commercial/Institutional	30 500	36 900	43 200	44 300	40 800	39 100	41 200	39 500
Commercial and Other Institutional	26 200	32 400	37 100	38 100	35 200	33 000	35 000	33 200
Off-road Commercial & Institutional	4 310	4 510	6 080	6 190	5 610	6 120	6 210	6 320
Residential	43 500	44 300	41 100	41 700	39 200	37 800	39 400	35 800
Stationary Combustion	43 200	43 100	40 100	40 700	38 200	36 900	38 600	35 000
Off-road Residential	368	1 230	1 030	1 030	970	920	850	840
Agriculture/Forestry/Fishing	12 000	12 900	17 600	17 600	16 400	16 700	16 600	16 600
Agriculture and Forestry	2 410	2 180	3 180	3 340	3 030	3 170	3 310	3 260
Off-Road Agriculture/Forestry/Fishing	9 570	10 740	14 390	14 310	13 380	13 500	13 310	13 360

Note: Totals may not add up due to rounding.

### 3.2.7.2. Methodological Issues

Emission calculations for these source categories use the methodology described in section A3.1.4.1, 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 (CRT 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), sludge gas from wastewater treatment, and digester gas from centralized anaerobic digesters, ECCC collects production volumes. CH<sub>4</sub> and N<sub>2</sub>O emissions from the combustion of LFG are included in this category, with CO<sub>2</sub> emissions excluded from totals and reported separately in the UNFCCC CRT as a memo item. In the case of waste incineration for energy purposes, ECCC collects consumption quantities of municipal solid waste and medical waste. See section A3.6.3 for further details. The CH<sub>4</sub> and N<sub>2</sub>O emissions from the biogenic portion of the waste are included, along with CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O combustion emissions from the non-biogenic portion of the waste. National GHG totals exclude CO<sub>2</sub> emissions from the biogenic portion of the waste; these numbers appear separately in the UNFCCC CRT 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 CRT categorization. Emissions from commercial and industrial lawn and garden maintenance, snow removal equipment, pumps, compressors, welders, and generator sets are also included here.

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

Emissions estimates in this category use RESD residential fuel-use data, except for biomass data which StatCan, ECCC and NRCan collect using a periodic stand-alone survey. Section A3.1.4.1.4 details the methodology for biomass combustion from residential firewood. The CH<sub>4</sub> and N<sub>2</sub>O emissions from firewood combustion are reported here, and CO<sub>2</sub> emissions, while not accounted for in the national residential GHG total, are reported as a memo item.

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

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

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

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

### 3.2.7.3. Uncertainty Assessment and Time-Series Consistency

The estimated uncertainty range for the Other Sectors category is  $\pm 3\%$  for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O combined and  $\pm 2\%$  for CO<sub>2</sub> alone.

The underlying fossil fuel quantities and non-biomass CO<sub>2</sub> emission factors have low uncertainties, since they are predominantly commercial fuels that have consistent properties and accurately tracked quantities, as compared to residential biomass data. As stated in section 3.2.4.3, additional expert elicitation will improve the associated CH<sub>4</sub> and N<sub>2</sub>O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions.

These estimates use the same methodology and are consistent over the time series. Section 3.2.7.5, 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. Any mathematical, referencing or data errors found during QC checks were corrected prior to publication. The data, methodologies, and changes related to the QC activities are documented and archived.

### 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 2022 revised downwards by 0.5 Mt CO<sub>2</sub> eq over the previous submission, because of:

- revised RESD data, including heavy fuel oil, kerosene & stove oil, natural gas, and propane, which affected 2005 to 2022 (emissions change ranged from -0.1 Mt in 2015 to +0.1 Mt in 2021);
- revised landfill gas, sludge gas, and digester gas data, which affected the entire time series (emissions change ranged from +0.005 kt to +0.6 kt);
- revised CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emission factors for residential firewood data, which affected the entire time series (emissions change ranged from -0.8 Mt in 1990 to -0.3 Mt in 2017); and
- revised off-road activity data between 1990 and 2022 because of revisions to off-road vehicles/equipment in operation, RESD data, the railways emission methodology, and road vehicle populations.

### 3.2.7.6. Planned Improvements

Although improvements were implemented to the RESD (refer to section 3.1.1), ECCC, NRCan, and StatCan continue to work jointly to improve the underlying quality of the national energy balance and to further disaggregate fuel-use information. Refer to 3.2.4.6 for more detail on the StatCan and the Trilateral Energy Working Group's activities.

Several updates to off-road emissions modelling inputs are also planned. Refer to 3.2.6.6 for further details.

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

The MPGs assign mobile military fuel combustion to CRT category 1.A.5.b. Emissions generated by military aviation are estimated by AGEM whereas emissions generated by military water-borne navigation are estimated by MEIT. As in previous submissions, emissions related to military vehicles have been included in the Transport category, whereas stationary military fuel use has been included in the Commercial/Institutional subcategory (section 3.2.7) in accordance with the RESD fuel data. See Table 3–9 for additional data.

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>OTHER (NOT SPECIFIED ELSEWHERE) TOTAL (1.A.5)</b>	<b>262</b>	<b>286</b>	<b>358</b>	<b>371</b>	<b>291</b>	<b>328</b>	<b>309</b>	<b>309</b>

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

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

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

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

In 2023, the Fugitive Emissions from Fuels category accounted for 68 Mt (10%) of Canada's total GHG emissions, with a 4.5% (3 Mt) growth in emissions since 1990. Fugitive emissions from oil and natural gas increased by 7.1% (4.5 Mt) and those from solid fuels decreased by 48% (-1.5 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 <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>FUGITIVE EMISSIONS FROM FUELS (1.B)</b>	<b>66 000</b>	<b>98 000</b>	<b>88 000</b>	<b>84 000</b>	<b>75 000</b>	<b>75 000</b>	<b>70 000</b>	<b>68 000</b>
<b>Solid Fuels – Coal Mining (1.B.1)</b>	<b>3 200</b>	<b>1 500</b>	<b>1 600</b>	<b>1 600</b>	<b>1 400</b>	<b>1 400</b>	<b>1 400</b>	<b>1 600</b>
a. Underground – Mining activities	1 700	100	190	190	80	NO	20	150
b. Abandoned Underground Mines	210	190	70	70	120	110	100	120
c. Surface – Mining activities	1 300	1 300	1 300	1 400	1 200	1 300	1 300	1 400
<b>Oil and Natural Gas (1.B.2)</b>	<b>62 000</b>	<b>96 000</b>	<b>86 000</b>	<b>83 000</b>	<b>73 000</b>	<b>73 000</b>	<b>69 000</b>	<b>67 000</b>
a. Oil <sup>a</sup>	4 700	7 200	8 100	8 200	7 800	7 800	8 000	8 000
b. Natural Gas <sup>a</sup>	11 000	13 000	9 000	9 000	9 000	8 000	8 000	8 000
c. Venting and Flaring <sup>b</sup>	47 000	76 000	69 000	66 000	57 000	57 000	53 000	51 000
i. Venting	42 000	70 000	63 000	60 000	51 000	50 000	46 000	43 000
ii. Flaring	5 360	5 270	6 000	5 800	6 380	6 990	7 040	7 530

## Notes:

NO = Not occurring

Totals may not add up due to rounding.

a. All other fugitives except venting and flaring.

b. Both oil and gas activities.

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

#### 3.3.1.1. Category Description

Canada's fugitive emissions from the solid fuels category are inclusive of active surface and underground coal mines along with abandoned underground mines. Combustion emissions in CRT category 1.A.2.a., include fugitive emissions from coke manufacturing (flaring). Other sources of solid fuel transformation emissions are unknown and assumed insignificant.

#### Coal Mining and Handling

Sources of mining emissions include exposed coal surfaces, coal rubble, and the venting of CH<sub>4</sub> from within the deposit. Post-mining activities such as preparation, transportation, storage, and final processing prior to combustion also release CH<sub>4</sub>. In 2023, emissions from active surface and underground mines contributed 84% (1.4 Mt) and 9% (0.15 Mt), respectively. No underground coal mines were operating in 2021.

#### 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 2023, emissions from abandoned mines were approximately 120 kt CO<sub>2</sub> eq.

#### Solid Fuel Transformation

Solid fuel transformations include activities such as the production of charcoal briquettes, or activated carbon, from coal. There is currently only one facility in Canada engaged in this activity and reliable data was only available for a year when the plant's peak production of 100 kt occurred. Using the default IPCC EF values of 1,570 g CO<sub>2</sub>/kg and 40.3 g CH<sub>4</sub>/kg from IPCC guidelines (IPCC, 2019 vol. 4, chap. 4.3.2.1, p.4.103), this source would produce approximately 260 kt CO<sub>2</sub> eq. This is below the reporting threshold of 0.05% of Canada's national total emissions, and below 500 kt CO<sub>2</sub> eq, so in accordance with the latest reporting requirements (MPGs), an NE notation key is reported in the CRT for this source.

#### 3.3.1.2. Methodological Issues

#### Coal Mining and Handling

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

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

In late February 2014, a field-testing campaign measured fugitive emissions of CH<sub>4</sub>, CO<sub>2</sub>, 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<sub>4</sub>) 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<sub>4</sub> 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<sub>2</sub> emissions from flaring or drainage activities at any mine in Canada.

## Abandoned Underground Mines

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

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

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

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

### 3.3.1.3. Uncertainty Assessment and Time-Series Consistency

#### Coal Mining and Handling

The estimated range of CH<sub>4</sub> 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<sub>4</sub> 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. Any mathematical errors found during QC checks were corrected prior to publication. All QC activities, data and methods are documented and archived.

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

### 3.3.1.5. Recalculations

#### Coal Mining and Handling

Corrections to gross production volumes for Alberta and updates for Nova Scotia resulted in recalculations. StatCan's new coal mine data capture process excluded production from one mine due to a coding error. Corrected activity data was then compared with provincial statistics as coal mine reports directly to both provincial and federal agencies. Updates to activity data for the Coal Mining and Handling sector resulted in revisions, with a maximum decrease of around -140 kt in 2022 and an increase of 80 kt in 2018.

#### Abandoned Underground Mines

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

### 3.3.1.6. Planned Improvements

#### Coal Mining and Handling

No improvements are currently planned for this category.

#### Abandoned Underground Mines

No improvements are currently planned for this category.

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

### 3.3.2.1. Category Description

Fugitive emissions in the Oil and Natural Gas category include emissions from oil and gas production, processing, oil sands mining, bitumen extraction, in-situ bitumen production, heavy oil/bitumen upgrading, abandoned oil and gas wells, petroleum refining, natural gas transmission and storage, natural gas distribution, and post-meter fugitives from natural gas consumption. Fuel combustion emissions from facilities in the oil and gas industry (when used for energy) are included under the Petroleum Refining, Manufacture of Solid Fuels and Other Energy Industries, and Pipeline Transport subcategories.

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

#### Upstream Oil and Gas

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

The emission sources fall into these major groups.

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

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

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

**Light/Medium Oil Production:** Light and medium crude oils have a density of less than 900 kg/m<sup>3</sup>. 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<sup>3</sup>. Production of this viscous liquid requires special infrastructure. There are generally two types of heavy oil production systems: primary and thermal. The emission sources for both types are wells, flow lines, batteries (single and satellite) and cleaning plants. The largest source is venting of casing and solution gas.

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

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

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

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

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

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

## Abandoned Oil and Gas Wells

Oil and gas wells are required to be plugged with cement prior to abandonment to prevent both gas leakage from the well and migration of oil and gas to the surrounding strata. Despite the well abandonment regulations, wells exist that were not properly decommissioned. This occurs for several reasons, including abandonment prior to the enactment of regulations and bankruptcy of the well owner. While emissions arise from both plugged and unplugged wells, emissions from unplugged wells are significantly higher than from plugged wells. [Table 3–11](#) presents emission estimates from abandoned oil and gas wells.

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>ABANDONED OIL AND GAS WELLS</b>	<b>170</b>	<b>320</b>	<b>590</b>	<b>600</b>	<b>610</b>	<b>600</b>	<b>560</b>	<b>570</b>
Abandoned Oil Wells <sup>a</sup>	90	140	290	300	310	300	280	280
Abandoned Gas Wells <sup>b</sup>	80	180	290	300	300	300	280	290

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

## Oil Sands / Bitumen

This component includes emissions from open pit mining operations and heavy oil/bitumen upgrading to produce synthetic crude oil and other derived products for sale. Fugitive emissions are primarily from hydrogen production, flue gas desulphurization (FGD), venting and flaring activities, storage and handling losses, fugitive equipment leaks, and CH<sub>4</sub> from the open mine surfaces and from methanogenic bacteria in the mine tailings settling ponds.

## Downstream Oil and Gas

Downstream oil and gas includes all fugitive emissions from petroleum refining and natural gas distribution to end consumers, including fugitive emissions at the point of consumption (post-meter fugitives). Reported emissions fall into the three major groups described below.

**Petroleum Refining:** There are three main sources of fugitive emissions from refineries: process, unintentional fugitive, and flaring. Process emissions result from the production of hydrogen as well as from process vents. Unintentional fugitive emissions result from equipment leaks, wastewater treatment, cooling towers, storage tanks, and loading operations. Flaring emissions result from the combustion of hazardous waste gas streams (such as acid gas and still gas) and natural gas. The Energy Industries category reports GHG emissions from the combustion of fuel for energy purposes.

**Natural Gas Distribution:** The natural gas distribution system receives high-pressure gas from the gate of the transmission system, reduces the pressure, and distributes the gas through underground gas mains and service lines to the end user. Emission sources include leaks from pipelines, metering and regulating stations, leaks from damaged lines, meters and short-term surface storage.

**Post-Meter Fugitives:** This segment includes fugitive emissions downstream of residential, commercial and industrial gas meters and from natural gas-fueled vehicles. Emission sources include leakage from internal piping and the end-of-pipe appliances (e.g., space heating, water heating, stoves, dryers, etc.). Emissions from start-stop-losses of appliances and combustion of gas are not included as they are part of fuel combustion estimates. Emissions for natural gas-fueled vehicles include releases during fueling, emptying of gas cylinders at high-pressure interim storage units for pressure tests, and leaks from vehicles' fuel tanks for pressure tests or decommissioning. [Table 3–12](#) presents emission estimates from post-meter fugitives.

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>Post-Meter Fugitives<sup>a</sup></b>	<b>1 200</b>	<b>1 600</b>	<b>1 900</b>	<b>2 000</b>	<b>2 000</b>	<b>2 000</b>	<b>2 100</b>	<b>2 100</b>
Natural gas appliances in residential and commercial sectors	1 000	1 400	1 600	1 600	1 700	1 700	1 700	1 700
Natural gas fueled vehicles	0.04	0.01	0.02	0.02	0.02	0.03	0.03	0.03
Power plants and industrial facilities consuming natural gas	250	260	320	330	320	350	370	400
<b>Notes:</b> Totals may not add up due to rounding. a. Included in CRT category 1.B.2.b – Fugitive emissions from fuels – Oil and natural gas – Natural Gas								

### 3.3.2.2. Methodological Issues

#### 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 reported venting and flaring emissions in Alberta and Saskatchewan, offshore flaring in Newfoundland and Labrador (see section A3.2.2.1.2), and surface casing vent flow emissions in Alberta and British Columbia (see 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 section A3.2.2.1.3.

**Atmospheric measurements:** source-resolved methane emission inventories, derived using atmospheric measurements, are the basis used to estimate emissions from storage tanks, compressor buildings, and unlit flares in British Columbia, Alberta and Saskatchewan, engine sheds in Alberta and Saskatchewan, and wellheads in Saskatchewan. The measurement-based methane estimates were developed by the Energy and Emissions Research Laboratory (EERL) at Carleton University using the results of aerial measurement campaigns conducted during 2020 in Saskatchewan and 2021 in all three western provinces (Conrad; 2023a, b; Johnson et al., 2023). For a full description of how atmospheric measurements are integrated into the inventory, see section A3.2.2.1.5.

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

Interpolated or extrapolated fugitive emission estimates for the UOG industry use information in two separate studies that follow the same methodology. The Canadian Association of Petroleum Producers' (CAPP) study titled *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H<sub>2</sub>S) 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<sub>2</sub> 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. 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<sub>4</sub> 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 section A3.2.2.6, for more details.

## Natural Gas Transmission and Storage

Fugitive emissions from venting, flaring, and spills/pipeline ruptures in the natural gas transmission sector for 1990–1996 are taken from the study titled *CH<sub>4</sub> and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP, 1999). This study follows a rigorous IPCC Tier 3 approach in estimating GHG emissions. Fugitive emission estimates for 1997–1999 were derived based on length of natural gas pipeline and emission rates developed using results from the original study. 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 2012–2022 following an IPCC Tier 3 approach. Emission estimates for 2023 are derived using length of natural gas transmission pipeline and the amount of gas deposited into and withdrawn from storage.

Between 2004 and 2011 and from 2015 onwards, emissions from equipment leaks, compressor seals, and pneumatic devices are estimated following the methodology described in the preceding paragraph. For the period between 1990 and 2003, emissions are based on CAPP (1999) with revised equipment leak estimates for the year 1995, and a combination of interpolation and extrapolation approaches. Equipment leak, compressor seal, and pneumatics emissions are also interpolated in 2012–2014, which addresses specific methodological consistency issues in the CEPEI reported data. Section A3.2.2.2 details the complete methodology.

## Oil Sands/Bitumen

Fugitive GHG emissions from oil sands mining, bitumen extraction and heavy oil/bitumen upgraders are developed based on two reports.

- *An Inventory of GHGs, CACs and H<sub>2</sub>S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP, 2006), prepared by Clearstone Engineering Ltd. (referred to here as the bitumen study).
- *An Inventory of GHGs, CACs and Other Priority Emissions by the Canadian Oil Sands Industry: 2003 to 2015* (ECCC, 2017a), prepared by Clearstone Engineering Ltd. (referred to here as the oil sands study).

Each operator in the oil sands mining and upgrading industry used an IPCC Tier 3 approach to develop detailed emission estimates. A review of facility inventories ensured that all estimates were complete, accurate and transparent. The completed QA/QC and an uncertainty analysis followed IPCC Good Practice Guidance (IPCC, 2000).

The bitumen study (CAPP, 2006) is the basis for the 1990–2003 fugitive emissions estimates, and the oil sands study (ECCC, 2017a) is the basis for the 2004–2023 fugitive emission estimates. An oil sands estimation model (referred to here as the oil sands model) allows annual updating of fugitive emissions from oil sands mining and bitumen/heavy oil upgrading activities from 2003 onwards. The oil sands model was developed using relevant parameters and results from the oil sands study, along with annual activity data. The activity data required by the model comes from the following sources: *Alberta Mineable Oil Sands Plant Statistics* by the Alberta Energy Regulator (AER, 1990–) and annual reports for the Lloydminster Upgrader (Cenovus, 2021–2024; Husky, 1998–2019). Section A3.2.2.5 also presents a summary of the estimation method of the oil sands model.

Emissions for oil sands facilities not included in the oil sands study, such as the Horizon Liquid Extraction Plant and the Fort Hills Mine, were estimated using emission factors from similar facilities or emission data reported to the GHGRP. See section A3.2.2.5 for more details.

The Scotford upgrader operated by Shell Canada Energy began capturing CO<sub>2</sub> emissions from its hydrogen production plant in 2015. The CO<sub>2</sub> venting emission for this facility exclude the captured CO<sub>2</sub> that is transported and injected into storage.

## Downstream Oil and Gas Production

Fugitive emissions from refineries are calculated using information contained in the Canadian Petroleum Products Institute (CPPI) study, *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI, 2004). Refer to the CPPI report for full details on the study. The Canadian Energy and Emissions Data Centre (CEEDC) and Canadian refineries provided historical fuel, energy and emission data, for the years 1990 and 1994–2002. 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. Section A3.2.2.3 provides a detailed description of the methodology used to estimate emissions from 1991 to 1993 and 2003 onward.

## Natural Gas Distribution

The emission estimates for the 1990–1999 period was derived from a study prepared for the Canadian Gas Association (CGA, 1997). The study estimated the emissions from the Canadian gas distribution pipeline industry, for the years 1990 and 1995, using an IPCC Tier 3 approach. Emissions in the study were calculated using emission factors from the U.S. EPA, other published sources and engineering estimates. The activity data in the study came from published sources and specialized surveys of gas distribution companies. The surveys obtained information on schedules of equipment, operation parameters of equipment, pipeline lengths used in the Canadian distribution system, etc. In the year 2000, the Gas Research Institute (GRI) reviewed and revised the 1997 CGA study, with more accurate and better-substantiated data for station vents (GRI, 2000). General emission factors were developed for the distribution system using the study data (CGA, 1997; GRI, 2000) and the gas distribution pipeline distances by province provided by StatCan.

For the year 2000 onwards, 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 2012–2022 following an IPCC Tier 3 approach.

ECCC determined the equipment leak estimates in the CGA (1997) and GRI (2000) studies did not accurately represent Canada's natural gas distribution sector, since country-specific EFs had not yet been developed at the time of their publication. To provide representative estimates and a consistent time series, equipment leak emissions were backcasted for 1990–2004 from the 2005 estimates in the UOG study (EC, 2014) using pipeline length as activity data. Historical equipment leak emissions from cast-iron pipelines are also estimated using a generalized EF from CEPEI (2016), and are included for years prior to the phase out of cast-iron as a pipeline material in Canada. Similar to the gas transmission sector, equipment leaks for 2012–2014 were interpolated to address a known methodological discontinuity in the CEPEI reported emissions in 2015.

Emissions for all sources in 2023 are estimated using the length of natural gas distribution pipeline. Section A3.2.2.4 presents more details on the methodology used to estimate fugitive emissions from natural gas distribution systems.

## Post-meter Fugitives

Emission estimates for post-meter fugitives from residential and commercial natural gas appliances, natural gas-fueled vehicles and industrial consumption of natural gas use an IPCC Tier 1 approach. IPCC Tier 1 emission factors were modified to reflect Canadian marketable natural gas compositions.

The number of residential natural gas appliances was taken from data published by NRCan (2022) for the years 2000–2020 by province/territory. Appliance counts for 1990–1999 and 2021–2023 were extrapolated based on the annual change in the number of residential natural gas customers by province. NRCan appliance count data was modified as necessary to reflect real-world conditions such as the lack of natural gas distribution systems in Prince Edward Island and Newfoundland and Labrador and unrealistic average appliance counts in New Brunswick, Nova Scotia and Northwest Territories. The number of commercial natural gas appliances were estimated based on the annual number of commercial natural gas customers by province/territory and the national average number of residential appliances per customer.

ECCC internal vehicle fleet statistics provided the number of natural gas-fueled vehicles for each province and year.

Natural gas consumption data from the RESD was used to estimate post-meter fugitives from industrial consumption of natural gas. Since fugitive emissions at oil and gas facilities are already estimated using the methods discussed previously, any natural gas consumption occurring at oil and gas facilities was excluded from the post-meter fugitive emissions calculations.

See section A3.2.2.7 for more details.

### 3.3.2.3. Uncertainty Assessment and Time-Series Consistency

#### Upstream Oil and Gas

The overall uncertainty for the 2023 upstream oil and gas fugitive emissions is -4.0% to +6.0%. Table 3–13 lists the uncertainties for specific oil and gas categories. Accidents and equipment failures, post-meter fugitives, and abandoned oil and gas wells, have the highest uncertainty, while oil production and transport have the lowest uncertainty.

Table 3–13 <b>Uncertainty in Oil and Gas Fugitive Emissions (Excluding Petroleum Refining)</b>				
Industry Segment	GHG Source Category Uncertainty (%)			
	Flaring	Fugitive	Venting	Total
Oil Production and Transport	-7.1 to +7.2	-8.3 to +12.4	-7.9 to +9.4	-5.7 to +6.9
Oil Sands Mining and Bitumen / Heavy Oil Upgrading	-23.4 to +23.5	-30.8 to +34.1	-28.9 to +29.6	-19.0 to +19.8
Gas Production / Processing	-4.6 to +4.7	-1.4 to +2.1	-8.4 to +16.2	-6.0 to +11.6
Gas Transmission, Storage and Distribution	-14.4 to +17.9	-15.7 to +17.4	-11.1 to +12.8	-9.8 to +10.9
Accidents and Equipment Failures	—	± 28.2	—	± 28.2
Well Drilling, Servicing and Testing	-23.2 to +19.3	-24.7 to +28.2	-17.9 to +32.3	-19.2 to +16.6
Abandoned Oil and Gas Wells	—	-39.0 to +58.1	—	-39.0 to +58.1
Post-meter Fugitives	—	± 28.1	—	± 28.1

The uncertainties were determined using the Tier 1 uncertainty approach presented in the IPCC Good Practice Guidance (IPCC, 2000). According to the IPCC (2000), there are three sources of uncertainties: definitions, natural variability of the process that produces the emissions, and the assessment of the process or quantity. The analysis considered only the last two sources of uncertainty; uncertainties from the definitions are assumed negligible, as they were adequately controlled through QA/QC procedures.

Oil Sands/Bitumen

The overall uncertainty for the 2022 oil sands/bitumen fugitive emissions is -19.0% to +19.8%. 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, 2017a). Table 3–13 shows the aggregation of facility-level uncertainties by emission sources.

Downstream Oil and Gas

The CPPI (2004) study provides the data used in the inventory for fugitive emissions from refineries for 1990 and for 1994–2002. There is greater uncertainty for the 1991–1993 and 2003–2023 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<sub>2</sub> 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 3–14 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 there were no errors, omissions or double counting. Then, individual companies reviewed and commented on the report. The project steering committee and nominated experts performed a second level of review. Where possible, results were compared with previous baseline data and other corporate, industrial and national inventories. Any anomalies were verified through examination of activity levels, changes in regulations, and voluntary industry initiatives.

The review of the methodology and parameters used to model fugitive emissions from pneumatic devices, compressor seals, and equipment leaks included several steps. It began with the completion of two third-party technical reviews of the updated modelling approach through contracts with Navius Research Inc. and Clearstone Engineering Ltd. Reviewers provided feedback on the underlying assumptions, parameters, and emission factors. The purpose of these expert reviews was not to receive validation of modelled estimates, but rather to assess the approach and to highlight areas for potential improvements. Then, in July 2021, provincial governments received a presentation of the updated methodology and comments were solicited. Within ECCC, internal reviews conducted in collaboration with the Oil, Gas and Alternative Energy Division of the Environmental Protection Branch, included QA/QC and verification of calculated model parameters and emission factors.

Methane emission estimates derived from atmospheric measurements for Canada’s main oil and gas producing provinces of Alberta, British Columbia and Saskatchewan (Chan et al., 2020; Conrad et al., 2023a, b; Johnson et al., 2023) were compared against inventory estimates to verify emission levels and trends.

### 3.3.2.5. Recalculations

Fugitive emissions from oil and natural gas were revised for the 1990–2022 period because of changes to activity data and methodologies. See [Table 3–2](#) for a summary of the impact of the recalculations.

CH<sub>4</sub> emissions from UOG sources estimated using atmospheric measurements (compressor buildings, engine sheds, storage tanks, unlit flares, and wellheads) were recalculated for the year 2022. Previously, these estimates were based only on measurement data for 2020 (Saskatchewan only) and 2021. The addition of 2023 measurement data and interpolation of 2022 emissions resulted in changes to venting estimates, which were revised downward by -0.7 Mt (-18%) in British Columbia, -0.9 Mt (-2.9%) in Alberta, and -0.6 Mt (-4.3%) in Saskatchewan. For a full description of the methodology and how atmospheric measurements have been incorporated for the UOG sector, see section A3.2.2.1.5.

The reconciliation procedure applied to reported venting emissions in the Saskatchewan UOG sector was updated for the period from 2020 to 2022. Previously, modelled emissions from compressor seals were subtracted from reported venting estimates to align definitionally with provincial reporting requirements (detailed in section A3.2.2.1.6), and to mitigate double-counting when including measurement-based compressor building fugitives. However, this compressor seal emissions are no longer subtracted for 2020 onwards as the modelled estimates cannot be reconciled with reported venting emissions at the UOG sub-sector level. Further delineation of reported vent volumes by source would be necessary to correctly reconcile reported venting estimates with atmospheric measurements, but such information is not currently available for Saskatchewan.

Additional methodological improvements resulted in recalculations with various impacts for the UOG sector. Alberta equipment leak estimates were revised downward for 2022 due to higher reported operator compliance with provincial leak detection and repair requirements. Improvements to model parameters used to estimate emissions from pneumatic devices in British Columbia resulted in upward revisions from 1990 to 2020. And in a separate improvement, the methodology for British Columbia formation CO<sub>2</sub> emissions was updated to incorporate annual changes in the composition of produced natural gas in the province. As a result, formation CO<sub>2</sub> estimates were revised upwards in 2013 and downwards from 2014 to 2022.

The methodologies for the gas transmission, gas storage, and gas distribution sectors have been updated to directly incorporate operator reported fugitive emissions data from 2015 onwards. Historical estimates were also updated to utilize more accurate EFs for equipment leaks and to account for the gradual phase out of cast-iron piping. For a full description of the new methodologies, see sections A3.2.2.2 and A3.2.2.4.

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

- **Oil:** recalculations due to methodological changes and updated activity data resulted in downward revisions in all years, ranging from -5.7 kt (-0.1%) in 2019 to -56 kt (-0.7%) in 2022.
- **Natural Gas:** recalculations cumulatively resulted in downward revisions from 1990 to 2000 and from 2012 to 2022 for the natural gas category, ranging from -174 kt (-1.5%) in 2012 to -3.8 Mt (-25.4%) in 1999. Upward revisions occurred from 2001 to 2011, of which the maximum was +1.2 Mt (+11.7%) in 2002.
- **Venting:** cumulatively, recalculations due to all methodological updates resulted in upward revisions to venting emissions for 1990 to 2015, with changes ranging from +117 kt (+0.3%) in 1990 to +885 kt (+1.2%) in 2013. Downward revisions occurred in the remaining years and ranged from -151 kt (-0.2%) in 2016 to -3.4 Mt (-7.0%) in 2022.
- **Flaring:** recalculations due to methodological changes and updated activity data resulted in upward revisions in all years. Revisions were minor (<1.0%) from 1990 to 2020, with a maximum change of +184 kt (+2.7%) in 2022.

### 3.3.2.6. Planned Improvements

#### Upstream Oil and Gas

Various items have been identified to improve the accuracy of fugitive oil and gas emission estimates.

- Additional source-level estimates derived from atmospheric measurements of CH<sub>4</sub> in Alberta, British Columbia, and Saskatchewan may be incorporated to further refine emission estimates. Similar methodological updates may be implemented for Manitoba, once results of aerial surveys in the province become available.
- Raw gas composition data collected by the British Columbia Energy Regulator (BCER) will be analyzed and assessed for incorporation into fugitive emission estimates from oil and gas facilities in British Columbia.
- Data reported to British Columbia's industrial GHG reporting program and Alberta's OneStop reporting system will be analyzed to potentially improve emission estimates from equipment leaks, enabling modelled estimates to track the impact of Leak Detection and Repair (LDAR) programs.
- Recent field studies have expanded geographic coverage and improved source attribution of measured emissions from abandoned and inactive wells in Canada. New EFs derived from these studies are being evaluated for incorporation into emission estimates.

## Downstream Oil and Gas

Work is underway to evaluate data collected under ECCC's expanded GHG Reporting Program for the purpose of improving the quality of petroleum refining fugitive emissions (flaring, venting, and other unintentional leaks).

### 3.4. CO<sub>2</sub> Transport and Storage (CRT Category 1.C)

This section presents information on existing commercial operations involved in carbon capture, transport, use, and storage (CCTUS) and their associated CO<sub>2</sub> emissions. Currently, CCTUS includes the capture of anthropogenic CO<sub>2</sub> from industrial processes or combustion and its transport to a long-term storage (LTS) facility or enhanced oil recovery (EOR) operation. Table 3–15 summarizes existing sources of CO<sub>2</sub> captured, and transported, in Canada: CO<sub>2</sub> imported from the Dakota Gasification Company in North Dakota, United States; and domestically captured CO<sub>2</sub> from SaskPower's Boundary Dam power station, in Saskatchewan and Shell's Scotford bitumen upgrader, Agrium's fertilizer plant and North-West Redwater Partnership's Sturgeon refinery, in Alberta. Table 3–15 also summarizes the annual, and cumulative, final disposition of CO<sub>2</sub> imported to, or captured in, Canada: whether used for EOR or injected into long-term storage.

In 2023, fugitive CO<sub>2</sub> emissions from the four active pipelines and four capture sites were approximately 36.9 kt, as shown in Table 3–16. Of the four pipelines in Canada, three currently transport only CO<sub>2</sub> used for EOR. Any fugitive emissions from projects that use CO<sub>2</sub> injection to enhance oil production appear in subcategories 1.B.2.a.2 oil – production, 1.B.2.c.1.i venting – oil and 1.B.2.c.2.i flaring – oil in the reporting tables.

The net impacts of GHG emissions from all capture activities are included in Canada's inventory as part of the Energy Industries (1.A.1), Oil and natural gas and other emissions from energy production (1.B.2), CO<sub>2</sub> Transport and Storage (1.C) and Ammonia Production (2.B.1) categories.

	CO <sub>2</sub> Quantity (kt of CO <sub>2</sub> )							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>CAPTURED CO<sub>2</sub> SOURCE</b>								
Imported	NO	2 010	1 580	1 760	1 590	1 670	1 600	1 070
Domestic Capture – Total	NO	NO	1 690	1 740	2 660	2 780	2 810	3 320
Energy Industries (1.A.1)	NO	NO	630	620	730	440	750	790
Oil, Natural Gas (1.B.2)	NO	NO	1 070	1 130	1 760	2 200	1 900	2 290
Ammonia Production (2.B.1)	NO	NO	NO	NO	170	140	160	250
<b>CAPTURED CO<sub>2</sub> USE AND STORAGE</b>								
Enhanced Oil Recovery	NO	2 010	2 090	2 310	3 200	3 310	3 310	3 240
Cumulative EOR <sup>a</sup>	NO	8 930	36 900	39 000	41 300	44 500	47 800	51 100
Long-term Geologic Storage	NO	NO	1 140	1 200	1 020	1 100	1 070	1 090
Cumulative LTS <sup>b</sup>	NO	NO	2 740	3 880	5 070	6 090	7 190	8 260
Notes: Total quantities for capture source, and use and storage, may not be equal due to rounding. NO = Not occurring a. Cumulative EOR = On January 1st of the year, the total historic volume used for enhanced oil recovery (EOR). b. Cumulative LTS = On January 1st of the year, the total historic volume injected into long-term storage (LTS).								

GHG Source Category	CO <sub>2</sub> Emissions (kt of CO <sub>2</sub> )							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>CO<sub>2</sub> EMISSIONS FROM TRANSPORT AND STORAGE (1.C)</b>	<b>NO</b>	<b>0.09</b>	<b>0.28</b>	<b>57.9</b>	<b>109</b>	<b>30.9</b>	<b>36.0</b>	<b>36.9</b>
CO <sub>2</sub> Pipeline (1.C.1)	NO	0.09	0.27	0.27	109	30.8	36.0	36.9
CO <sub>2</sub> Injection Site (1.C.2)	NO	NO	0.01	57.6	0.06	0.06	0.05	0.04
Note: NO = Not occurring								

### 3.4.1. Captured CO<sub>2</sub> Usage

Currently, commercial use of the captured CO<sub>2</sub> presented in this category includes only EOR or direct injection into LTS. In the future, captured CO<sub>2</sub> may be used, and permanently stored, in a much wider range of approved sites and products, such as cement and agriculture, and these volumes will appear in the 1.C category at that time.

#### 3.4.1.1. Captured CO<sub>2</sub> Usage – Enhanced Oil Recovery

In Canada, imported CO<sub>2</sub> and CO<sub>2</sub> captured at a coal-fired power plant in Saskatchewan, and from fertilizer and refinery production in Alberta, are used as an EOR flooding agent to increase crude oil production at three oil reservoirs. This CO<sub>2</sub> acts as a solvent and increases reservoir pressure, loosening and moving trapped hydrocarbons to production wells. The high-pressure flooding process also traps CO<sub>2</sub> in the voids previously occupied by hydrocarbon molecules. In the future, when oil production stops, the reservoirs will provide long-term geological storage of CO<sub>2</sub>.

In Saskatchewan, CO<sub>2</sub> flooding started in 2000 at the Weyburn site, currently operated by Whitecap Resources Inc, and in 2005 at the nearby Midale site, currently operated by Cardinal Energy Ltd, with the goal of extending reservoir life by 30 years. Carbon dioxide, purchased from the Dakota Gasification Company located in North Dakota and SaskPower's Boundary Dam coal-fired power station, arrives via pipeline. By the end of 2023, the Boundary Dam facility had captured approximately 787 kt of CO<sub>2</sub> for shipment to the Weyburn site (SaskPower, 2024). While total annual injection volumes at this reservoir include the fresh supply of CO<sub>2</sub> and the recovered CO<sub>2</sub> from previous flooding cycles, Canada only reports the yearly fresh supply. The current CO<sub>2</sub> injection rate at the Weyburn-Midale operations is about 2 Mt per year, and from 2000 to 2022 the Weyburn and Midale sites have injected over 45 Mt of new CO<sub>2</sub>.

In addition to being an EOR operation, Weyburn was the site of a full-scale geological CO<sub>2</sub> storage research program led by the International Energy Agency's Greenhouse Gas Research and Development Programme (IEAGHG) with the support of various industries, research organizations and governments. The IEA Weyburn-Midale research project focused on developing a best practice manual for future geological CO<sub>2</sub> storage projects.

Modelling and simulation results from the first phase (2000 to 2004) of the IEAGHG's CO<sub>2</sub> monitoring and storage project, managed by the Petroleum Technology Research Centre (PTRC), indicate that, after EOR operations are completed, over 98% of CO<sub>2</sub> will remain trapped in the Weyburn reservoir after 5000 years, with only 0.14% of the remainder released to the atmosphere (Mourits, 2008). Soil gas sampling campaigns were conducted yearly between 2000 and 2006, and again in 2011. This protracted monitoring of soil gas geochemistry at the Weyburn oil field found no evidence of leakage of the injected CO<sub>2</sub> to the surface (Lawton, et al., 2021). Additional details on the findings of the research project are available on the PTRC website.

Whitecap Resources Inc. has an ongoing Measurement, Monitoring and Verification (MMV) program at the Weyburn EOR site. While looking at a broad range of potential emission sources, the program specifically looks for any leakage from the site using methods, such as shallow aquifer regional fluid characterization that employs isotope and chemical water tests to confirm that injected CO<sub>2</sub> is not appearing in surface water, and 4D Seismic testing to evaluate CO<sub>2</sub> in-zone conformance and verify no vertical migration to the surface (Whitecap Resources, 2018).

Cardinal Energy Ltd. has an ongoing MMV program at the Midale EOR site. In 2022, Cardinal Energy had their previously sequestered CO<sub>2</sub> volumes verified by an independent third party (Cardinal Energy, 2023).

Enhance Energy Inc. operates the Clive Leduc Field EOR site in central Alberta and has a monitoring program mandated by the Alberta government's Ministry of Environment and Parks that is described in available quantification documents (AEP, 2022). This comprehensive monitoring plan involves testing in the hydrosphere, biosphere and atmosphere with the goal of assuring that CO<sub>2</sub> is contained within the working formation (Enhance Energy, 2019). The plan includes seismic testing, monitoring wells in the production and overlying formations, soil gas surveys, water well surveys, injection well pressure monitoring and CO<sub>2</sub> isotope measurements. The unique isotope composition of the injected CO<sub>2</sub>, and H<sub>2</sub>S present in the working formation, will make any leakage from the formation readily observable. In addition, the presence of many coal bed methane (CBM) wells in the area provides an additional opportunity to test for the presence of the unique isotope profiles in the injected CO<sub>2</sub> outside of the working formation.

As of 2023, on-going monitoring, measurement and verification programs show no evidence that CO<sub>2</sub> from any of the current EOR sites has leaked to nearby formations or the atmosphere.

#### 3.4.1.2. Captured CO<sub>2</sub> Usage – Long-term Storage Injection

Canada has two operational long-term storage (LTS) sites, the Quest CCS facility operated by Shell Canada and the Aquistore Deep Saline CO<sub>2</sub> Storage Project operated by PTRC near Estevan, Saskatchewan. Both sites began injecting CO<sub>2</sub> in 2015 with Quest having injected approximately 7.5 Mt and Aquistore approximately 500 kt, by 2022.

The Alberta government's Ministry of Environment and Parks has extensive quantification and MMV requirements related to carbon sequestration (AEP, 2023). The Quest CCS facility has a monitoring plan that tests the hydrosphere, biosphere and atmosphere with the goal of assuring that CO<sub>2</sub> is contained within the working formation. As per, *Quest Carbon Capture and Storage Project Annual Summary Report - Alberta Department of Energy: 2022 MMV*, "activities are focused on operational monitoring and optimization and MMV data indicate that no CO<sub>2</sub> has migrated outside of the Basal Cambrian Sands (BCS) injection reservoir to date" (Shell Canada Energy, 2023).

The Aquestore storage site has a range of technologies installed on the surface, shallow subsurface and deep subsurface, along with seismic monitoring and isotope measurements (Aquestore, 2015). The MMV process includes groundwater and soil-gas monitoring, on-going seismic measurements and down-hole monitoring of a temperature, pressure and fluid composition. Any changes to monitored characteristics would indicate possible leakage from the storage formation.

As of 2023, on-going monitoring, measurement and verification programs show no evidence that CO<sub>2</sub> from any of the current long-term sites has leaked to nearby formations or the atmosphere.

### 3.4.2. Transport of CO<sub>2</sub> – Pipelines (CRT Category 1.C.1.a)

Two CO<sub>2</sub> pipelines transport captured CO<sub>2</sub> from the Dakota Gasification Company's Great Plains Synfuels Plant in North Dakota (CO<sub>2</sub> import began 2000) and SaskPower's Boundary Dam Power Station near Estevan (CO<sub>2</sub> capture began November 2014) to the Weyburn and Midale EOR sites near Weyburn, Saskatchewan.

A pipeline associated with Shell Canada's Quest CCS project moves captured CO<sub>2</sub> from the Scotford upgrader, near Edmonton, Alberta, to Quest's LTS site north-east of the city.

The Alberta Carbon Trunk Line (ACTL) became active in 2020 and transports CO<sub>2</sub> captured at the Agrium fertilizer plant and Sturgeon refinery, near Edmonton, Alberta, to the Clive Leduc EOR site, operated by Enhance Energy Inc., in central Alberta.

#### 3.4.2.1. Category Description

The source is fugitive emissions from pipeline systems used to transport CO<sub>2</sub> to injection sites.

#### 3.4.2.2. Methodological Issues

The 2006 IPCC Guidelines provide a Tier 1 methodology for emissions from pipeline transport of CO<sub>2</sub>. Pipeline lengths from both the Canada/United States border to the EOR facilities at Weyburn and from Boundary Dam to Weyburn are both approximately 60 km. The pipeline length between the Scotford refinery and the associated long-term geological storage site is about 80 km. The pipeline length between the Agrium and Sturgeon facilities, and the associated EOR site, is approximately 240 km. Emission calculations use the IPCC default medium emission factor of 0.0014 kt CO<sub>2</sub>/km pipeline length/year.

#### 3.4.2.3. Uncertainty Assessment and Time-Series Consistency

Uncertainty estimates for emissions from CO<sub>2</sub> pipelines use 2006 IPCC Tier 1 defaults of +200% to -50% (± a factor of 2). For emission estimates based on facility reported volumes, it is expected that the overall uncertainty of CO<sub>2</sub> volumes at the gate is within +/- 3% due to metering standards.

#### 3.4.2.4. QA/QC and Verification

Estimates underwent QC checks consistent with the 2006 IPCC Guidelines.

#### 3.4.2.5. Recalculations

2019 to 2022 fugitive emissions from CO<sub>2</sub> pipelines and injection activities were recalculated to improve accuracy and completeness. Recalculation activities are 1) a result of updated facility reported data and 2) inclusion of missing or new information from facilities that did not previously report relevant data. Recalculations resulted in an increase of 57.6 kt CO<sub>2</sub> eq in 2019 from CO<sub>2</sub> injection and 108 kt CO<sub>2</sub> eq in 2020 from CO<sub>2</sub> pipelines.

#### 3.4.2.6. Planned Improvements

Future emissions estimates will include additional CO<sub>2</sub> capture facilities and pipelines, currently planned or under construction, as they come on-line and report their data to Canada's GHGRP. Inclusion of new facility-reported data will require an assessment for compliance with quality (such as completeness, transparency, etc.) and methodology standards, as prescribed in Canada's Greenhouse Gas Quantification Requirements (ECCC, 2021).

## 3.5. Other Issues

### 3.5.1. CO<sub>2</sub> Emissions from Biofuels: Biodiesel and Ethanol

As per MPGs, a memo item reports CO<sub>2</sub> from sustainably produced biomass fuels combusted to produce energy, and the energy sector totals exclude these emissions. The LULUCF sector tracks the CO<sub>2</sub> as a loss of biomass (forest) stocks. The energy sector reports the CH<sub>4</sub> and N<sub>2</sub>O 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)<sup>6</sup> of 29.67 kJ/g, a carbon content of 52.14% and a density of 789.3 kg/m<sup>3</sup> (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<sub>4</sub> and N<sub>2</sub>O from ethanol, the representative gasoline emission factor was applied as per mode and technology class. CO<sub>2</sub> emission factors used are those based on true chemical characteristics mentioned previously and a 100% oxidation rate.

Table 3–17 Ethanol Used for Transport in Canada

	1990	2005	2018	2019	2020	2021	2022	2023
Ethanol Consumed (ML)	7	267	2 739	2 778	2 320	2 386	2 444	2 496

#### 3.5.1.2. Fuel Biodiesel

Table 3–18 presents the quantities of biodiesel used in transportation. A study conducted between 2004 and 2005 (BioMer, 2005) provided the properties used for biodiesel. Those properties include an HHV of 35.18 TJ/ML, with a carbon content of 76.5% and a density of 882 kg/m<sup>3</sup>.

The RESD biodiesel consumption data is included in its diesel fuel oil total. On-going work is being done to improve the quality and coverage of these data 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<sub>4</sub> and N<sub>2</sub>O for biodiesel, the representative fossil fuel-based diesel emission factor was applied as per mode and technology class. CO<sub>2</sub> emission factors used are those based on true chemical characteristics mentioned previously and a 100% oxidation rate.

Table 3–18 Biodiesel Used for Transport in Canada

	1990	2005	2018	2019	2020	2021	2022	2023
Biodiesel Consumed (ML)	NO	NO	904	897	800	865	908	884

Note:  
NO = Not occurring

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

# CHAPTER 4

## INDUSTRIAL PROCESSES AND PRODUCT USE (CRT SECTOR 2)

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### 4.1. Overview

This chapter covers greenhouse gas (GHG) emissions produced by various industrial processes that chemically or physically transform materials. These processes include the production and use of mineral products, metal production, chemical production, consumption of sulphur hexafluoride (SF<sub>6</sub>) and nitrogen trifluoride (NF<sub>3</sub>), 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 53.5 Mt CO<sub>2</sub> eq to the 2023 national GHG inventory (Table 4–1), compared with 56.0 Mt CO<sub>2</sub> eq in 2005. IPPU emissions represented 7.7% of total Canadian GHG emissions in 2023. The contributing factors of the long-term and short-term trends in this sector are discussed in Chapter 2.

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>INDUSTRIAL PROCESSES AND PRODUCT USE TOTAL</b>	<b>55 100</b>	<b>56 000</b>	<b>54 700</b>	<b>53 700</b>	<b>51 400</b>	<b>53 200</b>	<b>52 500</b>	<b>53 500</b>
<b>Mineral Products (CRT 2.A)</b>	<b>8 490</b>	<b>10 300</b>	<b>8 680</b>	<b>8 850</b>	<b>8 210</b>	<b>9 010</b>	<b>8 410</b>	<b>8 850</b>
Cement Production (CRT 2.A.1)	5 820	7 610	6 990	7 200	6 710	7 380	6 750	7 300
Lime Production (CRT 2.A.2)	1 860	1 830	1 360	1 340	1 190	1 310	1 340	1 240
Mineral Product Use (CRT 2.A.3 and 2.A.4)	800	830	330	320	310	310	310	300
<b>Chemical Industry (CRT 2.B, except 2.B.9)</b>	<b>16 300</b>	<b>9 970</b>	<b>6 350</b>	<b>6 200</b>	<b>5 930</b>	<b>5 710</b>	<b>5 740</b>	<b>5 600</b>
Ammonia Production (CRT 2.B.1)	2 740	2 700	2 420	2 500	2 290	2 540	2 590	2 410
Nitric Acid Production (CRT 2.B.2)	865	1 070	242	225	168	192	128	133
Adipic Acid Production (CRT 2.B.3)	9 160	2 260	-	-	-	-	-	-
Petrochemical and Carbon Black Production (CRT 2.B.5, 2.B.8 and 2.B.10)	3 520	3 930	3 690	3 470	3 470	2 990	3 020	3 050
<b>Metal Production (CRT 2.C)</b>	<b>23 200</b>	<b>20 500</b>	<b>16 100</b>	<b>15 100</b>	<b>14 100</b>	<b>15 400</b>	<b>14 800</b>	<b>15 800</b>
Iron and Steel Production (CRT 2.C.1 and 2.C.2)	10 500	10 800	10 500	9 590	8 140	9 490	9 000	9 510
Aluminium Production (CRT 2.C.3)	9 560	8 300	5 450	5 250	5 840	5 770	5 660	6 090
Magnesium Production and Casting (CRT 2.C.4)	3 180	1 420	141	291	105	144	167	247
<b>Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub> (CRT 2.B.9, 2.E and 2.F)</b>	<b>820</b>	<b>4 800</b>	<b>11 000</b>	<b>11 000</b>	<b>11 000</b>	<b>11 000</b>	<b>11 000</b>	<b>10 000</b>
<b>Non-Energy Products from Fuels and Solvent Use (CRT 2.D)</b>	<b>5 900</b>	<b>9 900</b>	<b>12 000</b>	<b>12 000</b>	<b>11 000</b>	<b>12 000</b>	<b>12 000</b>	<b>12 000</b>
<b>Other Product Manufacture and Use (CRT 2.G)</b>	<b>360</b>	<b>510</b>	<b>650</b>	<b>620</b>	<b>660</b>	<b>660</b>	<b>610</b>	<b>650</b>

Note: Totals may not add up due to rounding.

## 4.2. Cement Production (CRT 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<sub>2</sub>) emissions associated with the production of clinker, the precursor of Portland cement, and excludes other cement production (IPCC, 2006). There are 15 separate facilities that produce clinker in Canada, all of which use dry kilns. These facilities are in Nova Scotia, Quebec, Ontario, Alberta and British Columbia.<sup>1</sup> Total clinker production capacity in Canada is approximately 18 Mt/year.

The Cement Production category accounted for 7300 kt (or 1.1%) of Canada’s total emissions in 2023, a 4% decrease from 2005.

Emissions that result from the combustion of fossil fuels to generate heat to drive the reaction in the kiln fall under the Energy sector and are not considered in this category.

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

Table 4–2 **Summary of Recalculations for the Industrial Processes and Product Use Sector, Selected Years**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2017	2018	2019	2020	2021	2022
<b>INDUSTRIAL PROCESSES AND PRODUCT USE</b>								
Previous Submission (2024 NIR)	54 900	55 400	52 300	53 500	52 300	49 700	51 500	51 300
Current Submission (2025 NIR)	55 100	56 000	53 000	54 700	53 700	51 400	53 200	52 500
Change in Emissions	+205	+637	+682	+1 220	+1 420	+1 730	+1 720	+1 210
	0.4%	1.1%	1.3%	2.3%	2.7%	3.5%	3.3%	2.4%
<b>Mineral Products (CRT 2.A)</b>								
Previous Submission (2024 NIR)	8 490	10 300	8 610	8 710	8 850	8 220	9 000	8 400
Current Submission (2025 NIR)	8 490	10 300	8 610	8 680	8 850	8 210	9 010	8 410
Change in Emissions	+1.2	+0.1	-0.5	-29.5	+0.2	-1.9	+10.3	+3.3
	0.0%	0.0%	0.0%	-0.3%	0.0%	0.0%	0.1%	0.0%
<b>Chemical Industry (CRT 2.B, except 2.B.9)</b>								
Previous Submission (2024 NIR)	16 300	9 970	6 320	6 400	6 220	5 940	5 730	5 780
Current Submission (2025 NIR)	16 300	9 970	6 300	6 350	6 200	5 930	5 710	5 740
Change in Emissions	+0.0	+0.0	-19.5	-46.5	-19.9	-12.0	-18.4	-42.0
	0.0%	0.0%	-0.3%	-0.7%	-0.3%	-0.2%	-0.3%	-0.7%
<b>Metal Production (CRT 2.C)</b>								
Previous Submission (2024 NIR)	23 100	19 900	15 100	14 900	14 100	13 200	14 100	13 600
Current Submission (2025 NIR)	23 200	20 500	15 700	16 100	15 100	14 100	15 400	14 800
Change in Emissions	+134	+637	+556	+1 160	+1 030	+873	+1 270	+1 190
	0.6%	3.2%	3.7%	7.8%	7.3%	6.6%	9.0%	8.7%
<b>Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub> (CRT 2.B.9, 2.E and 2.F)</b>								
Previous Submission (2024 NIR)	820	4 800	11 000	12 000	11 000	11 000	11 000	11 000
Current Submission (2025 NIR)	820	4 800	10 000	11 000	11 000	11 000	11 000	11 000
Change in Emissions	-	-	-40	-45	-48	-45	-43	-42
	-	-	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
<b>Non-Energy Products from Fuels and Solvent Use (CRT 2.D)</b>								
Previous Submission (2024 NIR)	5 800	9 900	11 000	11 000	11 000	10 000	11 000	12 000
Current Submission (2025 NIR)	5 900	9 900	11 000	12 000	12 000	11 000	12 000	12 000
Change in Emissions	+70	-0	+190	+180	+460	+920	+500	+140
	1.2%	0.0%	1.7%	1.6%	4.1%	8.8%	4.4%	1.2%
<b>Other Product Manufacture and Use (CRT 2.G)</b>								
Previous Submission (2024 NIR)	360	510	580	650	620	660	660	650
Current Submission (2025 NIR)	360	510	580	650	620	660	660	610
Change in Emissions	-	-	-	-	-	-	-	-38
	-	-	-	-	-	-	-	-5.9%

Notes:

Totals may not add up due to rounding.

“-” in the “Change in Emissions” data indicates that there were no recalculations.

“0.0” in the “Change in Emissions” data indicates that there were small recalculations that were truncated due to rounding.

## 4.2.2. Methodological Issues

CO<sub>2</sub> emissions from Cement Production were estimated for 1990–2016 using a modified Tier 2 method (Equation 4–1) that incorporates country-specific emission factors and emissions from carbon-bearing non-fuel materials (IPCC, 2006). For 2017 onwards, CO<sub>2</sub> emission estimates came directly from the CO<sub>2</sub> emissions reported by Canadian cement production facilities to the Greenhouse Gas Reporting Program (GHGRP) (ECCC, 2024). The CO<sub>2</sub> 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

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

$EF_{cl}$  = annual calcination emission factor based on clinker production, kt CO<sub>2</sub>/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<sub>2</sub> emissions from total organic carbon in the raw feed, kt CO<sub>2</sub>/kt clinker

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

$E_{CO_2}$	=	the total annual quantity of CO <sub>2</sub> 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 <sub>2</sub> /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 <sub>2</sub> /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 <sub>2</sub> 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<sub>cl</sub>) and annual amounts of bypass dust and CKD are available from the Cement Association of Canada (CAC) for 1990, 2000 and 2002–2014 (CAC, 2014) and from the GHGRP for 2017 onwards (ECCC, 2024). These same quantities have been estimated for the remaining reporting years (1991–1999, 2001, 2015–2016). The CAC receives plant-based data from its member companies in accordance with the quantification method published under the umbrella of the Cement Sustainability Initiative of the World Business Council for Sustainable Development (WBCSD), CO<sub>2</sub> Emissions Inventory Protocol, Version 3.0. The protocol provides for two pathways for estimating process-related CO<sub>2</sub> 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](#) (ECCC, 2023).

Equation 4–2 sums CO<sub>2</sub> emissions from clinker production, CO<sub>2</sub> emissions from cement kiln dust, and CO<sub>2</sub> emissions from organic carbon oxidation in raw materials. CO<sub>2</sub> emissions from cement kiln dust are calculated using plant-specific emission factors of CKD not recycled back to the kiln, which are calculated using Equation 4–3. In contrast to the 2006 IPCC Tier 3 method, this modified Tier 3 method does not require the subtraction of CO<sub>2</sub> emissions from uncalcined carbonate in CKD not recycled to the kiln, as this is accounted for using the plant-specific emission factors of CKD.

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

$EF_{CKD_q}$	=	the plant specific emission factor of CKD not recycled back to the kiln in quarter “q” (tonnes CO <sub>2</sub> / tonnes CKD)
$CaO_{CKD_q}$	=	the total calcium (expressed as CaO) content of CKD not recycled back to the kiln in quarter “q” (tonnes CaO / tonnes CKD)
$fCaO_q$	=	the non-calcined calcium oxide (CaO) content of CKD not recycled back to the kiln in quarter “q” (tonne CaO / tonne CKD)
$MgO_{CKD_q}$	=	the total magnesium (expressed as MgO) content of CKD not recycled back to the kiln in quarter “q” (tonne MgO / tonne CKD)
$fMgO_q$	=	the non-calcined magnesium oxide (MgO) content of CKD not recycled back to the kiln in quarter “q” (tonne MgO / tonne CKD)
$0.785$	=	ratio of molecular weights of CO <sub>2</sub> to CaO
$1.092$	=	ratio of molecular weights of CO <sub>2</sub> to MgO

The CO<sub>2</sub> calcination emission factor, organic carbon emission factor, and CKD/bypass dust correction factor vary from year to year and are based on the available data from the CAC for 1990, 2000 and 2002–2014 and from the GHGRP facility-reported data for 2017 onwards. For the unknown data years (1991–1999, 2001, 2015–2016), an average is taken from the years before and after the unknown data point.

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

Provincial/territorial emission estimates are apportioned from national emission estimates based on the clinker production capacity of each province/territory for 1990–2016. The source of 1990–2006 data was the *Canadian Minerals Yearbook* (NRCan, 1990–2006). For 2007–2013, Natural Resources Canada provided capacity information directly via personal communication.<sup>2</sup> For 2014–2016, the Mining and Processing Division of ECCC provided clinker production capacity via personal communication.<sup>3</sup> For 2017 onwards, provincial/territorial emission estimates are based on the emissions reported to the GHGRP by cement production facilities in each province/territory.

2 Panagapko D. 2008–2014. Personal communications (emails from Panagapko D to EC, last email dated September 16, 2014). Natural Resources Canada.

3 Sunstrum J. 2020. Personal communications (emails Sunstrum J to ECCC, last email dated July 9, 2020). Mining and Processing Division, Environment and Climate Change Canada.

### 4.2.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty estimate has been developed based on the default uncertainty values set out in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) for the parameters in the modified Tier 2 method and modified Tier 3 method. The error associated with the non-response rate of the Statistics Canada survey for clinker production data has also been considered in the uncertainty estimate. The Tier 1 uncertainty associated with the CO<sub>2</sub> emission estimates for clinker production has been calculated to be  $\pm 13.8\%$  for 1990–2016 and  $\pm 8.5\%$  for 2017 onwards. Equation 3.1 from Volume 1, Chapter 3 (IPCC, 2006) has been applied over the time series. The activity data sources have changed over the time series from CIEEDAC publications to data collected by Statistics Canada, as described in section 4.2.2.

To address time-series consistency between the Tier 2 method applied for 1990–2016 and modified Tier 3 method applied for 2017 onwards, splicing techniques were assessed from Volume 1, Chapter 5, section 5.3.3 (IPCC, 2006) and a modified average splicing technique was chosen as being the most suitable. With this approach, the annual EF<sub>cl</sub>, EF<sub>toc</sub>, and CF<sub>ckd</sub> 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<sub>cl</sub>, EF<sub>toc</sub>, and CF<sub>ckd</sub> were last updated in 2014 by the CAC and the EF<sub>cl</sub>, EF<sub>toc</sub>, and CF<sub>ckd</sub> calculated from the 2017 GHGRP facility-reported data were comparable with the EF<sub>cl</sub>, EF<sub>toc</sub>, and CF<sub>ckd</sub> updated by the CAC in 2014. A similar approach was applied for 1990–2014 to ensure time-series consistency for the EF<sub>cl</sub>, EF<sub>toc</sub>, and CF<sub>ckd</sub>. The CAC provided national cement production data for the calculation of EF<sub>cl</sub>, EF<sub>toc</sub>, and CF<sub>ckd</sub> for years 1990, 2000 and 2002–2014 (CAC, 2014). The EF<sub>cl</sub>, EF<sub>toc</sub>, and CF<sub>ckd</sub> for 1991–1999 were taken to be an average of the 1990 and 2000 EF<sub>cl</sub>, EF<sub>toc</sub>, and CF<sub>ckd</sub>, while the EF<sub>cl</sub>, EF<sub>toc</sub>, and CF<sub>ckd</sub> for 2002 was taken to be an average of the 2000 and 2002 EF<sub>cl</sub>, EF<sub>toc</sub>, and CF<sub>ckd</sub>.

### 4.2.4. QA/QC 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. Recalculations

CO<sub>2</sub> emissions for this category were recalculated due to corrections to data calculations for 2019 and 2021, which resulted in a decrease of 0.42 kt CO<sub>2</sub> in 2019 and 6.3 kt CO<sub>2</sub> in 2021.

### 4.2.6. Planned Improvements

An outlier in 2018 was identified, which impacts the Implied Emission Factor for that year, as can be seen in the Common Reporting Tables (CRT). Activity data is currently under review to determine if corrections are required, to resolve or explain this discrepancy.

## 4.3. Lime Production (CRT 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 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 1240 kt (0.2%) to Canada's total emissions in 2023, a 32% 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<sub>2</sub> emissions that are associated with the use of natural limestone for lime production in the pulp and paper industry are accounted for in the Other Limestone and Dolomite Use category (section 4.4).

### 4.3.2. Methodological Issues

A Tier 2 methodology (Equation 4–4) was used to estimate the CO<sub>2</sub> 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<sup>4</sup> and from annual averages of all lime production facilities in Canada that reported to the GHGRP for 2017–2023, and are provided in Annex 6. Data on total national lime production, hydrated lime production and lime plant calcining capacities were obtained from the *Canadian Minerals Yearbook* (NRCan, 1990–2006)<sup>5</sup> for the period up to and including 2006. In subsequent years, information was provided directly by Natural Resources Canada via personal communication.<sup>6</sup>

For 2017 onwards, lime production activity data came directly from data reported by facilities in Canada to the GHGRP (ECCC, 2024). The CO<sub>2</sub> emissions were calculated based on facility-reported data, using a modified Tier 3 method in accordance with section 3 of *Canada's Greenhouse Gas Quantification Requirements* (ECCC, 2023).

Equation 4–4

$$E_{CO_2} = \sum_i (Q_i \times EF_i) \times CF_{LKD} \times CF_{hydrated}$$

$Q_i$	=	production data of lime i, kt of lime i
$EF_i$	=	emission factor for lime type i produced in Canada, kt CO <sub>2</sub> /kt of lime i
$CF_{LKD}$	=	correction factor that corrects for the loss of lime kiln dust and production of byproducts and wastes, fraction
$CF_{hydrated}$	=	correction factor that corrects for hydrated lime, fraction

Canadian lime plants are classified into three types based on their final products: dolomitic lime only, high-calcium lime only, and both dolomitic and high-calcium lime. Information on lime type(s) produced at each facility was sourced from the *Canadian Minerals Yearbook* for data years 1990–2006 (NRCan, 1990–2006), and from detailed facility-level data reported to Canada's GHGRP for 2017 onwards. For the 2025 submission, when facility-level information was available on major product(s) and/or the ratio of dolomitic to high-calcium lime for facilities producing both lime types, this was applied to the facility's capacity for 1990–2016. In the absence of facility-level information on the breakdown of lime types, for 1990–2016, a 15/85 ratio for dolomitic lime/high-calcium lime was assumed for lime plants that produced both types of lime. Previously, facilities producing both types of lime were all assumed to have a 15/85 ratio of dolomitic/high-calcium lime. Table 4–3 provides the breakdown between dolomitic lime and high-calcium lime production in Canada for 1990–2016. National CO<sub>2</sub> 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%.<sup>7</sup> The water content of hydrated lime is deducted from national lime production to calculate the amount of “dry” lime production, which is broken down into dolomitic lime and high-calcium lime. Corresponding emission factors are subsequently applied.

The lime kiln dust (LKD) correction factor was developed from annual averages of emissions from all byproducts and wastes, including LKD, from all lime production facilities in Canada, as reported to the GHGRP for 2017–2023. This correction factor was applied to national emissions estimates from lime production for 1990–2016. In the 2025 submission, to further retain time-series consistency between the Tier 2 and Tier 3 methods, emissions from byproducts and wastes other than LKD were included in this correction factor. In previous submissions, only emissions from LKD were used to calculate the correction factor.

Provincial CO<sub>2</sub> emission estimates are apportioned from national emission estimates based on the total calcining capacity of each province/territory for 1990–2016. The *Canadian Minerals Yearbook* (NRCan, 1990–2006) provided data on calcining capacity for 1990–2006. For 2007–2013, Natural Resources Canada provided capacity information directly via personal communication.<sup>8</sup> For 2014–2016, the Mining and Processing Division of ECCC provided calcining capacity via personal communication.<sup>9</sup> For 2017 onwards, provincial/territorial emission estimates are based on facility-reported data reported to the GHGRP by lime production facilities in each province/territory.

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

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

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

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

8 Panagapko D. 2013. Personal communication (email from Panagapko D to Edalatmanesh M, Environment Canada, dated November 6, 2013). Natural Resources Canada.

9 Sunstrum J. 2020. Personal communications (emails from Sunstrum J to ECCC, last email dated July 9, 2020). Mining and Processing Division, Environment and Climate Change Canada.

Table 4–3 **Split between Dolomitic and High-Calcium Lime Production in Canada (1990–2016)**

Year	% Split	
	Dolomitic Lime	High-Calcium Lime
1990–1992	18%	82%
1993–1994	19%	81%
1995–1997	20%	80%
1998–1999	19%	81%
2000–2006	20%	80%
2007–2008	18%	82%
2009–2010	16%	84%
2011–2014	17%	83%
2015–2016	18%	82%

The variation in the percent split of dolomitic and high-calcium lime over the time series can be attributed to changes in production and capacities at facilities across Canada, as well as facility closures. For instance, the slight decrease in the share of dolomitic lime in 2008–2009 is attributed to the closure of the Timminco Limited plant in Haley Station, Ontario that produced only dolomitic lime.

Canada’s average annual proportion of dolomitic lime over the time series (19%) was greater than the default value (15%) outlined in the 2006 IPCC Guidelines (IPCC, 2006). Along with the incorporation of emissions from byproducts and wastes other than LKD, this resulted in the Implied Emission Factors being closer to the high end of the range of default emission factors associated with Lime Production, as presented in the 2006 IPCC Guidelines.

#### 4.3.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty estimate has been developed based on the default uncertainty values set out in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) for the parameters in the modified Tier 2 method and modified Tier 3 method. The Tier 1 uncertainty associated with the CO<sub>2</sub> emission estimates for Lime Production has been calculated to be ±33.2% for 1990–2016 and ±6.7% for 2017–2023. Equation 3.1 from Volume 1, Chapter 3 (IPCC, 2006) has been applied over the time series.

To address time-series consistency between the Tier 2 method applied for 1990–2016 and Tier 3 method applied for 2017 onwards, splicing techniques were assessed from Volume 1, Chapter 5, section 5.3.3 (IPCC, 2006) and a modified average splicing technique was chosen as being the most suitable. With this approach, the annual EF for dolomitic lime production (EF<sub>dol</sub>) and the annual EF for high-calcium lime production (EF<sub>h-c</sub>) for 2009–2016 are averages calculated based on the 2008 values provided by the Canadian Lime Institute and the 2017–2023 values calculated from the GHGRP facility-reported data. The LKD correction factor applied for 1990–2016 was calculated based on GHGRP facility-reported data for 2017–2023. This modified average splicing technique was chosen because the country-specific EF<sub>dol</sub> and EF<sub>h-c</sub> were last provided in 2008 by the Canadian Lime Institute, and the EF<sub>dol</sub> and EF<sub>h-c</sub> calculated from the 2017–2023 GHGRP facility-reported data were comparable with the EF<sub>dol</sub> and EF<sub>h-c</sub> provided by the Canadian Lime Institute in 2008. The 1990–2007 EF<sub>dol</sub> and EF<sub>h-c</sub> were assumed to be the same as the 2008 EF<sub>dol</sub> and EF<sub>h-c</sub> provided from the Canadian Lime Institute because no other national EFs were available from Canadian Lime Institute and were considered the most representative EFs for that time period. The source of activity data has changed over the time series from the Canadian Lime Institute to Natural Resources Canada and Canada’s GHGRP, as described in section 4.3.2.

#### 4.3.4. QA/QC and Verification

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

#### 4.3.5. Recalculations

Recalculations for this category occurred due to an update to the Tier 2 and Tier 3 methodologies, and from updated facility-reported data to the GHGRP. The magnitude of the recalculations ranged from -30 kt CO<sub>2</sub> in 2018 to +95 kt in 2000.

#### 4.3.6. Planned Improvements

No improvements are currently planned for this category.

## 4.4. Mineral Product Use (CRT 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 (CRT category 2.A.3), Ceramics Production (CRT category 2.A.4.a), Other Uses of Soda Ash (CRT category 2.A.4.b), Non-Metallurgical Magnesia Production (i.e., magnesite use) (CRT category 2.A.4.c) and Other Limestone and Dolomite Use (CRT category 2.A.4.d).

In 2023, the aggregate category accounted for 300 kt (or 0.04%) of Canada’s total GHG emissions, with a decrease of approximately 64% in total emissions since 2005. Non-metallurgical Magnesia Production accounted for 39% of Mineral Product Use emissions, whereas Other Limestone and Dolomite Use, Other Uses of Soda Ash, and Glass Production contributed 34%, 14% and 13% of emissions, respectively.

#### Glass Production (CRT Category 2.A.3)

CO<sub>2</sub> 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<sub>2</sub> emissions from Glass Production throughout the entire time series.

#### Ceramics Production (CRT Category 2.A.4.a)

The production of bricks, roof tiles, vitrified clay pipes, refractory products, expanded clay products, wall and floor tiles, table and ornamental ware, sanitary ware, technical ceramics, and inorganic bonded abrasives are included in the Ceramics Production category. Calcination of carbonates in the clay results in process emissions of CO<sub>2</sub>.

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

Soda ash is used in the production of chemicals, soaps and detergents, pulp and paper, flue gas desulphurization (FGD), and water treatment.

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

Magnesite ore is processed to produce magnesia (MgO) at one facility in Canada, which has been operational throughout the entire time series. Emissions associated with use of magnesite and other carbonates in metallurgical magnesium production are reported under CRT category 2.C.4.

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

Limestone and dolomite are used in several industrial applications in Canada, including the production of cement, lime, glass, and iron and steel. The emissions associated with these industrial applications are reported within their respective categories.

The emissions included in the Other Limestone and Dolomite Use category are associated with other applications, such as its use in pulp and paper mills as makeup lime, and other chemical uses, including FGD and wastewater treatment.

### 4.4.2. Methodological Issues

#### Glass Production (CRT Category 2.A.3)

National CO<sub>2</sub> 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.<sup>10</sup>

#### Ceramics Production (CRT Category 2.A.4.a)

To assess the significance of CO<sub>2</sub> emissions from Ceramics Production, a Tier 1 method was used to estimate emissions for 2005 to 2007 and for 2011 to 2023. For 2005 to 2007, national total annual amounts of clay used for ceramics were obtained from the *Canadian Minerals Yearbook* (NRCan, 1990–2008). A default carbon content of 10% was applied to the

<sup>10</sup> 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.

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<sub>2</sub> emissions per year. For 2011 to 2023, 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<sub>2</sub> in 2006 to 54 kt CO<sub>2</sub> in 2007 and for 2011 to 2023 ranged from 23 kt CO<sub>2</sub> in 2014 to 52 kt CO<sub>2</sub> in 2017, which were below 0.05% of Canada's national total GHG emissions and did not exceed 500 kt CO<sub>2</sub> eq. Subsequently, CO<sub>2</sub> emissions from Ceramic Production are considered “insignificant” under paragraph 32 of the Modalities, procedures, and guidelines (MPGs) for the Enhanced Transparency Framework of the Paris Agreement. As of the 2020 inventory submission, they are reported in the CRT Reporter as “NE” (“not estimated”) with an explanation provided.

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

National CO<sub>2</sub> emissions are calculated using a Tier 1 method that applies the stoichiometry-based emission factor of 415 g CO<sub>2</sub>/kg soda ash to the national consumption data, assuming 100% purity of soda ash used in Canada.

Soda ash consumption data has been estimated based on soda ash production, import and export data.

Import and export data have been obtained from Statistics Canada's Canadian International Merchandise Trade Web Application (Statistics Canada, 2024). The total quantities of soda ash used have been distributed by application type, based on the U.S. pattern of soda ash consumption: glass, chemical, soaps and detergents, pulp and paper, FGD and other. Likewise, provincial emissions have been estimated by apportioning the national emissions according to the respective provincial gross output values of the same sectors.

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

A Tier 1 method is used to estimate CO<sub>2</sub> process emissions from the use of magnesite in magnesia production. The method applies an emission factor of 522 g CO<sub>2</sub>/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<sub>2</sub> emissions at provincial and national levels.

The only magnesia production plant has been operational for the full reporting period (1990–2023) and its annual activity data is sourced from British Columbia's Ministry of Energy and Mines (British Columbia Geological Survey, 2024).

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

Different Tier methodologies are used for different years and applications of limestone and dolomite across the time series, based on available activity data. IPCC Tier 2 and 3 methods are used across the time series to estimate CO<sub>2</sub> emissions from limestone and dolomite separately and by application, using respective consumption data (Table 4–4) and emission factors, as described below.

#### *Limestone and Dolomite as Flux in Iron and Steel Production*

Emissions from limestone and dolomite used as flux in iron and steel production are reported under CRT Category 2.C.1.f.

For the years 1990–2016, a Tier 2 methodology was used to estimate emissions from limestone and dolomite in iron and steel production, multiplying quantities of stone consumed (Table 4–4) by the corresponding emission factors, which vary depending on the year. Data on raw stone used as flux in iron and steel furnaces was gathered from the *Canadian Minerals Yearbook* (NRCan, 1990–2006) and directly from Natural Resources Canada via personal communication (2007–2016). The raw stone data was disaggregated between limestone and dolomite based on the average split of reported quantities of limestone and dolomite to Canada's Greenhouse Gas Reporting Program (GHGRP) for 2017–2023.

For 1990–2006, the emission factor used for Canadian limestone use is derived from the process stoichiometric ratio of 440 g of CO<sub>2</sub>/kg of limestone used and is adjusted to consider a purity fraction of 95% (Derry Michener Booth and Wahl and Ontario Geological Survey, 1989). The Canadian emission factor is therefore 418 g CO<sub>2</sub>/kg of limestone used (AMEC, 2006). An overall emission factor of 468 g CO<sub>2</sub>/kg of dolomite used was derived based on the emission factors for pure limestone (440 kg CO<sub>2</sub>/tonne) and magnesite (522 kg CO<sub>2</sub>/tonne) and on the assumption that dolomite is composed of approximately 58% CaCO<sub>3</sub> and 41% MgCO<sub>3</sub> (AMEC, 2006).

For 2007–2016, emission factors for each stone were derived by taking the average of the emission factors for limestone and dolomite, described above, with the average emission factors for each stone for 2017–2023, calculated from the facility-reported data to the GHGRP.

A Tier 3 methodology was used to estimate emissions from limestone and dolomite used in iron and steel furnaces for years 2017 onwards. Quantities of limestone and dolomite reported by iron and steel facilities to the GHGRP were used as activity data (ECCC, 2024). Reported carbon contents of limestone and dolomite from each facility were used respectively to calculate emissions, according to Equation 4–5, and summed to estimate national CO<sub>2</sub> emissions.

$$E_{CO_2, \text{carbonate}} = [(Q_L \times CC_L) + (Q_D \times CC_D)] \times 44/12$$

$E_{CO_2, \text{carbonate}}$	=	CO <sub>2</sub> emissions from carbonate (i.e., limestone, dolomite) used as flux in iron and steel production, kt CO <sub>2</sub>
$Q_x$	=	Quantity of carbonate x (limestone or dolomite) consumed in iron and steel production, kt
$CC_x$	=	Carbon content of carbonate x (limestone or dolomite), kt C/kt carbonate
$44/12$	=	Multiplication factor for the mass of CO <sub>2</sub> emitted from each mass unit of total carbon used, kt CO <sub>2</sub> /kt C

### Limestone in Pulp and Paper Mills

For the years 1990–2017, an IPCC Tier 2 methodology was used to estimate emissions from limestone used in pulp and paper mills, by multiplying quantities of limestone consumed (Table 4–4) by the Canadian limestone emission factor. Data on raw limestone was gathered from the *Canadian Minerals Yearbook* (NRCan, 1990–2006) and directly from Natural Resources Canada via personal communication (2007–2017). The emission factor applied, 418 g CO<sub>2</sub>/kg of limestone, is the Canadian limestone emission factor (AMEC, 2006), derived as described above.

Table 4–4 **High Calcium Limestone and Dolomite Consumption in Canada**

Year	2.C.1 Iron and Steel			2.A.3 Glass Production		2.A.4.d Other Process Uses of Carbonates					
	High-Calcium Limestone (kt)	Dolomite (kt)	IPCC Tier	High-Calcium Limestone (kt)	IPCC Tier	Pulp and Paper Mills		Non-Ferrous Smelters		Other Chemical Uses	
						High-Calcium Limestone (kt)	IPCC Tier	High-Calcium Limestone (kt)	IPCC Tier	High-Calcium Limestone (kt)	IPCC Tier
1990	384	272	T2	171	T2	214	T2	16	T2	846	T2
1991	288	203	T2	169	T2	220	T2	162	T2	964	T2
1992	329	233	T2	154	T2	231	T2	167	T2	264	T2
1993	116	82	T2	161	T2	224	T2	176	T2	244	T2
1994	111	79	T2	146	T2	234	T2	154	T2	587	T2
1995	180	127	T2	146	T2	130	T2	181	T2	436	T2
1996	174	123	T2	146	T2	134	T2	164	T2	711	T2
1997	194	138	T2	181	T2	117	T2	158	T2	915	T2
1998	230	162	T2	158	T2	89	T2	129	T2	857	T2
1999	230	162	T2	137	T2	96	T2	101	T2	522	T2
2000	398	282	T2	51	T2	118	T2	39	T2	928	T2
2001	279	198	T2	44	T2	69	T2	94	T2	680	T2
2002	151	107	T2	46	T2	57	T2	55	T2	927	T2
2003	165	117	T2	18	T2	62	T2	46	T2	939	T2
2004	122	87	T2	18	T2	75	T2	51	T2	1 109	T2
2005	127	89	T2	18	T2	80	T2	47	T2	1 175	T2
2006	117	83	T2	18	T2	173	T2	57	T2	1 057	T2
2007	58	41	T2	32	T2	41	T2	64	T2	1 178	T2
2008	186	132	T2	12	T2	15	T2	65	T2	1 182	T2
2009	152	108	T2	0	T2	36	T2	74	T2	923	T2
2010	183	130	T2	0	T2	41	T2	65	T2	423	T2
2011	293	207	T2	0	T2	40	T2	52	T2	508	T2
2012	445	315	T2	0	T2	31	T2	34	T2	521	T2
2013	366	259	T2	0	T2	30	T2	46	T2	342	T2
2014	593	420	T2	0	T2	40	T2	32	T2	364	T2
2015	725	512	T2	0	T2	37	T2	32	T2	356	T2
2016	662	468	T2	0	T2	36	T2	28	T2	350	T2
2017	324		T3	0	T2	45	T2	28	T2	196	T2
2018	425		T3	0	T2	44	T3	28	T2	201	T2
2019	222		T3	0	T2	32	T3	26	T2	189	T2
2020	179		T3	0	T2	42	T3	21	T2	190	T2
2021	248		T3	0	T2	35	T3	20	T2	202	T2
2022	174		T3	0	T2	30	T3	18	T2	201	T2
2023	181		T3	0	T2	31	T3	17	T2	197	T2

Note: Quantities of limestone and dolomite for 2017–2023 are aggregated to protect confidentiality.

An IPCC Tier 3 methodology was used to estimate CO<sub>2</sub> emissions from limestone used in pulp and paper mills for the years 2018 onwards. Emissions were calculated according to Equation 2.16 in Volume 3, Chapter 2 of the 2006 IPCC Guidelines, using the default fraction of calcination of 1.00 (IPCC, 2006). Quantities of limestone used reported by pulp and paper facilities to the GHGRP were used as activity data, and the emission factor was derived from the default emission factor for limestone (0.43791 tonnes CO<sub>2</sub>/tonne limestone) with a default 95% purity fraction.

### *Limestone in Non-Ferrous Smelters, Glass Factories, Other Chemical Uses*

An IPCC Tier 2 methodology is used to estimate CO<sub>2</sub> emissions from limestone use in non-ferrous smelters, glass factories, and other chemical uses for the entire time series (1990–2023).

For the years 1990 through 2006, data on raw stone use in each application was gathered from the *Canadian Minerals Yearbook* (NRCan, 1990–2006). For subsequent years, information has been provided directly by Natural Resources Canada via personal communication. National CO<sub>2</sub> emissions are estimated by multiplying the quantities of limestone consumed (Table 4–4) by the Canadian limestone emission factor, 418 g CO<sub>2</sub>/kg of limestone (AMEC, 2006), derived as described above. The emissions are subsequently allocated to the respective reporting categories of Glass Production (CRT category 2.A.3) and Other Limestone and Dolomite Use (CRT category 2.A.4.d).

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

According to Canadian information,<sup>11</sup> only limestone is used for FGD processes in Canadian coal power plants.

Provincial emission estimates have been obtained by apportioning the national emissions according to the sum of the provincial gross output values for the major sectors in which limestone and dolomite have been used (i.e., pulp and paper, non-ferrous metal, glass, and chemical sectors) for the applications and years where a Tier 2 methodology is applied. For applications and years where a Tier 3 methodology is applied, provincial emission estimates are based on facility-reported data to the GHGRP.

## 4.4.3. Uncertainty Assessment and Time-series Consistency

Tier 1 uncertainty assessments were performed for the categories of Glass Production, Other Uses of Soda Ash, Non-Metallurgical Magnesia Production, and Other Limestone and Dolomite Use. The uncertainty assessments considered uncertainties associated with consumption data, production data, import and export data, emission factors, and assumptions, where applicable. Uncertainties associated with each category are outlined in Table 4–5. No uncertainty assessment was performed for the category of Ceramics Production because this category was determined insignificant under paragraph 32 of the MPGs, as described in section 4.4.2.

To retain time series consistency in the categories of Glass Production, Other Uses of Soda Ash, and Non-Metallurgical Magnesia Production, the same emission factors have been consistently applied over the time series for each respective category. The respective activity data sources and emission factors are described in section 4.4.2.

To address time-series consistency between the Tier 2 method applied for 1990–2016 and Tier 3 method applied for 2017 onwards for limestone and dolomite used as flux in iron and steel production, splicing techniques were assessed from Volume 1, Chapter 5, section 5.3.3 (IPCC, 2006) and a modified average splicing technique was chosen as being the most suitable. Emission factors for 1990–2006 were applied based on a study completed in 2006 (AMEC, 2006), and emission factors for 2007–2016 were an average of the values established in 2006 and the emission factors calculated from facility-reported data to the GHGRP for 2017–2023. Activity data sources and emission factors are described in section 4.4.2.

For limestone used in pulp and paper mills, the Tier 2 method applied for 1990–2017 and the Tier 3 method applied for 2018 onwards retain time-series consistency. The emission factor used for the Tier 2 method, calculated for Canadian limestone (AMEC, 2006), is equivalent to the emission factor calculated using the method outlined in the 2006 IPCC Guidelines (IPCC, 2006) that is applied for the Tier 3 method. Activity data sources are provided in section 4.4.2.

The same emission factor has been consistently applied over the time series for all other applications of limestone use. The activity data source is provided in section 4.4.2.

11 Cook S. 2013. Personal communication (email from Cook S to Edalatmanesh M, Environment Canada dated November 18, 2013). Canadian Electricity Association.

Table 4–5 **Summary of Uncertainty Assessments for Mineral Product Use Categories**

Category	CRT Category	Uncertainty Assessment Tier level	Gas	Uncertainty Range	Year Range
Glass Production	2.A.3	Tier 1	CO <sub>2</sub>	±7.2% to ±10.2%	1990–2023
Ceramics Production	2.A.4.a	NA	NA	NA	NA
Other Uses of Soda Ash	2.A.4.b	Tier 1	CO <sub>2</sub>	±5.9% to ±7.5%	1990–2023
Non-Metallurgical Magnesia Production (Magnesite Use)	2.A.4.c	Tier 1	CO <sub>2</sub>	±8.1%	1990–2023
Other Limestone and Dolomite Use	2.A.4.d	Tier 1	CO <sub>2</sub>	±15.4% to ±38.0%	1990–2023
Note: NA = Not applicable, category was not assessed for uncertainty as emissions from this category were determined insignificant.					

#### 4.4.4. QA/QC and Verification

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

#### 4.4.5. Recalculations

For the Other Uses of Soda Ash category, updates to the activity data resulted in an increase of less than 1 kt CO<sub>2</sub> for the 2021 data year.

For the Non-Metallurgical Magnesia Production category, emissions from use of magnesite in magnesium production were reallocated to CRT Category 2.C.4, Magnesium Production, in accordance with the 2006 IPCC Guidelines. This resulted in recalculations for 1990–2007, ranging from -17 kt CO<sub>2</sub> in 2007 to -88 kt CO<sub>2</sub> in 2006.

For the Other Limestone and Dolomite Use category, minor recalculations for 2020–2022 were a result of updated proxy data, ranging from +1 kt CO<sub>2</sub> in 2020 to +4 kt CO<sub>2</sub> in 2021.

#### 4.4.6. Planned Improvements

No improvements are currently planned for this category.

### 4.5. Ammonia Production (CRT Category 2.B.1)

#### 4.5.1. Category Description

Ammonia Production (CRT category 2.B.1) accounted for 2410 kt (0.3%) of Canada's emissions in 2023. This category accounts for CO<sub>2</sub> emissions from the feedstock use (typically natural gas) in the steam methane reformation (SMR) process, CO<sub>2</sub> emissions recovered for urea production, and CO<sub>2</sub> emissions recovered for carbon capture and storage (CCS) activities. SMR may use natural gas as energy to drive the process of generating hydrogen, an essential feedstock for the Haber-Bosch process in the production of ammonia. Natural gas can also be used as feedstock for the SMR process to provide a source of hydrogen. In both uses, the majority of carbon in natural gas ends up as CO<sub>2</sub> emissions. It should be noted that GHG emissions (CO<sub>2</sub>, nitrous oxide [N<sub>2</sub>O], and methane [CH<sub>4</sub>]) from the energy use of natural gas in SMR process and GHG emissions from fuels used in non-SMR ammonia production processes are accounted for in the Energy sector.

There are currently nine ammonia production plants operating in Canada, located in Alberta, Saskatchewan, Manitoba and Ontario (Fertilizer Canada, 2023). One plant uses by-product hydrogen (purchased from a neighbouring chemical plant) to feed into the Haber-Bosch reaction and is therefore assumed to have negligible process-related CO<sub>2</sub> emissions. Eight plants use steam-methane reformers to produce ammonia, of which most recover CO<sub>2</sub> emissions to produce urea. Two of the eight SMR plants conduct carbon capture and storage (CCS) activities.

Urea production is a downstream process associated with ammonia production plants. The process recovers and uses the by-product CO<sub>2</sub> stream from the ammonia synthesis process. To avoid overestimation of CO<sub>2</sub> emissions, the use of recovered CO<sub>2</sub> in urea production is accounted for as part of estimations for this category (see Equation 4–6). The use of urea as a fertilizer and its associated emissions are reported in the AFOLU sector, as per Box 3.2 of 2006 IPCC Guidelines,

Volume 3, Chapter 3. Emissions from use of urea-based additives in catalytic converters are discussed in section 4.15 and reported in CRT category 2.D.3. Other uses of urea (e.g., its use as an ingredient in manufacturing of resins, plastics or coatings) are reported in CRT category 2.B.10.

Two SMR facilities recover CO<sub>2</sub> emissions for enhanced oil recovery (EOR). Recovered emissions from CCS activities are deducted from gross ammonia production emissions in the calculation of net ammonia production emissions (see Equation 4–6), as per Box 3 of Figure 3.1 in the 2006 IPCC Guidelines, Volume 3, Chapter 3.

## 4.5.2. Methodological Issues

A Tier 3 country-specific method is applied in accordance with the 2006 IPCC Guidelines (IPCC, 2006) for the years 2018 onwards, while a Tier 2 country-specific method was applied for years 1990–2017. Collection of facility-reported data from the federal Greenhouse Gas Reporting Program (GHGRP) allowed for sufficient information to transition into a Tier 3 approach for years 2018 and after. Since disaggregated activity data (i.e., natural gas used as feedstock and that used for energy purposes) are available, GHG emissions (CO<sub>2</sub>, nitrous oxide [N<sub>2</sub>O], and methane [CH<sub>4</sub>]) resulting from the energy use of natural gas are accounted for in the Energy sector.

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

Equation 4–6 CO<sub>2</sub> Emissions from Ammonia Production

$$E_{CO_2} = \sum_i \frac{44}{12} \times NG_i \times CC_i \times COF - E_{CO_2Urea\ i} - E_{CCS\ i}$$

$E_{CO_2}$  = national emissions of CO<sub>2</sub>, kt  
 $NG_i$  = natural gas used as feed of facility i, m<sup>3</sup>  
 $CC_i$  = carbon content factor of facility i, kt carbon/m<sup>3</sup> of natural gas  
 $44/12$  = ratio of molecular weights, CO<sub>2</sub> to carbon  
 $COF$  = carbon oxidation factor = 1 (unitless)  
 $E_{CO_2Urea\ i}$  = CO<sub>2</sub> recovered for urea production of facility i, kt  
 $E_{CCS\ i}$  = carbon capture and storage for facility, i, kt

For 1990 to 2017, the feedstock use of natural gas is determined by multiplying the annual ammonia production by the calculated ammonia-to-feed fuel conversion factor that is specific to each facility. The annual ammonia production data for 1990–2004 were gathered in a study conducted by Cheminfo Services (2006); that for 2005–2009 was collected by Environment Canada through a voluntary data submission process with the fertilizer industry; and that for 2008–2017 was obtained from Statistics Canada’s Industrial Chemicals and Synthetic Resins Survey (Statistics Canada, n.d.[c]). The ammonia-to-feed fuel conversion factors were developed from the facility-level data collected between 2005 and 2009 as part of the voluntary data submission. For the 2005–2009 period, there were nine plants in operation (two others stopped operating in 2005). Seven of the nine plants (two of which have 2 SMR units each) provided ammonia-to-feed fuel factors. These facility-specific ammonia-to-feed fuel factors are considered confidential and are therefore not published. Based on the data collected, the average ammonia-to-feed fuel factor was calculated to be 671 m<sup>3</sup> of natural gas/tonne of NH<sub>3</sub> produced, and was used to estimate emissions for one SMR facility that did not participate in the voluntary data collection. The remaining facility does not use the SMR process. At the plant level, the variability of the ammonia-to-feed fuel conversion factor is very steady, varying by less than 0.001% from year to year over the five years. Similarly, the average value varied by less than 0.001% from year to year over the five years. For the years 2018 and after, the natural gas quantity used as feedstock reported by facilities through the GHGRP was directly used in the CO<sub>2</sub> emission estimation.

All of the eight active facilities that use steam methane reformation have voluntarily confirmed or provided natural gas carbon content values used for estimating 1990 to 2017 emissions. Table 4–6 below provides a summary of the description of the natural gas carbon content of each facility. In general, it is observed that natural gas carbon contents do not vary significantly from year to year and from facility to facility. The range of facility-confirmed natural gas content values is 0.49 to 0.54 kgC/kl feedstock, which is comparable to the values obtained through the GHGRP. For 2018 and after, facility-reported natural gas carbon content values obtained through the GHGRP were applied.

For 1990 to 2017, it is assumed that the urea production process consumes a stoichiometric quantity of CO<sub>2</sub> of 0.733 kg CO<sub>2</sub>/kg urea. For 1990–2007, plant-specific urea production was estimated on the basis of actual ammonia production and the respective average ratio of ammonia-to-urea production for each plant taken over data years 2008 to 2013. Urea production data for 2008–2017 was retrieved from Statistics Canada’s Industrial Chemicals and Synthetic Resins Survey. For 2018 and after, CO<sub>2</sub> recovered for urea production was directly reported by facilities through the GHGRP.

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

Active Facility	Time Period	Natural Gas Carbon Content Description
A	1990 to 2017	Facility confirmed the use of the average of 2018 to 2020 carbon contents reported to the GHGRP to be suitable.
B	1990 to 2017	Facility provided facility-specific average carbon content value (based on 1998 to 2017 values).
C	1990 to 2017	Facility provided facility-specific average carbon content value (based on 2003 to 2017 values).
D	1990 to 2017	Facility provided facility-specific average carbon content value (based on 2004 to 2017 values).
E*	1990 to 2009	Facility confirmed the use of the average of 2018 to 2020 carbon contents reported to the GHGRP to be suitable.
	2010 to 2017	Facility provided facility- and year-specific carbon content values.
F	1990 to 2007	Facility provided facility-specific average carbon content value (based on 2008 to 2012 values).
	2008 to 2018	Facility provided facility- and year-specific carbon content values.
G	1990 to 2017	Facility confirmed the use of the average of 2018 to 2020 carbon contents reported to the GHGRP to be suitable.
H	1990 to 2017	Facility suggested the use of annual provincial carbon content values. Internally developed annual and province-specific carbon content values found in Table A6.1-1 were used.

Note:

\*Facility E provided carbon content values in KgC/KgFeedstock from 2010 to 2017. These values were converted to KgC/KIFeedstock 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.

Two of the eight SMR facilities conduct CCS activities, and emissions recovered for CCS activities are estimated since 1990. Facilities were identified as being involved in CCS activities through the reporting of emissions under “Other Recovered CO<sub>2</sub>” in the GHGRP and additional communication to confirm the activities/uses of the recovered emissions. Both facilities engage in CO<sub>2</sub> recovery through enhanced oil recovery (EOR). Table 4–7 summarizes the CCS and other carbon recovery activities for each facility using SMR. The facilities were contacted again in 2024 and confirmed that there have been no changes in their CCS activities.

Finally, the quantity of natural gas used to produce hydrogen for ammonia production was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double counting, the natural gas amounts allocated by Statistics Canada for hydrogen production are systematically removed from the non-energy use of natural gas reported under the Non-Energy Products from Fuels and Solvent Use category (refer to section A3.3.2, Non-energy Products from Fuels and Solvent Use).

Table 4–7 Summary of Carbon Capture and Storage and CO<sub>2</sub> Recovery Activities

Facility ID	CCS or CO <sub>2</sub> Recovery Summary
A	No past, current or planned CCS activities. Facility recovers CO <sub>2</sub> 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 <sub>2</sub> sent to greenhouse is not expected to be accounted for elsewhere in the NIR. Therefore, it is not subtracted from the ammonia emission estimate. <sup>a</sup>
B	Facility has been exporting carbon dioxide to the Alberta Carbon Trunkline since 2019 and this CO <sub>2</sub> is used in enhanced oil recovery. It is expected that the CO <sub>2</sub> 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 <sub>2</sub> to third party company over the past 30-40 years. The company uses approximately 20% of the recovered CO <sub>2</sub> in enhanced oil recovery. It is expected that the CO <sub>2</sub> 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 <sub>2</sub> 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 <sub>2</sub> gets sent to a long-term storage, it is not subtracted from the ammonia emission estimate. <sup>b</sup>

Notes:

a. Volume 3, section 1.2.2 of the 2006 IPCC Guidelines explains that “quantities of CO<sub>2</sub> for later use and short-term storage should not be deducted from CO<sub>2</sub> emissions, except when the CO<sub>2</sub> emissions are accounted for elsewhere in the inventory.”

b. Ibid

#### 4.5.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for the category of Ammonia Production. The assessment considered 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<sub>2</sub> emissions from the category vary over time from 6.2% 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. QA/QC and Verification

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

#### 4.5.5. Recalculations

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

#### 4.5.6. Planned Improvements

No improvements are currently planned for this category.

### 4.6. Nitric Acid Production (CRT 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. As shown in Table 4–8, 14 nitric acid production lines (plants) at 9 facilities have operated during the time series (Cheminfo Services, 2006). Since 2005, national nitric acid production has decreased by 24%, mainly due to the closure of all plants at the Dyno Nobel Nitrogen Inc. facility in Maitland, ON in 2010. In 2023, 8 plants were operational at 5 facilities.

The Nitric Acid Production category accounted for 133 kt CO<sub>2</sub> eq of Canada's emissions in 2023, an 88% decrease from 2005. This decrease is driven by the installation of secondary and tertiary N<sub>2</sub>O abatement technologies at the Orica Canada Inc. Carseland Works facility. All operational plants in Canada currently have N<sub>2</sub>O abatement systems installed.

Nitric acid is produced in two stages. In the first stage, ammonia is catalytically oxidized on a platinum-rhodium gauze, which produces nitrogen oxides (NO<sub>x</sub>), notably, nitrogen dioxide (NO<sub>2</sub>). In the second stage, the NO<sub>2</sub> is then absorbed into water in an absorption tower to produce nitric acid (HNO<sub>3</sub>). During the oxidation of ammonia, some N<sub>2</sub>O is produced as a by-product.

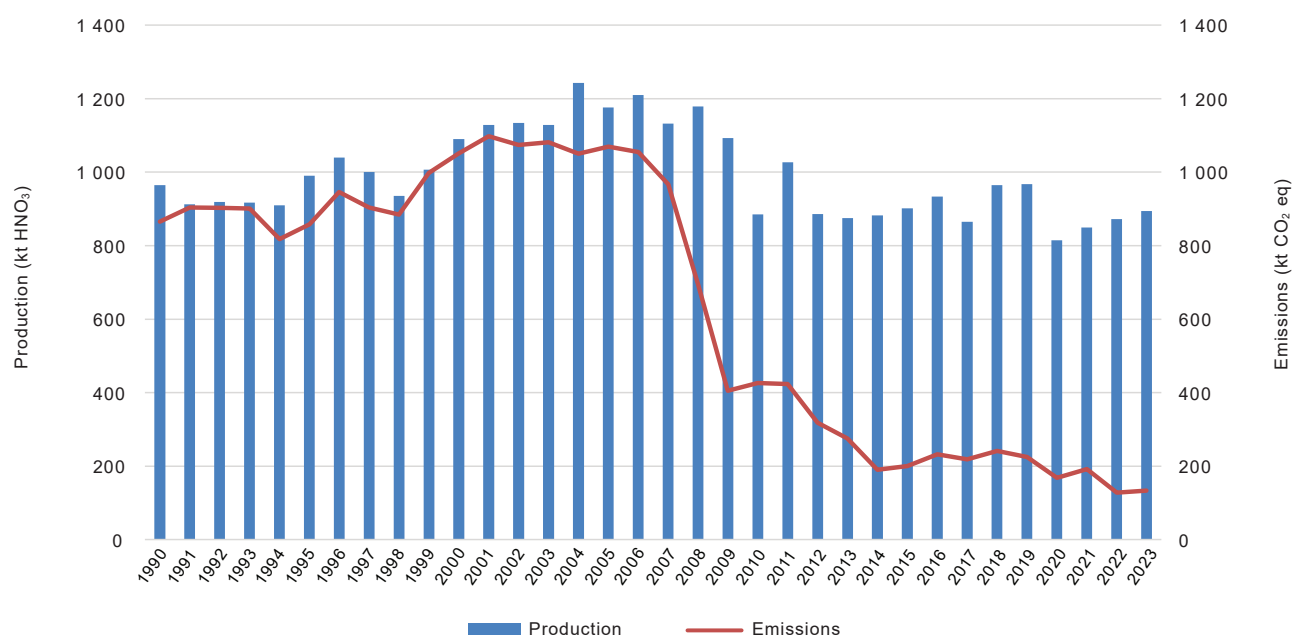
There are two nitric acid production process types used in Canada: high pressure and dual pressure. The high pressure design, commonly used in North America, applies a single pressure throughout the oxidation and absorption stages (Cheminfo Services, 2006). Dual pressure plants use a lower pressure for the reaction stage and higher pressure for the absorption stage (Cheminfo Services, 2006). To increase the efficiency of the absorption stage, plants can “extend” the absorption tower by adding more trays. In Table 4–8, this is referred to as “Extended Absorption Type 1” (Cheminfo Services, 2006). Plants can also have a second tower in place to allow for “double absorption.” This is referred to as “Extended Absorption Type 2” in Table 4–8 (Cheminfo Services, 2006).

The most commonly used N<sub>2</sub>O abatement technology type at Canadian plants are non-selective catalytic reduction (NSCR) systems. The emission abatement systems are classified as “non-selective” when a reductant such as natural gas or ammonia purge gas is used to reduce nitrogen oxides (NO<sub>x</sub>) and nitrous oxide (N<sub>2</sub>O). In contrast, a selective catalytic reduction (SCR) system uses ammonia and reacts with N<sub>2</sub>O only (Perez-Ramirez et al., 2003). Catalytic reduction systems are installed downstream of the absorption tower tail-gases. They are considered a tertiary abatement measure when they are installed between the absorption column and the tail-gas expansion turbine, and a quaternary or end-of-pipe solution when installed downstream of the tail-gas expansion turbine prior to the stack (IPCC, 2006). 6 of the 8 active plants have employed NSCR systems since 1990 or since their startup (Cheminfo Services, 2006). In 2021, a tertiary SCR system was retroactively installed at plant 1 at the Orica Canada Inc. Carseland Works site.<sup>12</sup> This installation is the main driver for an emission decrease of 33% in this category between 2021 and 2022.

Process-gas catalytic decomposition (PGCD) systems are also employed in some Canadian nitric acid production plants. These systems are a secondary abatement measure that consist of catalysts installed underneath the ammonia burner that catalyze the N<sub>2</sub>O formed during the ammonia oxidation reaction. PGCD systems were installed retroactively in the two plants at Orica Canada Inc.'s Carseland Works in 2008 and 2012 (Orica Canada Inc., 2014, 2016). These installations are responsible for the majority of the emission decrease observed since 2005 in this category. Figure 4–1 shows the production and emission trends for the category.

<sup>12</sup> Orica Canada Inc. 2024. Personal communication (email from Orica Canada Inc. to Greenhouse Gas Reporting Program dated September 10, 2024). Orica Canada Inc.

Figure 4–1 Nitric Acid Production and N<sub>2</sub>O Process Emission Trends



#### 4.6.2. Methodological Issues

A mix of Tier 3, Tier 2, and Tier 1 methods were used in the estimation of N<sub>2</sub>O from Nitric Acid Production. Higher tiers were used when possible, depending on the availability of data:

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

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

For 1990–2004, plant activity data were from the 2006 Cheminfo study (Cheminfo Services, 2006) when they were possible to collect. To fill in missing activity data gaps, plant capacities from the Cheminfo study and national production quantities from Statistics Canada's Industrial Chemicals and Synthetic Resins (ICSR) survey were used to estimate production as shown here (Cheminfo Services, 2006):

Equation 4–7

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

Table 4–8 Nitric Acid Production Facilities in Canada

Company	Location	Production Lines	Years in Operation during Time-Series	Process Type <sup>a</sup>	N <sub>2</sub> O Emission Controls <sup>b</sup>	Production Data		Emission Factors		Emission Estimate Quality
						Estimated (allocation of national production)	Facility data	Country-specific (CS) or technology-specific	Facility data	IPCC Tier
Cominco Inc.	Calgary, AB	1	1990–1994	DP (M/H), EA2	None	1990–1994	N/A	1990	N/A	T1 (1990–1994)
Cyanamid Canada	Niagara Falls, ON	1	1990	HP	NSCR	1990	N/A	1990–1994	N/A	T1 (1990)
Dyno Nobel Nitrogen Inc.	Maitland, ON	3	1990–2010	HP	NSCR	N/A	1990–2010	1990–2010	N/A	T2 (1990–2010)
Koch Fertilizer Canada, ULC	Brandon, MB	3	Plant 1: 1990–present Plant 2: 1994–present Plant 3: 1997–present	HP	NSCR	1991–1999, 2007	1990, 2000–2006, 2008–present	1990–present	N/A	T1 (1991–1999, 2007) T2 (1990, 2000–2006, 2008–present)
Nutrien (Canada) Holdings ULC.	Redwater, AB	1	1990–present	HP	NSCR	1991–1999	1990, 2000–present	2005–present	1990–2004	T1 (1991–1999) T2 (2005–present) T3 (1990, 2000–2004)
Orica Canada Inc.	Carseland, AB	2	Plant 1: 1990–present Plant 2: 1999–present	Plant 1: DP (M/H), EA1 Plant 2: HP	Plant 1: None (1990–2008), PGCD (2008–2021), PGCD & SCR (2021–present) Plant 2: None (1999–2012), PGCD (2012–present)	N/A	1990–present	Plant 1: 1990–2008 Plant 2: 1999–2012	Plant 1: 2008–present Plant 2: 2012–present	Plant 1: T2 (1990–2008), T3 (2008–present) Plant 2: T2 (1999–2012), T3 (2012–present)
Orica Canada Inc.	Beloeil, QC	1	1990–1999	HP, EA2	NSCR	1990–1999	N/A	1990–1999	N/A	T1 (1990–1999)
Terra International (Canada) Inc.	Courtright, ON	1	1990–present	HP	NSCR	N/A	1990–present	2005–present	1990–2004	T2 (2005–present) T3 (1990–2004)
Yara Belle Plaine Inc.	Belle Plaine, SK	1	2004–present	HP	NSCR	N/A	2004–present	2005–present	2004	T2 (2005–present) T3 (2004)

## Notes:

a. Process types use the definitions in the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019), and were determined from facility information collected during the Cheminfo Services (2006) study.

b. N<sub>2</sub>O emission controls are aligned with the definitions in the 2006 IPCC Guidelines (IPCC, 2006). Information on emission controls employed at facilities were collected during the Cheminfo Services (2006) study and from offset project verification reports (Orica Canada Inc., 2014, 2016). Information on the 2021 SCR installation at plant 1 of the Carseland, AB site was verified by Orica Canada Inc. in 2024.

HP = Single high-pressure of 6.5 - 13 bar, held constant through oxidation and absorption stages (IPCC, 2019).

DP (M/H) = Dual-pressure, with a medium applied pressure of 1.7 - 6.5 bar in the oxidation stage and a high applied pressure of 6.5 - 13 bar in the absorption stage (IPCC, 2019).

EA1 = Extended absorption by adding more trays in the absorption tower (Cheminfo Services, 2006).

EA2 = Extended absorption through the use of two absorption towers (Cheminfo Services, 2006).

N/A = not applicable

NSCR = Non-selective catalytic reduction system located downstream of the absorption stage (reducing both NO<sub>x</sub> and N<sub>2</sub>O emissions) (IPCC, 2006).

PGCD = Process-gas catalytic decomposition (located beneath the ammonia burner used for the oxidation stage) (IPCC, 2006).

SCR = Selective catalytic reduction system located downstream of the absorption stage (reducing N<sub>2</sub>O emissions only) (Perez-Ramirez et al., 2003)

For 2005–2009, activity data was reported by companies to Environment and Climate Change Canada on a voluntary basis. Missing data from the voluntary survey was filled in using facility-level ICSR survey data when available. Rarely, when plant or facility-level data was unavailable from voluntary surveys and the ICSR, Equation 4–7 was used to estimate production.

For 2010 onwards, facility-level production data was primarily obtained from the ICSR survey. In certain cases, plant-level production data from the GHGRP or separate company data requests were used when facility-reported ICSR data did not pass quality control checks. This included instances when companies did not report on a calendar year basis, or when companies reported outlier production values that exceeded their production capacity.

Tier 3 plant-specific emission factors or Continuous Emissions Monitoring Systems (CEMS) data were used to estimate emissions from five plants when available and applicable to the specific years of activity data. Those for years prior to 2005 were collected from facilities during the 2006 Cheminfo study (Cheminfo Services, 2006). CEMS systems were installed during the installation of PGCD emission control systems at the Orica Canada Inc. Carseland Works site in 2008 and 2012. Facility-provided CEMS data was collected in conjunction with the Greenhouse Gas Reporting Program (GHGRP) and has been used to estimate emissions for all years since installation. For years where a Tier 3 method could not be applied due to lack of emission factor data, a Tier 2 method was used, using technology-specific emission factors provided by plant equipment vendors or the Canadian Fertilizers Institute. It should be noted that to ensure that confidential plant- or facility-specific production data is fully protected, it is not possible to specifically associate emission factors with the plants. A weighted average emission factor for 2023 is available in Table A6.2–3.

#### 4.6.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for the category of Nitric Acid Production. It considers the uncertainties associated with the national, facility, and plant-specific nitric acid production data, the production allocation process (when applicable) and emission factors. The uncertainty values associated with N<sub>2</sub>O emissions from the category vary from 8.8% to 9.7% between 1990–1998, drop to 6.9% to 7.3% between 2000–2007, and drop again to 3.3% to 4.5% from 2012–2023. 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 ( $\pm 45\%$ ). 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 Tier 3 CEMS data from Orica Canada Inc. Carseland Works, which has low uncertainty. The emission factors are the largest contributors to the uncertainty for this category.

All activity data is derived from facility-reported production data. When individual facility-level data is unavailable, production data is estimated using national total production data, which is compiled from facility-level data reporting to the ICSR.

When plant- and year-specific Tier 3 emission factors are unavailable, plant equipment vendor or technology-specific emission factors (Tier 2) are used for estimating facility emissions. In general, the plant- and year-specific emission factors fluctuate upwards and downwards from the technology-specific emission factors, confirming the validity of the Tier 2 emission factors as an appropriate average. Input from facilities indicates that it is inappropriate to use plant- and year-specific emission factors for other years in the time-series, since plant emission factors can fluctuate over time depending on the age of abatement catalysts and other factors. Therefore, the Tier 2 emission factors serve as an average and are used in the absence of year-specific emission factors.

#### 4.6.4. QA/QC 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<sub>3</sub> 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. Recalculations

Emissions for 2022 were recalculated upwards by less than 1 kt CO<sub>2</sub> eq using revised ISCR activity data.

#### 4.6.6. Planned Improvements

N<sub>2</sub>O 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<sub>2</sub>O emission factors for use in Tier 3 calculations.

ECCC is also working with nitric acid producers to receive information on CO<sub>2</sub> and CH<sub>4</sub> 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<sub>2</sub>O and NO<sub>x</sub> process emissions, and their use may contribute some process emissions.

## 4.7. Adipic Acid Production (CRT 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<sub>2</sub>O 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<sub>2</sub>O and CO<sub>2</sub> are indicated as “NO” in the CRT.

### 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<sub>2</sub>O/kg adipic acid.

Since 1997, the total emissions for the category are the sum of two modes of operation, either with or without an abator, as shown in Equation 4–8. The estimated emissions that occur when the abator is operating (Equation 4–9) are calculated separately from emissions that occur when the abator is not operating (Equation 4–10) due to maintenance or technical problems.

Equation 4–8

$$\text{Total Emissions (t)} = \text{N}_2\text{O Emissions (t) with abator} + \text{N}_2\text{O Emissions (t) without abator}$$

N<sub>2</sub>O Emissions with Abator:

Equation 4–9

**N<sub>2</sub>O Emissions (t) with Abator**

$$= (\text{Production(t)}) \times \left( \frac{0.3 \text{ t N}_2\text{O}}{\text{t adipic acid}} \right) \times (1 - \text{Destruction Efficiency}) \\ \times (\text{Abatement Utilization Ratio})$$

**Destruction Efficiency** = determined on the basis of the difference between the amount of N<sub>2</sub>O 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<sub>2</sub>O goes through the abator divided by the total operating time

N<sub>2</sub>O Emissions without Abator:

Equation 4–10

**N<sub>2</sub>O Emissions (t) without Abator**

$$= (\text{Production(t)}) \times \left( \frac{0.3 \text{ t N}_2\text{O}}{\text{t adipic acid}} \right) \times (1 - \text{Abatement Utilization Ratio})$$

**Abatement Utilization Ratio** = number of hours during which N<sub>2</sub>O 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<sub>2</sub>O emissions. This is because the analyzer is limited to accurately measuring relatively low concentrations of N<sub>2</sub>O only when the reactor is online and abating N<sub>2</sub>O gas. The analyzer is not capable of measuring the full range of N<sub>2</sub>O concentrations that could potentially exist in the stack. The N<sub>2</sub>O 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<sub>2</sub>O in the unabated stream. When the abatement reactor is bypassed, there is no N<sub>2</sub>O abatement occurring and the analyzer will not record N<sub>2</sub>O 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. Uncertainty Assessment 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  $\pm 11\%$ , 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. QA/QC 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. Recalculations

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

#### 4.7.6. Planned Improvements

No improvements are currently planned for this category.

### 4.8. Soda Ash Production (CRT 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions potentially generated from the ash production process for the applicable reporting years (1990–2001). However, the net CO<sub>2</sub> emissions are considered negligible because the CO<sub>2</sub> resulting from the Solvay process was recovered for re-use and has been recorded as such in CRT category 2.B.7 (AMEC, 2006).

#### 4.8.3. Uncertainty Assessment 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. QA/QC and Verification

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

#### 4.8.5. Recalculations

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

#### 4.8.6. Planned Improvements

No improvements are currently planned for this category.

## 4.9. Carbide Production, Titanium Dioxide Production, Petrochemical and Carbon Black Production, Fluorochemical Production and Other Uses of Urea (CRT 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 (CRT Category 2.B.5)

Two kinds of carbide are considered in this section: silicon carbide (SiC) and calcium carbide (CaC<sub>2</sub>). SiC and CaC<sub>2</sub> are no longer produced in Canada; the last of two SiC plants closed in 2002 and the only CaC<sub>2</sub> plant closed in 1992.

#### Titanium Dioxide Production (CRT Category 2.B.6)

Titanium dioxide (TiO<sub>2</sub>) 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<sub>2</sub> production that can lead to significant greenhouse gas emissions: titanium slag production, synthetic rutile production, and rutile TiO<sub>2</sub> production using the chloride process (IPCC, 2006). Another TiO<sub>2</sub> production route, anatase TiO<sub>2</sub> 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<sub>2</sub> production that give rise to process GHG emissions: Rio Tinto Fer et Titane and Kronos Canada. Rio Tinto Fer et Titane in Sorel-Tracy, Quebec, produces titanium slag by smelting ilmenite in an electric arc furnace using anthracite coal as a reductant (Weidenhammer, 2021). The titanium slag products are shipped as process inputs for producing TiO<sub>2</sub> using the sulphate process and the chloride process. Kronos Canada in Varennes, Quebec produces TiO<sub>2</sub> 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<sub>2</sub> using the sulphate process until 1993 (Environment Canada, 1996).

#### Methanol Production (CRT Category 2.B.8 and CRT Category 2.B.10)

There were three methanol production facilities operating in Canada between 1990 and 2006. One was closed in 2001, another in 2005 and the last in 2006. Methanol production in Canada ceased in 2006 but resumed in 2011 at one location.

Process GHG (CO<sub>2</sub>, methane [CH<sub>4</sub>] and N<sub>2</sub>O) 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<sub>2</sub> and light hydrocarbons. Additional CH<sub>4</sub> emissions can occur in venting of process gases containing CH<sub>4</sub> from the methanol distillation train and methanol storage tanks and from fugitive emissions from equipment leaks (Cheminfo Services 2010). N<sub>2</sub>O emissions are reported in CRT category 2.B.10 Other (Methanol Production – N<sub>2</sub>O Emissions).

#### Ethylene Production (CRT Category 2.B.8 and CRT Category 2.B.10)

There were five ethylene facilities in operation in Canada between 1990 and 2023, 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<sub>2</sub> and CH<sub>4</sub> emissions are reported in CRT category 2.B.8.b and N<sub>2</sub>O emissions are reported in CRT category 2.B.10 Other (Ethylene Production – N<sub>2</sub>O Emission).

#### Ethylene Dichloride Production (CRT 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<sub>2</sub>. The process CO<sub>2</sub> emissions from EDC production come from the side reaction of feedstock oxidation. The process CH<sub>4</sub> emissions would most likely come from light hydrocarbons from distillation operations that are not captured by a flare gas recovery system. These emissions are vented to the atmosphere (Cheminfo Services, 2010).

## Ethylene Oxide Production (CRT Category 2.B.8)

Ethylene Oxide is a chemical intermediate that is used in the manufacture of glycols, including monoethylene glycol. Table 4–9 presents an overview of Canadian ethylene oxide production during the time-series.

CO<sub>2</sub> emissions are produced as a by-product of the direct oxidation of ethylene feedstock and are dependent on the selectivity of the process (IPCC, 2006). CH<sub>4</sub> is used to carry all reaction gases through the process (IPCC, 2006). It can be emitted through the ethylene oxide process vent, the purification process exhaust gas stream, and as fugitive (IPCC, 2006).

Table 4–9 Ethylene Oxide Production Facilities in Canada				
Company	Location	Production Lines	Years in Operation during Time-Series	Process Type
MEGlobal Canada ULC	Fort Saskatchewan, AB	1	1990–present	Oxygen
MEGlobal Canada ULC	Prentiss, AB	2	Plant 1: 1990–present Plant 2: 1994–present	Oxygen
Shell Chemicals Canada	Scotford, AB	1	2000–present	Oxygen
Union Carbide Canada	Montréal-Est, QC	1	1990–1993	Oxygen

Note: Adapted from Cheminfo, 2010.

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

Four facilities produced carbon black in Canada between 1990 and 2023, three of which are currently operating. CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions can arise from carbon black production. It should be noted that N<sub>2</sub>O emissions are reported in CRT category 2.B.10 Other (Carbon Black Production – N<sub>2</sub>O Emissions), whereas CO<sub>2</sub> emissions are included in CRT category 2.D (Non-Energy Products from Fuels and Solvent Use). Because CRT category 2.D cannot be disaggregated, CO<sub>2</sub> emissions from carbon black production are reported as “IE” (“included elsewhere”) in the CRT Reporter.

## Styrene Production (CRT Category 2.B.8)

Three styrene facilities produced styrene in Canada since 1990, one of which closed in 1998. CO<sub>2</sub> and CH<sub>4</sub> emissions can arise from styrene production. It should be noted that CO<sub>2</sub> emissions are included in CRT category 2.D (Non-Energy Products from Fuels and Solvent Use) and CRT category 2.D cannot be disaggregated. Therefore, CO<sub>2</sub> emissions from styrene production are reported as “IE” in the CRT Reporter.

## Fluorochemical Production (By-product Emissions, CRT Category 2.B.9.a)

During the manufacture of chlorodifluoromethane (HCFC-22), trifluoromethane (HFC-23 or CHF<sub>3</sub>) is generated as a by-product (IPCC, 2006). Two HCFC-22 producers (Dupont Canada and Allied-Signal) operated in Canada in the 1980s and early 1990s, but production ended in 1992. In Canada, there has been no manufacturing or import of equipment containing HCFC-22 as of January 1, 2010 (HRAI, 2008). HFC-23 releases as a by-product of HCFC-22 production were 810 kt, 890 kt and 700 kt (in 1990, 1991 and 1992, respectively). There has been no known production of sulphur hexafluoride (SF<sub>6</sub>) or perfluorocarbons (PFCs) in Canada throughout the time series.

## Other Uses of Urea (CRT Category 2.B.10 Other [Other uses of Urea – CO<sub>2</sub> Emissions])

The Other Uses of Urea category accounts for potential emissions from urea used as an ingredient in the manufacturing of resins, plastics, and coatings products. To determine the amount of Other Uses of Urea, the total quantity of urea produced at ammonia plants is balanced with the urea that is imported to and exported from Canada, the quantity used for agriculture, and the estimated amount of urea-based additives required in catalytic converters for vehicles.

## 4.9.2. Methodological Issues

### Carbide Production (CRT Category 2.B.5)

Tier 1 IPCC default emission factors were applied to estimate CH<sub>4</sub> 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<sub>4</sub> 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<sub>4</sub> emission factors. Only production capacity data (SiC and CaC<sub>2</sub>) over the time series was identified in the study. The following Equation 4–11 was used to estimate total CH<sub>4</sub> emissions from carbide production:

$$\begin{aligned}
 & \text{Total CH}_4 \text{ emissions (t) =} \\
 & \sum_y [(SiC \text{ capacity} \times \text{capacity utilization} \times \text{Emission Factor}_{SiC}) \\
 & \quad + (CaC_2 \text{ capacity} \times \text{capacity utilization} \times \text{Emission Factor}_{CaC_2})]
 \end{aligned}$$

$y$  = companies  
*SiC or CaC<sub>2</sub> capacity* = data collected from the industry, kt  
*Capacity utilization* = based on Cheminfo Services' knowledge of the industry, %  
*Emission Factor<sub>SiC</sub>* = see Annex 6  
*Emission Factor<sub>CaC<sub>2</sub></sub>* = see Annex 6

## Titanium Dioxide Production (CRT Category 2.B.6)

Generally, the titanium dioxide facilities have reported their process inputs to the Report on Energy Supply and Demand (RES-D) feeder surveys as energy inputs rather than process inputs. Therefore, process emissions are mainly included in the Energy sector estimates (Table 4–10). To reflect this situation, CO<sub>2</sub> emissions from the Titanium Dioxide Production category are reported as “Included Elsewhere” (notation key “IE”) in the CRT.

Table 4–10 **Titanium Dioxide Production in Canada, and Location of Process Emissions in the CRT**

Company	Location	Producta	Primary Process Input <sup>a</sup>	Years	Location of Process Emissions in the CRT <sup>b</sup>
Rio Tinto Fer et Titane	Sorel-Tracy, QC	Titanium Slag	Anthracite Coal	1990–present	1.A.2.b – Non-Ferrous Metals
Kronos Canada	Varennes, QC	TiO <sub>2</sub> – Chloride Route	Petroleum Coke	1990–2020	1.A.2.c – Chemicals
				2021–present	2.C.1.a – Steel, 2.C.3 – Aluminium, and 2.D.3.d – Non-energy products from fuels and solvent use – Other and Undifferentiated

Notes:

a. Product types use the definitions from the 2006 IPCC Guidelines (IPCC, 2006), and product types and primary process inputs were determined from Developments in Canadian Hydrometallurgy Since 1950 (Weidenhammer, 2021) and from a contracted Cheminfo study (Cheminfo, 2010).

b. From 2021 onwards, the use of petroleum coke in titanium dioxide production was reported in the RES-D with all other non-energy uses of petroleum coke. To avoid double-counting, quantities of petroleum coke estimated to be used in steel and aluminium production are subtracted from all other non-energy uses of petroleum coke. The remaining petroleum coke (if any) is used to estimate emissions in CRT category 2.D.3.d.

## Methanol Production (CRT Category 2.B.8 and CRT Category 2.B.10)

When available, facility-reported CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O 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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. 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<sub>2</sub> and CH<sub>4</sub> Emissions) and Category 2.B.10 Other (Confidential Petrochemicals – N<sub>2</sub>O Emissions).

Methanol production restarted in Canada in 2011 in a facility that had previously been included in the inventory. The country-specific emission factors were updated in 2023 to take into account the single facility's emissions reported to the GHGRP. For 2012 onwards, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

## Ethylene Production (CRT Category 2.B.8 and CRT Category 2.B.10)

Two consulting studies were commissioned to evaluate CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emission sources in Canadian petrochemical production as well as the quantity of fuels consumed as feedstocks. The latter was required to differentiate the emissions associated with petrochemical production (CRT category 2.B.8) from the emissions associated with non-energy uses of fuels (CRT category 2.D).

As part of the first study (Cheminfo Services 2010), a questionnaire was sent on behalf of Environment Canada to the four companies that have had ethylene production operations in Canada. Three of the four operating plants responded to the voluntary questionnaire request, representing 90% of Canadian ethylene production capacity in 2009. The data provided included emissions and production values for the years 2007 to 2009 and was used to develop the facility-level N<sub>2</sub>O 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<sub>2</sub> and CH<sub>4</sub> on a year-by-year basis. The two emission factors change over time in step with changes to the feedstocks consumed in Canadian

ethylene production. In 2021, an in-house analysis of feedstock used by facilities was completed and showed that in 2016, two companies had changed the type of fuel used in their production. The emission factors for those facilities were updated according to the new feedstock using the Cheminfo Service, 2015 methodology.

National ethylene production data is taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. For 2008 onwards, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. The facility-specific emission factors applied are treated as confidential since they are derived from business-sensitive data. However, average industry-wide emission factors are recorded in Annex 6.

When process GHGs were reported directly by a facility, the reported data was used in the inventory. When reported emission data is not available, estimated emissions are calculated using the estimated ethylene production (allocated to each non-reporting facility by share of capacity) and the corresponding plant-specific emission factors. N<sub>2</sub>O emissions for 2007 and 2008 were reported under Category 2.B.10 Other (Confidential Petrochemicals – N<sub>2</sub>O Emissions) due to confidentiality of carbon black production data.

### Ethylene Dichloride Production (CRT Category 2.B.8)

CH<sub>4</sub> 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<sub>4</sub> emission estimates. The annual EDC production data comes from the Canadian C<sub>2</sub>+ 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<sub>4</sub> 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<sub>4</sub> emissions are reported under CRT Category 2.B.8.g Other (Confidential Petrochemicals – CO<sub>2</sub> and CH<sub>4</sub> Emissions).

### Ethylene Oxide (CRT Category 2.B.8)

CO<sub>2</sub> and CH<sub>4</sub> emissions from the production of Ethylene Oxide were estimated using a 2006 IPCC Tier 1 method, which involved multiplication of annual plant-specific production quantities by emission factors. Tier 1 CO<sub>2</sub> and CH<sub>4</sub> emission factors used were selected from tables 3.20 and 3.21 of the 2006 IPCC Guidelines based on consultant knowledge of the industry (Cheminfo, 2010). The sources of activity data and emission factors, in addition to all data disaggregation methodologies, assumptions, and missing data imputation techniques are described in Table 4–11.

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

Table 4–11 Data Sources and Methodologies Used in the Ethylene Oxide Estimate

Variable	Years	Data Source and Methodology
Activity Data	1990–2009	National production from the Canadian C <sub>2</sub> + Petrochemical Report was disaggregated to individual plants based on their capacity share (Cheminfo, 2010).
	2010–2015	Interpolated at the plant-level using 2009 and 2016 data.
	2016	All plants: Plant-level data reported to Statistics Canada's Industrial Chemicals and Synthetic Resins (ISCR) survey.
	2017–2018	2 plants: Plant-level data reported the ICSR. 2 plants: Aggregated company-level data reported to the ICSR, disaggregated using 2016 plant-level production ratios
	2019–present	2 plants: Plant-level data reported the ICSR. 2 plants: Missing company-level data was imputed by Statistics Canada by deflating monetary shipment data from the Annual Survey of Manufacturing and Logging or the Monthly Survey of Manufacturing to calculate growth or decline from 2018 production levels. This aggregated company-level imputed data was then disaggregated using 2016 plant-level production ratios.
CO <sub>2</sub> Emission Factors	All years	3 plants: The consultant had knowledge of plant catalyst selectivities and industrial process CO <sub>2</sub> rates; Tier 1 CO <sub>2</sub> emission factors were selected or calculated using Table 3.20 of 2006 IPCC Guidelines (Cheminfo, 2010). 2 plants: The consultant did not have knowledge of plant catalyst selectivities; the default Tier 1 CO <sub>2</sub> emission factor for the oxygen process in Table 3.20 was selected (Cheminfo, 2010).
CH <sub>4</sub> Emission Factors	All years	All plants: No information on thermal treatment was available; the default Tier 1 CH <sub>4</sub> emission factor was selected from Table 3.21 of the 2006 IPCC Guidelines, Volume 3 (Cheminfo, 2010).

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

CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> were derived as weighted averages of the reported 2007–2009 data. Two sector-wide process emission factors, one for each CH<sub>4</sub> and N<sub>2</sub>O, were also calculated as weighted averages using the same set of data reported by the two facilities (1.3 kg CH<sub>4</sub>/t product and 0.032 kg N<sub>2</sub>O/t product).

The sector-wide CH<sub>4</sub> EF value is lower than the IPCC default value of 11 kg CH<sub>4</sub>/t product. It is suspected that the IPCC default EF, which is based on only one study, has included CH<sub>4</sub> from the combustion of fuel as well. The Canadian EF only includes the CH<sub>4</sub> 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 onwards are obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

To protect confidential carbon black activity data, CH<sub>4</sub> emission values are reported under 2.B.8.g Other (Confidential Petrochemicals – CO<sub>2</sub> and CH<sub>4</sub> Emissions) and N<sub>2</sub>O emissions values are reported under 2.B.10 Other (Confidential Petrochemicals – N<sub>2</sub>O Emissions) from 1990 to 2008.

## Styrene Production (CRT Category 2.B.8)

Process CO<sub>2</sub> emissions can come from the combustion of the process off-gas (fuel gas) as fuel or from flaring of over-pressured process streams. CH<sub>4</sub> could be present along with the process reactants ethylene and benzene and would be emitted if there is any venting of these process or recycle streams. Fugitive emissions from these streams would also contain methane (Cheminfo Services, 2010).

In the absence of data from operating facilities, a Tier 1 approach was taken to develop process CH<sub>4</sub> emission estimates. Annual styrene production data were retrieved from the Canadian C<sub>2</sub>+ 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 onwards, production data are retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

The default process CH<sub>4</sub> 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<sub>4</sub> emission values are reported under 2.B.8.g Other (Confidential Petrochemicals – CO<sub>2</sub> and CH<sub>4</sub> Emissions) for the entire time series to protect confidential styrene activity data.

Activity data for several petrochemical categories contain confidential data that needs to be protected for certain years within the time series. Table 4–12 summarizes, by period of the time series, the categories that need to have their associated GHG emission estimates aggregated in the CRT reporting. CO<sub>2</sub> emissions and CH<sub>4</sub> emissions are aggregated under category 2.B.8.g Other (Confidential Petrochemicals – CO<sub>2</sub> and CH<sub>4</sub> Emissions) and N<sub>2</sub>O emissions are aggregated under category 2.B.10 Other (Confidential Petrochemicals – N<sub>2</sub>O Emissions).

Table 4–12 Categories Included in Confidential CRT Node

	1990–2006	2007–2008	2009–present
Methanol	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	-	-
Ethylene	-	N <sub>2</sub> O	-
Ethylene dichloride and vinyl chloride monomer	CH <sub>4</sub>	-	-
Ethylene oxide	CO <sub>2</sub> , CH <sub>4</sub>	CH <sub>4</sub>	CH <sub>4</sub>
Carbon black	CH <sub>4</sub> , N <sub>2</sub> O	CH <sub>4</sub> , N <sub>2</sub> O	-
Styrene	CH <sub>4</sub>	CH <sub>4</sub>	CH <sub>4</sub>
Note: - indicates no aggregation is occurring			

### Fluorochemical Production (By-product Emissions, CRT Category 2.B.9.a)

To estimate HFC-23 emissions from HCFC-22 production, the total HCFC-22 production was multiplied by the IPCC Tier 1 default emission factor of 0.04 t HFC-23/t HCFC-22 produced (IPCC, 2006). It was assumed that destruction (through thermal oxidation) or transformation of HFC-23 was not practised in Canada. The 1990–1992 production data was collected by Environment Canada from HCFC producers.<sup>13</sup>

### Other Uses of Urea (CRT Category 2.B.10 Other [Other uses of Urea – CO<sub>2</sub> Emissions])

There is no available methodology in the IPCC 2006 Guidelines for the estimation of emissions coming from other uses of urea. Because it is believed that the Canadian context would be similar to that of the United States for this category, the Canadian methodology in the following equation was derived from that described in the U.S. National GHG Inventory.<sup>14</sup>

Equation 4–12

$$\begin{aligned}
 & \text{Total CO}_2 \text{ emissions (t) =} \\
 & [U_{\text{production}} - U_{\text{fertilizer}} + U_{\text{imports}} - U_{\text{exports}} - (U_{\text{UAN fertilizer}} - U_{\text{UAN imports}}) - U_{\text{UAN exports}} - U_{\text{SCR}}] \times EF
 \end{aligned}$$

$U_{\text{production}}$  = Urea produced in Canada (t)  
 $U_{\text{fertilizer}}, U_{\text{UAN fertilizer}}$  = Urea applied as fertilizer (t) from urea and urea-ammonium-nitrate (UAN)  
 $U_{\text{imports}}, U_{\text{UAN imports}}$  = Urea imported to Canada (t) as urea or urea-ammonium-nitrate (UAN)  
 $U_{\text{exports}}, U_{\text{UAN exports}}$  = Urea exported from Canada (t) as urea or urea-ammonium-nitrate (UAN)  
 $U_{\text{SCR}}$  = Urea used as an additive in catalytic converters (t)  
 $EF$  = 0.733 t CO<sub>2</sub> emitted per t urea

The collection of urea production data is described in section 4.5.

Import and export data for urea and urea-ammonium-nitrate from 1990–present were obtained from Statistics Canada's Canadian International Merchandise Trade Web Application.<sup>15</sup>

Provincial-level data for quantities of urea and urea-ammonium-nitrate used as fertilizer were obtained from the AFOLU sector and summed to determine the national total. Lastly, national totals for urea used as an additive in catalytic converters was calculated based on the estimated emissions, which are discussed in section 4.15 and reported in CRT 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.

To estimate the CO<sub>2</sub> emitted from Other Uses of Urea, an emission factor of 0.733 kg CO<sub>2</sub> emitted/kg of urea used is applied. This factor is the stoichiometric quantity of CO<sub>2</sub> required to produce urea, assuming the complete conversion of ammonia and CO<sub>2</sub> to urea (IPCC, 2006). The same factor is used as the emission factor based on the assumption that all CO<sub>2</sub> contained in the manufactured urea is emitted upon use.

13 Bovet Y and Guilbault Y. 2004–2006. Personal communications (emails from Bovet Y and Guilbault Y to Au A, Environment Canada dated 2004–2006). UPCIS.

14 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](https://www.epa.gov/sites/production/files/2018-01/documents/2018_complete_report.pdf), pg.4-28.

15 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. Uncertainty Assessment and Time-series Consistency

The uncertainty assessments for Carbide Production, Petrochemical and Carbon Black Production were based on the Cheminfo Services (2010) study, while the assessment for Fluorochemical production and Other Uses of Urea follow the 2006 IPCC Guidelines. As part of the Cheminfo (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided uncertainty estimates for their data. As a result, uncertainties based on expert knowledge of the industry were used in the analysis. Table 4–13 summarizes the Tier level and uncertainty ranges estimated for each subcategory.

Category	CRT Category	Uncertainty Assessment Tier level	Gas	Uncertainty Range	Year Range
Carbide Production	2.B.5	Tier 1	CO <sub>2</sub>	±16% to ±27%	1990–2001
Methanol Production	2.B.8.a, 2.B.10	Tier 1	CH <sub>4</sub>	±8% to ±15%	1990–2023
			N <sub>2</sub> O	±11% to ±30%	
			CO <sub>2</sub>	±4% to ±11%	
Ethylene Production	2.B.8.b, 2.B.10	Tier 1	CH <sub>4</sub>	±7% to ±12%	1990–2023
			N <sub>2</sub> O	±12% to ±21%	
			CO <sub>2</sub>	±4% to ±7%	
Ethylene Dichloride Production	2.B.8.c	Tier 1	CH <sub>4</sub>	±21%	1990–2006
Ethylene Oxide	2.B.8.d	Tier 2	CH <sub>4</sub>	±30% & ±39%	1990–2023
			CO <sub>2</sub>	±5% & ±8%	
Carbon Black Production	2.B.8.f, 2.B.10	Tier 1	CH <sub>4</sub>	±6% to ±11%	1990–2023
			N <sub>2</sub> O	±11% to ±13%	
			CO <sub>2</sub>	±2% to ±7%	
Styrene Production	2.B.8.g	Tier 1	CH <sub>4</sub>	±20% to ±22%	1990–2023
Fluorochemical Production <sup>a</sup>	2.B.9.a	Tier 1	HFC-23	±50%	1990–1992
Other Uses of Urea <sup>b</sup>	2.B.10	Tier 1	CO <sub>2</sub>	±4% to ±8%	1990–2023

Notes:

a. Uncertainty in the HFC-23 emission estimates has not been assessed. However, it is believed that the production data reported by HCFC-22 producers was reasonably accurate. A significant source of uncertainty could be attributed to the Tier 1 default emission factor, which does not reflect facility-specific conditions, as the correlation between the quantity of HFC-23 emitted and the HCFC-22 production rate can vary with plant infrastructure and operating conditions (IPCC, 2006). The IPCC 2006 Guidelines state that a 50% uncertainty factor for a Tier 1 HFC production estimate may be appropriate.

b. The assessment considered the uncertainties associated with urea production data, import and export data, urea used in agriculture data, urea used in catalytic converters, and the urea-to-CO<sub>2</sub> 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<sub>2</sub>, regardless of the type of final product.

### 4.9.4. QA/QC and Verification

CO<sub>2</sub> and HFC emission estimates for categories under Petrochemical and Carbon Black Production and the Fluorochemical Production category have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Emission estimates of the other two GHGs (i.e., CH<sub>4</sub> and N<sub>2</sub>O) for the same categories have undergone informal quality control checks.

In addition to the Tier 1 QC Checklist, the following informal checks are conducted for Ethylene Oxide Production:

- Check to ensure that activity data are reported on a calendar year basis and that missing data is imputed by Statistics Canada using surrogate data consistent with methods in the 2006 IPCC Guidelines, Volume 1, Chapter 5.
- Check new or revised activity data for unexplained inter-year differences that are greater than 10%, and contacting data sources for verification and explanation as required.

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

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

#### 4.9.5. Recalculations

##### Methanol Production (CRT Category 2.B.8 and CRT Category 2.B.10)

Methanol Production emissions estimates were recalculated for 2011 to 2022 due to a method change that updated the emission factors to reflect data reported to the GHGRP. The impact of the change ranges from a maximum of -76 kt CO<sub>2</sub> eq in 2013 to a minimum of -8.1 kt CO<sub>2</sub> eq in 2016.

##### Ethylene Oxide Production (CRT Category 2.B.8)

Ethylene Oxide Production emission estimates for 2022 were recalculated downwards by -2.82 kt CO<sub>2</sub> eq using corrected ICSR activity data.

##### Other Uses of Urea (CRT Category 2.B.10 Other [Other Uses of Urea – CO<sub>2</sub> Emissions])

Other Uses of Urea emission estimates were recalculated for all years using revisions to 1990 to 2020 fertilizer use data, 2009 to 2022 SCR vehicles data, and 2021 to 2022 urea import data. The recalculations ranged from -0.9 kt CO<sub>2</sub> eq in 2015 to +1.8 kt CO<sub>2</sub> eq in 2019.

#### 4.9.6. Planned Improvements

##### Titanium Dioxide Production (CRT Category 2.B.6)

As noted in section 4.9.2, industrial process emissions from CRT Category 2.B.6 are currently reported in other Energy and IPPU sector categories (Table 4–10). As such, the notation key “IE” is used in the CRT for this category. To ensure proper emission reallocation back to the category for which order of magnitude is expected to be potentially greater than 500 kt CO<sub>2</sub> eq, various data sources are being explored. Efforts will also be made to ensure that process input quantities are reconciled with the other inventory categories to avoid double-counting.

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

##### 4.10.1. Category Description

The Iron and Steel Production category contributed 9510 kt (1.4%) to Canada’s total emissions in 2023, a 12% decrease from 2005.

There are four integrated iron and steel mills in Canada, all located in Ontario. One of the mills uses the electric arc furnace (EAF) process to produce a portion of its steel. In 2013, one of the integrated iron and steel mills closed its iron and steel producing facilities, while maintaining their coke oven battery for coke production. Annexe 3.3 provides additional detail on the technologies employed in Canada to produce iron and steel.

In the production of pig iron, carbon plays the dual role of fuel and reductant. Emissions from the combustion of fuels such as coke oven gas are not reported in this category, but rather under the appropriate industrial category in the Energy sector.

Total emissions in the Iron and Steel Production category are the sum of emissions from the following sources:

- CO<sub>2</sub> emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron
- CO<sub>2</sub> 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<sub>2</sub> emissions given off by limestone flux in the blast furnace
- CH<sub>4</sub> emissions from metallurgical coke and natural gas 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<sub>met\_coke</sub>), natural gas (EF<sub>NG</sub>) and carbon content of pig iron. For more specific information on the Canadian Iron and Steel sector, refer to section A3.3.

## Pig Iron Production (CRT Category 2.C.1.b)

CO<sub>2</sub> emissions from the production of pig iron from the blast furnace are reported under the CRT category 2.C.1.b Pig Iron. In 2024, a change in methodology was implemented to the emissions estimate of pig iron production. This involved the inclusion of natural gas used as a reductant, in addition to metallurgical coke, in the blast furnace. A voluntary survey was sent to facilities producing pig iron to obtain the volumes of natural gas used from 1990 to 2017. Two of the three blast furnace operators responded to the survey. The collected data, along with GHGRP data from 2018 to present were incorporated into the time series. Previously, all the natural gas used in the iron and steel sector was reported under CRT category 1.A.2.a. A reconciliation with the energy category was completed to eliminate double counting. These emissions were estimated using the following Equation 4–13:

Equation 4–13

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

$E_{CO2\_PI}$	=	process emissions from pig iron production, kt
$EF_{met\_coke}$	=	year-specific emission factors (t CO <sub>2</sub> / t metallurgical coke used)
$M_{met\_coke}$	=	mass of metallurgical coke, ore, kt;
$EF_{NG}$	=	year-specific emission factor (g CO <sub>2</sub> / m <sup>3</sup> of natural gas used)
$V_{NG}$	=	volume of natural gas (m <sup>3</sup> )
$CC_{PI}$	=	carbon content of metallurgical coke, pig iron, %
$P_{PI}$	=	production of pig iron, kt
$44/12$	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon

Table 4–14 summarizes the different sources of activity data and other variables used in the calculation of Equation 4–13.

The emission factors for coke use ( $EF_{met\_coke}$ ) were obtained from the Cheminfo Services (2010) study, where the four integrated steel mills in Canada were surveyed for their coke consumption and emission estimates for the years 1990 to 2009. The emission factors for natural gas ( $EF_{NG}$ ) were obtained from Annex 6, Table A6.1-1 CO<sub>2</sub> Emissions Factors for Marketable Natural Gas.

Facility-level data began being collected through the Greenhouse Gas Reporting Program in 2017 and year-specific national averages of facility provided data are used in the calculation of emissions from Pig Iron as indicated in Table 4–14.

CH<sub>4</sub> emissions were estimated by multiplying the mass of metallurgical coke (Statistics Canada 1990–2023) and the volume of natural gas used by their respective emission factor. The emission factor value for CH<sub>4</sub> emissions from coke use in the iron and steel industry is not presented in this report to protect the confidentiality of the data.

A range of emission factors used for iron ore reduction with coke and carbon contents of pig iron are included in Annex 6.

## Direct Reduced Iron (CRT Category 2.C.1.c)

In Canada, there is currently only one facility that produces sponge iron through the Direct Reduced Iron (DRI) process and these emissions are reported under category 1.A.2.a due to confidentiality concerns, as well as difficulty in disaggregating the use of natural gas.

Table 4–14 Sources of Iron Production Activity Data and Other Variables Used in Equation 4–13		
Variable	Year	Source
$M_{met\_coke}$ – metallurgical coke used	1990–present	RESO, Statistics Canada (Cat. No. 57-003)
$P_{PI}$ – Pig Iron production	1990–2003	Statistics Canada (Cat. No. 41-001)
	2004–2012	Statistics Canada (Cat. No. 41-019)
	2013–2016	Canadian Steel Producers Association (CSPA, 2019)
	2017–present	GHGRP (ECCC, 2024)
$EF_{met\_coke}$ – metallurgical coke emission factor	1990–2009	Cheminfo (2010)
	2010–2016	constant – average of 2009 (Cheminfo, 2010) and yearly national average of GHGRP data for the years 2017–2019 (ECCC, 2024)
	2017–present	GHGRP (ECCC, 2024)
$V_{NG}$ – volume of natural gas used	1990–2017	Voluntary facility survey responses
	2018–present	GHGRP (ECCC, 2024)
$EF_{NG}$ – natural gas emission factor	1990–present	Annex 6, Table A6.1-1 Emissions Factors for Marketable Natural Gas
$CC_{PI}$ – carbon content of pig iron	1990–2012	Canadian Steel Producers Association (Chan, 2009)
	2013–2016	constant – average of CSPA value and the national average of GHGRP data for 2017 (ECCC, 2024)
	2017–present	GHGRP (ECCC, 2024)

## Sinter (CRT Category 2.C.1.d)

Sinter production is occurring at the integrated mills, however the emissions of coke oven and blast furnace gases are reported under category 1.A.2.a since these gases are used in a variety of processes at the facilities and the specific portion used for sintering cannot be disaggregated. In addition, any other material used in the sinter process containing carbon is reported under category 2.D.3 Other and Undifferentiated, through data reported to the RESD.

## Steel Production (CRT Category 2.C.1.a)

CO<sub>2</sub> emissions from the production of steel and ferroalloys are reported under CRT category 2.C.1.a Steel since production of ferroalloys is a direct production of specialty steels from iron ore via the electric arc furnace process.

The emissions from steel production were estimated using [Equation 4–14](#):

Equation 4–14

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

$E_{CO2\_steel}$  = process emissions from steel production, kt  
 $CC_j$  = 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<sub>2</sub> to the molecular weight of carbon  
 $EF_k$  = emission factors (t CO<sub>2</sub> / t steel produced)  
 $P_k$  = steel production by either EAF or BOF, kt

According to [Equation 4–14](#), part of the CO<sub>2</sub> emitted from the steel production process is estimated on the basis of the difference between the amount of carbon in the iron and in scrap steel used to make steel and the amount of carbon in the steel produced in basic oxygen furnaces (BOFs) and electric arc furnaces (EAFs). It should be noted that the amount of pig iron fed to steel furnaces (used in [Equation 4–14](#)) is not equal to the amount of total pig iron production (used in [Equation 4–13](#)). As part of the steel production process, emissions are also generated by the consumption of electrodes in EAFs and in secondary ladle metallurgy. These are accounted for in the last two terms of the equation. [Table 4–15](#) summarizes all the sources of activity data and other variables used in the calculation of [Equation 4–14](#).

It should be noted that RESD data published for any given year is preliminary and subject to revision in subsequent publications. The use of petroleum coke in EAF electrodes is reported by Statistics Canada with all other non-energy uses of petroleum coke. To avoid double counting, the CO<sub>2</sub> 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<sub>2</sub> generated by the imported electrodes needs to be subtracted from the emissions from electrode consumption before being subtracted from the total non-energy emissions.

The facility-specific emission factors from the GHGRP are treated as confidential since they are derived from business-sensitive data. However, a range of national emission factors and carbon contents are available in Annex 6.

Table 4–15 **Steel Production Activity Data and Other Variables Used in Equation 4–14**

Variable	Year	Source
$M_i$ – pig iron, scrap steel, and $P_k$ – EAF and BOF production	1990–2003	Statistics Canada (Cat. No. 41-001)
	2004–2012	Statistics Canada (Cat. No. 41-019)
	2013–2017	Canadian Steel Producers Association (CSPA, 2019)
	2018–present	GHGRP (ECCC, 2024)
$CC_i$ – pig iron, scrap steel, EAF and BOF	1990–2012	Canadian Steel Producers Association (Chan K., 2009)
	2013–2016	constant – average of CSPA value and the national average of GHGRP data for 2017 (ECCC, 2024)
	2017–present	GHGRP (ECCC, 2024)
$EF_k$ – emissions factor for EAF and BOF	1990–2012	Canadian Steel Producers Association (Chan K., 2009)
	2013–2016	constant – average of CSPA value and the national average of GHGRP data for 2017 and 2018 (ECCC, 2024)
	2017–present	GHGRP (ECCC, 2024)

## Pellet Production (CRT Category 2.C.1.e)

In Canada, there are two iron ore pellet producing facilities, for which emissions are currently not estimated due to lack of suitable activity data for the entire time-series. Work is ongoing to identify potential sources of activity data for eventual inclusion in the inventory.

## Limestone use in Iron and Steel Furnaces (CRT Category 2.C.1.f)

The methodology used to estimate CO<sub>2</sub> emissions from limestone and dolomite consumed as a flux in iron and steel furnaces is described in section 4.4.2.

Data on provincial-level metallurgical coke use from RESD (Statistics Canada, n.d.[e]) was used to distribute national-level emissions to the applicable provinces.

### 4.10.3. Uncertainty Assessment 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 and natural gas use, the emission factors, 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<sub>2</sub> and CH<sub>4</sub> emission estimates associated with this category are ±5.15% and ±405%, respectively.

### 4.10.4. QA/QC and Verification

Iron and Steel Production (CO<sub>2</sub>) 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. Recalculations

CO<sub>2</sub> emissions for this category were recalculated due the methodological change to incorporate the use of natural gas as a reductant in pig iron production. The magnitude of the recalculations ranged from +6.8 kt to +1.3 Mt CO<sub>2</sub> eq and impacted the entire time series from 1990–2022.

### 4.10.6. Planned Improvements

Efforts are currently ongoing to find a suitable source of activity data to estimate the emissions from pellet production (CRT Category 2.C.1.e) for the entire time series.

## 4.11. Ferroalloy Production (CRT Category 2.C.2)

A 2010 Cheminfo study evaluated the potential emissions from the production of ferroalloys in Canada and found that there were 5 facilities known to have produced ferroalloys since 1990. Four of these facilities were still in operation in 2021, two of which produced ferrosilicon (FeSi) using conventional carbon-reduction-Electric Arc Furnace (EAF) process. The other two facilities use the aluminothermic process to reduce their oxides, and thus have no process CO<sub>2</sub> emissions. The fifth facility produced ferromanganese (FeMn) and siliconmanganese (SiMn) from manganese oxide ore, scrap iron and coke using an EAF, however it closed in May 1991.

Emissions from these facilities are included as part of the total production from EAF in CRT category 2.C.1.a Steel since they cannot be disaggregated due to confidentiality concerns.

## 4.12. Aluminium Production (CRT Category 2.C.3)

### 4.12.1. Category Description

The Aluminium Production category accounted for 6090 kt (0.9%) of Canada's emissions in 2023, representing an overall decrease in emissions of 27% since 2005.

Emissions from the combustion of fossil fuels used in the production of baked anodes are covered in the Energy sector, CRT category 1.A.2.b. Emissions arising from the combustion of volatile matter released during the baking operation and from the baking furnace packing material are accounted for under the Aluminium Production category 2.C.3 (IPCC 2006).

In addition to CO<sub>2</sub> emissions, primary aluminium smelting is a source of carbon tetrafluoride (CF<sub>4</sub>) and carbon hexafluoride (C<sub>2</sub>F<sub>6</sub>), which are included in this submission. This submission also includes a small amount of SF<sub>6</sub> 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.<sup>16</sup> The consumption of SF<sub>6</sub> is highly variable depending on whether one or both of these operations (SF<sub>6</sub> use as a cover gas and/or purifying agent) occur within a given year, causing significant changes in the trend of SF<sub>6</sub> in this source category.

Aluminium plants are characterized by the type of anode technology employed. In general, older plants using Söderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The last Söderberg aluminium smelter in Canada was closed in 2015,<sup>17</sup> and the 10 plants currently in operation have focused on modernizing their facilities and improving production efficiency.

### 4.12.2. Methodological Issues

As of 2013, Canada's aluminium companies, which operate in Quebec and British Columbia, have developed and reported their GHG emissions under the methodological protocols and reporting rules of the Western Climate Initiative, which are consistent with the methods presented in the 2006 IPCC Guidelines. Under a memorandum of understanding signed in 2006 between Environment Canada and the Aluminium Association of Canada (AAC), Environment Canada receives the same data sets as those provided by AAC member companies in the provinces. As of the data year 2018, aluminium companies have been reporting their emissions directly to ECCC's GHGRP (ECCC, 2024), 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<sub>2</sub>, PFC and SF<sub>6</sub> 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<sub>6</sub> emissions are equal to consumption in the aluminium industry.

Depending on data availability for each year in the time series, the estimation techniques applied vary between Tiers 2 and 3 and depend on the individual facility. All facilities in Canada have reported CO<sub>2</sub> emissions at a Tier 3 level since 2017, PFC emissions at a Tier 3 level since 2016, and SF<sub>6</sub> emissions at a Tier 3 level for the entire time series. [Table 4–16](#) 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).

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

17 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 4–16 Aluminium Facilities in Canada: Method Tier and Emission Factor Information

Aluminium Facility	Years in Operation	CO <sub>2</sub>		PFC		SF <sub>6</sub>	
		Method / EF		Method / EF		Method	EF
		T2 / CS	T3 / PS	T2 / CS	T3 / PS	Level	
Rio Tinto							
Usine Isle-Maligne	1990–2000	1990–2000		1990–2000		T3	PS
Usine de Bauhamois	1990–2009	1990–2009		1990–2009			
Usine Grande-Baie	1990–present	1990–2007	2008–present*	1990–1995	1996–present	T3	PS
Jonquière	1990–2004	1990–2004		1990–2004			
Usine Arvida	1990–present	1990–2007	2008–present	1990–2006	2007–present	T3	PS
AP-60	2013–present		2013–present	2013–2015	2016–present	T3	PS
Usine Laterrière	1990–present	1990–2007	2008–present	1990–2013	2014–present	T3	PS
Usine Shawinigan	1990–2013	1990–2007	2008–2013	1990–2013			
Usine Alma	2000–present	2000–2007	2008–present*	2000–2007	2008–present	T3	PS
Kitimat	1990–present	1990–2007	2008–present*	1990–2006	2007–present	T3	PS
Alcoa							
Usine Becancour	1990–present	1990–2016	2017–present*	1990–2004	2005–present	T3	PS
Usine de Baie-Comeau	1990–present	1990–2016	2017–present	1990–2003	2004–present	T3	PS
Deschambault	1993–present	1993–2016	2017–present*	1990–2004	2005–present	T3	PS
Alouette							
Sept-Iles	1992–present	1992–1994	1995–present*	1990–2004	2005–present	T3	PS
Notes: *Method uses facility specific variables, with the exception of hydrogen content of pitch from anode and cathode baking, which is obtained from IAI (2006). CS = country specific PS = plant specific							

#### 4.12.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for the Aluminium Production category (i.e., for the CO<sub>2</sub>, PFC and SF<sub>6</sub> 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<sub>2</sub>, PFC and SF<sub>6</sub> estimates are  $\pm 7\%$ ,  $\pm 9\%$  and  $\pm 5\%$ , respectively. For the CO<sub>2</sub> and PFC estimates, it should be noted that the uncertainty assessment is done for only one year of the time series (2006 for CO<sub>2</sub> 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<sub>6</sub> 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<sub>6</sub> emission estimates is the same for both Aluminium Production and Magnesium Casting.

#### 4.12.4. QA/QC and Verification

CO<sub>2</sub> and PFC emissions from Aluminium Production are key categories that have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

#### 4.12.5. Recalculations

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

#### 4.12.6. Planned Improvements

No improvements are currently planned for this category.

## 4.13. Magnesium Production (CRT Category 2.C.4)

### 4.13.1. Category Description

From 1990 to 2008, four magnesium production facilities operated in Canada: Norsk Hydro until 2007, Timminco Metals until 2008, Métallurgie Magnola between 2000 and 2003 and MagCan from 1990 to 1991. Review is conducted in-house periodically to ensure that new facilities are included in emission estimates. After 2008, there has been no magnesium production in Canada.

Primary magnesium is commonly produced through an electrolytic or thermal reduction process of mineral sources. CO<sub>2</sub> is released during the calcination of carbonate-based raw materials, which takes place prior to the main electrolytic or thermal reduction process. Of these facilities, two used magnesite as a raw material, one used dolomite and the remaining one used asbestos. Since asbestos is not a carbonate-containing raw material, CO<sub>2</sub> emissions were only estimated for facilities using magnesite and dolomite.

In addition, SF<sub>6</sub> is emitted during both magnesium production and casting processes, where it is used as a cover gas to prevent oxidation of the molten metals. For magnesium production, fluctuations in SF<sub>6</sub> emissions could be attributed to use of substitutes of SF<sub>6</sub> and variations in productions.

There were 11 magnesium casting companies in operation during the 1990–2004 period (Cheminfo Services, 2005b). Only a few of them had used SF<sub>6</sub> every year during the entire period. Some casters started using SF<sub>6</sub> towards the mid- or late 1990s, whereas others replaced it with an alternative gas, such as sulphur dioxide (SO<sub>2</sub>). During the 2005–2008 period, only seven companies were in operation and had used SF<sub>6</sub>. In 2009, one company shut down its operations and one moved its operations to the United States. It is estimated that the remaining five magnesium casting companies in operation released about 247 kt CO<sub>2</sub> eq in 2023 (< 0.1% of Canada's emissions).

### 4.13.2. Methodological Issues

CO<sub>2</sub> emissions from magnesium production facilities are calculated by applying Tier 1 IPCC default emission factors for magnesite (2.83 t CO<sub>2</sub>/t primary Mg produced) and for dolomite (5.13 t CO<sub>2</sub>/t primary Mg produced), based on the type of carbonate raw material used, to facility-specific production values.

When facility-specific production data were not available, they were estimated based on total national primary magnesium production obtained from the *Canadian Minerals Yearbook* (NRCan, 1990-2006) and facility-specific production capacities published by the United States Geological Survey (Kramer, 2001). For years where the production capacity data was not available, linear interpolation was done or held constant depending on the situation.

The technique applied to estimate SF<sub>6</sub> emissions from magnesium production and casting is considered to be a Tier 2 type method, as it is based on the reporting of facility-specific emission data, consumption data or both. The approach for estimating SF<sub>6</sub> emissions from production and casting companies assumes all SF<sub>6</sub> used as a cover gas is emitted to the atmosphere.

SF<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub> emissions. Both companies reported that they had estimated emissions based on the assumption that SF<sub>6</sub> emissions are equivalent to SF<sub>6</sub> consumption. However, they used different methods for estimating their SF<sub>6</sub> consumption. Norsk Hydro confirmed the use of the weight difference method,<sup>18</sup> 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<sub>6</sub> use.<sup>19</sup> In this method, accounting of delivered purchases and inventory changes of SF<sub>6</sub> 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.

SF<sub>6</sub> use data from casting facilities for the 1990–2023 time series came from a combination of data sources. For 1990 to 2004, the majority of the companies have provided SF<sub>6</sub> 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

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

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

studies to collect data. For 2005–2007, SF<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub> use data, but provided reasonable assumptions that could be used to estimate the 2009 SF<sub>6</sub> use. SF<sub>6</sub> use data for 2009 was provided by the other five companies. For 2014 to 2019, SF<sub>6</sub> use data was provided by four out of five operating magnesium casting companies through a voluntary data collection. For 2020 onwards, SF<sub>6</sub> data was obtained through a combination of voluntary data collection and SF<sub>6</sub> emission data reported in the GHGRP. Facilities that reported to the GHGRP confirmed that the SF<sub>6</sub> emission values reported were solely for emissions coming from the use of SF<sub>6</sub> as cover gas and it is assumed that the situation remains the same for subsequent years. In the case where SF<sub>6</sub> use data was not available for a company during the years 2010 to 2023, facility-specific SF<sub>6</sub> 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<sub>6</sub> use data” to “provincial gross output for the most recent year for which the facility provided SF<sub>6</sub> use data” was calculated. SF<sub>6</sub> emissions, for the years with no SF<sub>6</sub> use data, were then estimated by multiplying the ratio by the most recent facility-specific SF<sub>6</sub> emission value.

SF<sub>6</sub> 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<sub>6</sub> consumed over a period within the year.

#### 4.13.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for CO<sub>2</sub> emissions from Magnesium Production. It considers the uncertainty associated with facility production capacities, total primary magnesium production, interpolated values, and Tier 1 IPCC default emission factors. The uncertainty of CO<sub>2</sub> emissions varied from 5.40% to 42.43% over 1990 to 2008.

The IPCC Tier 1 methodology is used for the time series of 1990–2008 to quantify CO<sub>2</sub> emissions from Magnesium Production.

A combined Tier 1 uncertainty assessment of SF<sub>6</sub> emissions was performed for Magnesium Production and Magnesium Casting. It took into account the uncertainty associated with the SF<sub>6</sub> data reported by each facility. The uncertainty varied from ±2.6% to ±20.7% from 1990 to 2023.

The methodology, which equates consumption of SF<sub>6</sub> as a cover gas to emissions of SF<sub>6</sub>, is applied over the time series with some assumptions for some historical years, as discussed in the Methodological Issues section.

#### 4.13.4. QA/QC and Verification

The Magnesium Production category has undergone checks as outlined in Canada’s General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as outlined in Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. There is a step (step 4.4) in Canada’s current QC process for detecting large fluctuations (e.g., in production or in implied emission factors).

The Magnesium Casting category has undergone informal quality control checks.

#### 4.13.5. Recalculations

CO<sub>2</sub> emissions from Magnesium Production were previously reported in Non-Metallurgical Magnesia Production (Magnesite Use). These were recalculated and reallocated to improve alignment with 2006 IPCC Guidelines. The changes were between 15 kt to 178kt for 1990 to 2008.

Emission estimates for 2010 to 2022 were recalculated for Magnesium Casting due to updates in provincial gross output data. The changes were between -36 kt to +43 kt.

#### 4.13.6. Planned Improvements

No improvements are currently planned for this category.

## 4.14. Lead and Zinc Production (CRT Category 2.C.5 and 2.C.6)

### 4.14.1. Category Description

There were two primary lead production facilities in Canada throughout the time series using a direct smelting process, with one facility closing permanently in 2018. There were also nine secondary production facilities processing recycled lead for reuse and four of these facilities have since closed.

Zinc was produced at four facilities throughout the time series. Two of these facilities have ceased operation in 2010 and 2020. One of the two remaining facilities uses a pyro metallurgical process and the other a hydrometallurgical process. The two zinc facilities that closed used a hydrometallurgical process.

Based on national production data, a Tier 1 emission estimate was completed for lead and zinc. However, upon further investigation, the use of reductants accounts for most of these emissions. The fuel and reductant use data are reported to the RESD and owing to its aggregated format, it is currently not possible to allocate the appropriate portion of emissions to CRT category 2.C.5 for Lead Production and 2.C.6 for Zinc Production. Thus, emissions are currently accounted for as part of CRT Category 2.D.3 Other (Other and Undifferentiated), and Category 1.A.2.b Non Ferrous Metals. Work is ongoing to identify a method to disaggregate the quantity of reductants throughout the time series.

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

### 4.15.1. Category Description

#### Non-Energy Products from Fuels and Solvent Use (CRT 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<sub>2</sub> emissions. Also included in this category are emissions from the use of hydrocarbons (such as coal) as reductants for base metal smelting as well as petroleum-based solvents, cleaners and paint thinners.

The use of fossil fuels as feedstock, or for other non-energy purposes, is reported in an aggregated manner by Statistics Canada as “non-energy use” for each individual fuel. Also, to avoid double counting, in the event that CO<sub>2</sub> emissions resulting from non-energy fuel use are allocated to another category of the IPPU sector (as is the case for Ammonia Production, Petrochemical Production, Iron and Steel Production, and Aluminium Production), those emissions are subtracted from the total emissions from this category.

The Non-Energy Products from Fuels and Solvent Use category contributed 12 300 kt (1.8%) to Canada’s total emissions in 2023, a 24% increase from 2005.

#### CO<sub>2</sub> Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles (CRT Category 2.D.3)

Selective catalytic reduction (SCR) is an emission reduction technology that can use urea as a liquid-reducing agent to help reduce NO<sub>x</sub> emissions from vehicle exhaust. CO<sub>2</sub> emissions from the use of urea-based additives in the catalytic converters are considered non-combustive emissions. Emissions from the use of urea in SCR vehicles are estimated to be 42 kt CO<sub>2</sub> eq in 2023.

Table 4–17 **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 <sup>a</sup>
Note: a. Other products include waxes, paraffin and unfinished products (items that cannot be identified in end-product terms).		

## 4.15.2. Methodological Issues

### Non-Energy Products from Fuels and Solvent Use (CRT Category 2.D.1 and 2.D.3)

Emission factors for non-energy use of fuels were developed based on the total potential CO<sub>2</sub> emission rates and percentages of carbon stored in products. The total potential CO<sub>2</sub> 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 4–17](#).

Fuel quantity data for non-energy fuel usage was reported by the RESD (Statistics Canada, n.d.[e]). It should be noted that RESD data for any given year is preliminary and subject to revisions in subsequent publications. This data was multiplied by the emission factors shown in Annex 6 to estimate CO<sub>2</sub> 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<sub>2</sub> emission factor and by the ODU factor (which is 1 minus the percentage of carbon stored). The percentage of carbon stored in petroleum used as other products, which includes waxes, paraffin and unfinished products, was determined to be equivalent to the default factor from the revised 1996 IPCC Guidelines and not that for paraffin wax as per the 2006 IPCC guidelines, because the disaggregation of paraffin wax use is not possible due to the way the activity data is provided.

This technique is consistent with the method described in the 2006 IPCC Guidelines and is a Tier 1 type method, as it is based on the use of national consumption data and average national emission factors. Emissions of CH<sub>4</sub> and N<sub>2</sub>O for CRT category 2.D.3 are not estimated because there is no methodological guidance provided in the 2006 IPCC Guidelines. Additional details on the method used to calculate emissions from this category can be found in Annex 3.3, section A3.3.3.

### CO<sub>2</sub> Emissions from the Use of Urea in Selective Catalytic Reduction Vehicles (CRT Category 2.D.3)

The 2006 IPCC Guidelines recommend that Equation 3.2.2 (Volume 2) be used for the estimation of emissions from the use of urea-based additives in catalytic converters.

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 Annexe 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.<sup>20</sup>

<sup>20</sup> Rideout G. 2014. Personal communication (email from Rideout, G. to McKibbin S., Environment and Climate Change Canada dated November 4, 2014). Pollution Inventories and Reporting Division, Environment and Climate Change Canada.

#### 4.15.3. Uncertainty Assessment and Time-series Consistency

A Tier 1 uncertainty assessment was performed for the category of Non-Energy Products from Fuels and Solvent Use. The assessment considered the uncertainties associated with the activity data and emission factors (ICF Consulting, 2004). The uncertainty for the category was estimated at  $\pm 20\%$ . 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<sub>2</sub> Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles. The overall uncertainty was found to be  $\pm 50\%$ .

#### 4.15.4. QA/QC 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<sub>2</sub> Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles has undergone informal quality control checks throughout the emission estimation process.

#### 4.15.5. Recalculations

For the Non-Energy Products from Fuels and Solvent Use category, CO<sub>2</sub> emissions were recalculated for the entire time series due to updates to the RESD, updates to the use of lubricating oils and greases used in off-road two-stroke engines and the methodological change made to the Methanol Production model that impacted the amount of natural gas assumed to be used as feedstock. The overall impact of all the revisions ranges from a maximum of +920 kt in 2020 to a minimum -0.05 kt in 2006.

Revised activity data from 2009 to 2022 caused recalculations ranging from -1.8 kt in 2019 to +0.9 kt in 2015, for the category of use of urea in SCR vehicles.

#### 4.15.6. Planned Improvements

Emission factors for various non-energy petroleum products and natural gas were developed based on studies conducted in 1992 and 2005, respectively. Findings from Canada's 2023 in-country review recommended that the most critical improvement to be made is to better understand the extent to which the non-energy fuels accounted for by Statistics Canada are emissive or not, specifically for fuels that currently make-up most of the emissions for this category. There is a plan to evaluate the emissive nature of the most impactful fuels (e.g., Petroleum used for Other products) and update the ODU factor as necessary. In addition, as supporting information becomes available (i.e., information that would allow disaggregation of fuel data and allocation to the appropriate source category) for other (more specific) categories (e.g., iron and steel production, Pb and Zn Production), emissions in the Non-Energy Products from Fuels and Solvent Use category will be revised to avoid double counting of emissions and to improve transparency in the inventory.

No improvements are currently planned for estimating CO<sub>2</sub> from use of urea in SCR vehicles.

### 4.16. Electronics Industry (CRT Categories 2.E.1 and 2.E.5)

#### 4.16.1. Category Description

Industrial processes related to the electronics industry in Canada include the use of perfluorocarbons (PFCs), sulphur hexafluoride (SF<sub>6</sub>) and nitrogen trifluoride (NF<sub>3</sub>) in semiconductor manufacturing and in electronics industry quality control testing. This subsector does not include emissions of SF<sub>6</sub> used in electrical equipment or PFCs used as electrical insulation or a dielectric coolant, as these are included under Other Product Manufacture and Use (CRT subsector 2.G).

It is estimated that emissions from the electronics industry in Canada accounted for about 40 kt CO<sub>2</sub> eq in 2023, a 380% increase from 2005. The increase is driven by a large increase in the proportion of SF<sub>6</sub> sales for semiconductor manufacturing applications and an increase in the amount of PFCs and NF<sub>3</sub> sold for this purpose.

4.16.2. Methodological Issues

PFC Emissions from Semiconductor Manufacturing (CRT Category 2.E.1)

The activity data for PFC usage in the semiconductor industry was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRT category 2.F; refer to section 4.18). In addition, some users of PFCs for semiconductor manufacturing from the 2014–2020 gas distributor surveys were independently surveyed and provided annual use quantities for processes. 2020 use quantities were held constant for 2021 onwards in the absence of an up to date data collection. There are two main uses of PFCs in the semiconductor manufacturing industry in Canada: plasma etching of silicon wafers and plasma cleaning of chemical vapour deposition (CVD) chambers.

Over the time series, three PFCs have been used for semiconductor manufacturing: perfluoromethane (CF<sub>4</sub>), perfluoroethane (C<sub>2</sub>F<sub>6</sub>), and perfluorocyclobutane (c-C<sub>4</sub>F<sub>8</sub>). Use of C<sub>2</sub>F<sub>6</sub> in semiconductor processes produces emissions of C<sub>2</sub>F<sub>6</sub> as well as by-product emissions of CF<sub>4</sub>. Use of c-C<sub>4</sub>F<sub>8</sub> in semiconductor processes produces emissions of C<sub>4</sub>F<sub>8</sub> and by-product emissions of CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub>.

The IPCC Tier 2 methodology, as shown here, was used to estimate PFC emissions from the semiconductor manufacturing industry:

Equation 4–15

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

$E_{SC,PFC}$	=	total PFC emissions from PFC use in semiconductor manufacturing
$E_{FC}$	=	emissions resulting from the use of PFCs (see IPCC 2006 Volume 3, Equation 6.2)
$E_{CF_4}$	=	CF <sub>4</sub> emitted as a by-product during the use of PFCs (see IPCC 2006 Volume 3, Equation 6.3)
$E_{C_2F_6}$	=	C <sub>2</sub> F <sub>6</sub> 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 A6.2–11.

The heel (h) value, which is the amount assumed to remain in purchased gas canisters after use in semiconductor manufacturing, was assumed to equal 0.1, as suggested in the 2006 IPCC Guidelines. The heel value was not applied when semiconductor users provided data on PFCs fed into processes based on weighing canisters before and after use. As no information on emission control technologies for these processes in Canada was available for 1990–2013 data years, it was assumed that no emission control technologies were used. Two facilities provided annual gas-specific and process-specific values for the fraction of gas volume fed into process types with emission control technology and the fraction of gas destroyed by the emission control technology (respectively a<sub>i</sub> and d<sub>i</sub> in the IPCC Guidelines) for 2014–2020 data years. These fractions were used to estimate emissions from these facilities and data years. For all other 2014–2020 users, since no information on emission control technologies was available, it was assumed that none were used. In line with holding 2020 activity data constant in 2021 onwards, emission control use rates and destruction efficiencies were held constant at 2020 levels for 2021 onwards, resulting in a constant emissions trend.

NF<sub>3</sub> Emissions from Semiconductor Manufacturing (CRT Category 2.E.1)

In 2013, Environment Canada (EC) commissioned a study to determine the extent of NF<sub>3</sub> usage in Canada, including a survey of all potential NF<sub>3</sub> gas suppliers as well as seven identified potential users (Cheminfo Services, 2014). In the survey, only one semiconductor manufacturing facility indicated usage of NF<sub>3</sub> in 2013, and a gas distributor reported another 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 EC using the Domestic Substances List indicated that between 33 and 199 kg of NF<sub>3</sub> were sold in 1986 (EC, 1986). All NF<sub>3</sub> usage in Canada is believed to occur in the semiconductor manufacturing industry.

The use of NF<sub>3</sub> in the plasma cleaning of CVD chambers can produce by-product emissions of CF<sub>4</sub> (a PFC). The IPCC Tier 2 methodology, as shown here, was used to estimate NF<sub>3</sub> and by-product CF<sub>4</sub> emissions from the semiconductor manufacturing industry:

Equation 4–16

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

$E_{SC,NF_3}$	=	total emissions from NF <sub>3</sub> use in semiconductor manufacturing
$E_{NF_3}$	=	NF <sub>3</sub> emissions resulting from the use of NF <sub>3</sub> (see IPCC 2006 Volume 3, Equation 6.2)
$E_{CF_4}$	=	CF <sub>4</sub> emitted as a by-product during the use of NF <sub>3</sub> (see IPCC 2006 Volume 3, Equation 6.3)

To determine NF<sub>3</sub> 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<sub>3</sub> was assumed to be evenly distributed amongst the years since no information on annual use was available. Emissions for this purchaser were estimated using Tier 2a emission factors (EFs) and the default heel value of 10%. It was assumed that no emission control technologies were employed. The identified 2013 user stated that the NF<sub>3</sub> was used in an etching process and provided a purchase quantity and an amount fed into the process, so the heel value was not applied. Emissions for this facility were estimated using Tier 2b EFs representative of the etching process. The company indicated that no emission control technologies were employed. It was assumed that 2010–2012 use levels for this company were at 2013 levels, and emissions were calculated using the same method.

To estimate emissions for years 1990–2009, emissions for 1986 were first calculated using the midpoint value of the range from the Domestic Substances List using Tier 2a EFs and the default heel value, and it was assumed that no emission control technologies were used. Then, the 1990–2009 emissions were calculated by linearly interpolating the 1986 and 2010 NF<sub>3</sub> and by-product CF<sub>4</sub> emissions values. The emissions were interpolated, rather than interpolating the use of NF<sub>3</sub> and calculating emissions independently, because this latter approach would have induced a discontinuity with the by-product emissions of CF<sub>4</sub> from the application of different sets of EFs (Tier 2a EFs were used for 1986, and a combination of Tier 2a and 2b EFs were used for 2010).

Voluntary surveys were collected from major gas distributors and the identified 2013 user for data years 2014–2020. Other than the identified 2013 user, gas distributors did not sell any NF<sub>3</sub>, so the unidentified 2010–2013 user is assumed to have stopped using NF<sub>3</sub> 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<sub>3</sub> and CF<sub>4</sub> emissions, but that the process gases from this part of production are not fed into the abatement technology (a<sub>i</sub> is equal to 0 for 2014–2020). In the absence of a 2021–2023 data collection, NF<sub>3</sub> use data and the emission control use rate were held constant at 2020 levels for 2021 to 2023, yielding a constant emissions trend.

For all years where a Tier 2a method is applied (1990–2013), NF<sub>3</sub> usage was assumed, as opposed to NF<sub>3</sub> 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. 2014–2023 emissions are estimated using a Tier 2b method for etching processes, where remote NF<sub>3</sub> use is not applicable.

## SF<sub>6</sub> Emissions from Semiconductor Manufacturing (CRT Category 2.E.1)

The method applied to estimate SF<sub>6</sub> Emissions from Semiconductor Manufacturing was similar to what was used to estimate PFC and NF<sub>3</sub> emissions. However, use of SF<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub> used in the semiconductor manufacturing industry was estimated by multiplying the total SF<sub>6</sub> imported (from Statistics Canada) by the proportion of gas distributor SF<sub>6</sub> sales data attributed to semiconductor manufacturing (in %) (Cheminfo Services, 2005a and several ECCC surveys). No SF<sub>6</sub> sales data was collected for the years 2010–2013, so the proportions of gas distributor SF<sub>6</sub> sales data attributed to semiconductor manufacturing were linearly interpolated between 2009 and 2014. In the absence of the collection of SF<sub>6</sub> sales data for years 2021 and after, sales data characteristics were held constant at 2020 levels. SF<sub>6</sub> import data was available until 2011 from Statistics Canada. For 2012–2023 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<sub>6</sub> to the 2011 import data.

Due to the two different sources of SF<sub>6</sub> 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<sub>6</sub> import data for years 1998–2000).

Emissions were calculated using the heel value (*h*) of 12% provided and confirmed by two major SF<sub>6</sub> gas distributors, Air Liquide and Praxair.<sup>21</sup> The IPCC 2006 default emission factor (1-*U*) of 0.2 was used. From 1990 to 2013, it was assumed no emissions control technologies were used by the industry since no data is available. For 2014 to 2020, some SF<sub>6</sub> 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<sub>f</sub>* and *d<sub>f</sub>* 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<sub>f</sub>*) of the gas distributor SF<sub>6</sub> sales data attributed to semiconductor manufacturing were used in Equation 4–17 to calculate the total emissions from SF<sub>6</sub> use in semiconductor manufacturing. The use rates, destruction efficiencies, and market penetration rates of emission control technologies were held constant at 2020 levels for 2021 to 2023 in absence of a data collection. The following equation is an expanded country-specific version of IPCC 2006 Volume 3, Equation 6.2:

Equation 4–17

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

$E_{SC,SF_6}$	=	total emissions from SF <sub>6</sub> use in semiconductor manufacturing
$h$	=	heel value of 12%, as provided by gas distributors Air Liquide and Praxair
$FC$	=	total amount of SF <sub>6</sub> used in the semiconductor manufacturing industry (SF <sub>6</sub> imported multiplied by the proportion of gas distributor sales data attributed to semiconductor manufacturing)
$U$	=	<i>U</i> is the fractional use rate of SF <sub>6</sub> (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 <sub>6</sub> volume fed into process types with emission control technology
$d_f$	=	facility-specific fraction of SF <sub>6</sub> destroyed by the emission control technology

## PFC Emissions from Other Emissive Applications (CRT Category 2.E.5)

This category comprises PFCs used for the purposes of electronics industry quality control testing, including electrical environmental testing, gross leak testing, thermal shock testing, and failure analysis and short detection applications. Perfluoromethane (CF<sub>4</sub>), perfluoroethane (C<sub>2</sub>F<sub>6</sub>), perfluorocyclobutane (c-C<sub>4</sub>F<sub>8</sub>) and perfluorohexane (C<sub>6</sub>F<sub>14</sub>) have been used for these applications during the time series.

The activity data for PFC usage in Other Emissive Applications was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRT category 2.F; refer to section 4.18). Uses for these applications have been intermittently recorded in surveys during the time series.

Emissions from PFCs used in electronics quality control testing applications are assumed to be prompt and to have a similar emissive time profile to the uses of ozone-depleting substance substitutes in aerosols and solvents applications. The Tier 1a methodology from Equation 7.18 of the 2006 IPCC Guidelines was used to estimate emissions at the application level. Since no emission factors for Other Emissive Applications were available in the 2006 IPCC Guidelines, the default emission factor from the IPCC 2000 Good Practice Guidance document was applied, where 50% of the initial charge is emitted during the first year and the remaining in the following year.

### 4.16.3. Uncertainty Assessment and Time-series Consistency

#### PFC Emissions from Semiconductor Manufacturing (CRT 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<sub>3</sub> usage, so the base year activity data uncertainty was assumed to be the same as NF<sub>3</sub>. 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%.

21 Rahal H and Tardif A. 2006. Personal communications (emails from Rahal H and Tardif A to Au A, Environment Canada dated November 22, 2006, and November 13, 2006, respectively). Praxair and Air Liquide, respectively.

## NF<sub>3</sub> Emissions from Semiconductor Manufacturing (CRT Category 2.E.1)

A Tier 1 uncertainty assessment was performed for the category of NF<sub>3</sub> Emissions from Semiconductor Manufacturing. The base year NF<sub>3</sub> activity data uncertainty is based on the 1986 NF<sub>3</sub> 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<sub>3</sub> 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 2023. The uncertainty of holding the 2020 data constant for 2023 was determined using the variance of the 2013 to 2020 use rates reported by the facility. The NF<sub>3</sub> 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<sub>6</sub> Emissions from Semiconductor Manufacturing (CRT Category 2.E.1)

A Tier 1 uncertainty assessment was performed for the category of SF<sub>6</sub> Emissions from Semiconductor Manufacturing that took into account the uncertainty of the SF<sub>6</sub> import data, the total reported SF<sub>6</sub> sales data, the proportion attributed to semiconductor manufacturing, and the emission factors ( $\pm 45\%$ ). This uncertainty value is assumed to be representative of the entire time series.

## PFC Emissions from Other Emissive Applications (CRT Category 2.E.5)

A Tier 1 uncertainty assessment was performed for the category of PFC Emissions from Other Emissive Applications. The base year uncertainty is zero since there are no emissions until 1995. The current year activity data uncertainty from facility and gas-distributor reported data is 2%, and the emission factor uncertainty was assessed to be 50% (Japan Ministry of the Environment, 2009). Therefore, the current year uncertainty is 50%.

### 4.16.4. QA/QC 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<sub>3</sub>, and SF<sub>6</sub> emissions from semiconductor manufacturing:

- Large inter-year changes in activity data (i.e., the annual number of users and quantities of specific gases sold by each gas distributor) prompt verification and explanation from the data provider.
- User-level purchase and use data are compared against the sales reports of gas distributors.
- At a facility-level, the specific gas/process combinations are compared between years for consistency.
- Facility-provided destruction efficiencies for abatement equipment are compared with those provided by the equipment manufacturers and are cross-checked against the Tier 2a and Tier 2b default efficiency parameters in IPCC 2006, Volume 3, Table 6.6.

### 4.16.5. Recalculations

#### SF<sub>6</sub> Emissions from Semiconductor Manufacturing (CRT Category 2.E.1)

Emissions were recalculated downwards for years 2012–2022 due to the revision of gross output data for the Computer and Electronic Products Manufacturing NAICS (334), which are used to extrapolate SF<sub>6</sub> imports from 2011 levels. The maximum impact of these recalculations was -11 kt CO<sub>2</sub> eq in 2020.

### 4.16.6. Planned Improvements

Voluntary data surveys for 2021–2023 were not collected, and 2021–2023 use levels and emissions were held constant at 2020 levels. A voluntary data collection of 2021–2023 data is planned in 2025 to obtain updated PFC, SF<sub>6</sub>, and NF<sub>3</sub> use data.

## 4.17. Product Uses as Substitutes for Ozone-Depleting Substances (CRT Category 2.F, HFCs)

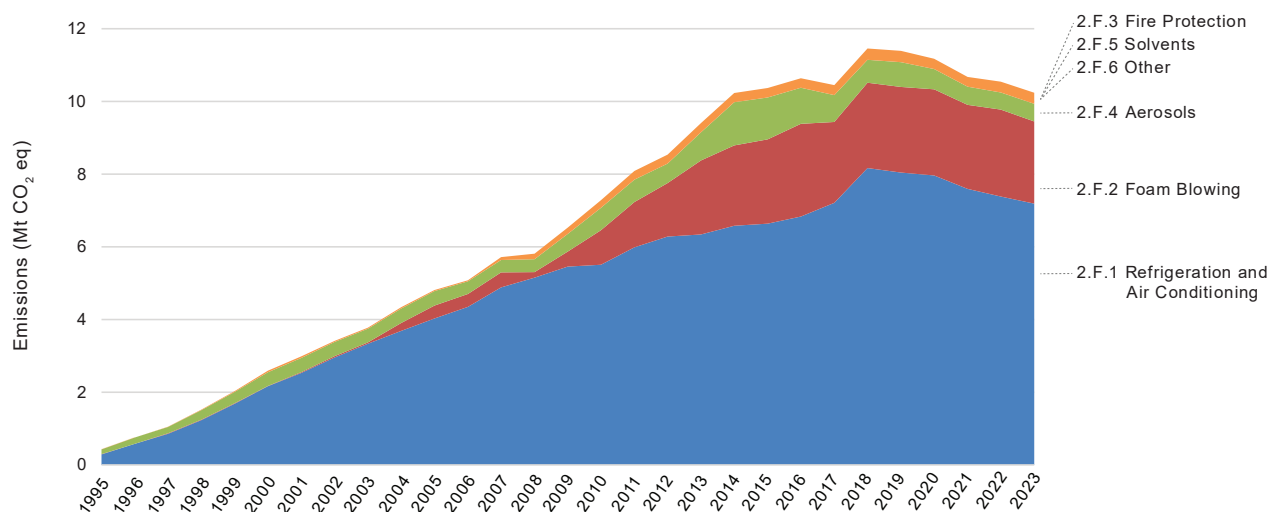
### 4.17.1. Category Description

In order to provide a clear representation of the Canadian category of Product Uses as Substitutes for Ozone-Depleting Substances, explanations on hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) have been divided into two separate sections in this report (4.17 and 4.18, respectively).

Before the Montreal Protocol ban on the production and use of chlorofluorocarbons (CFCs) came into effect in 1996, very few HFCs were produced and used globally. There has never been production of HFCs in Canada. Also, Canadian emissions from HFC consumption were considered negligible for the 1990–1994 period (IPCC/OECD/IEA, 1997). HFC consumption in Canada began in 1995. HFCs are used in a variety of applications, including refrigeration, air conditioning, fire protection, aerosols, solvent cleaning, and foam blowing. All HFCs consumed in Canada are imported in bulk or in manufactured items and products (e.g., refrigerators).

HFC releases contributed approximately 10 000 kt CO<sub>2</sub> eq (1.5%) to Canada's total emissions in 2023, a 113% increase from 2005 that can be explained by their phase-in as substitutes for CFCs and hydrochlorofluorocarbons (HCFCs). HFC emission trends and contributions from applications are presented in Figure 4–2. Refrigeration and air conditioning applications comprise the majority of HFC emissions in Canada. Use as foam blowing agents and in aerosol products are also significant contributors. Since a peak in 2018 at 11 000 kt CO<sub>2</sub> eq, HFC emissions have declined by 12%, in part due to reduced imports of bulk HFCs. This reduction coincides with the implementation of the Ozone-depleting Substance and Halocarbon Alternatives Regulations, which for calendar years 2019 to 2023 limited national net HFC imports (expressed in CO<sub>2</sub> equivalent mass) to 90% of average annual net imports seen from 2011 to 2013.<sup>22</sup>

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



<sup>22</sup> The Ozone-depleting Substances and Halocarbon Alternative Regulations can be accessed here: <https://laws-lois.justice.gc.ca/eng/regulations/SOR-2016-137/>.

## 4.17.2. Methodological Issues

### Activity Data

Canadian HFC use data is derived from bulk imports, and imports and exports of manufactured items (MIs). Canada occasionally re-exports small quantities of unused HFCs in bulk.

Data on bulk HFC imports and exports or domestic sales are available for most of the time-series and were collected through a mix of mandatory and voluntary surveys. A data gap for the year 2016 was filled in using extrapolation from 2015. Most recently, for calendar years 2017 onwards, bulk HFC data has been collected from mandatory reporting under the *Ozone-depleting Substances and Halocarbon Alternatives Regulations*.<sup>23</sup>

Data on HFCs within MI imports and exports are available until 2015 and were collected sporadically through a mix of mandatory and voluntary surveys. Data gaps were filled using interpolation or extrapolation. The last comprehensive MI data year is 2010. Imports and exports of MIs have been extrapolated from 2011 onwards using proxy variables such as deflated economic data to estimate the growth or decline in HFC consumption for a given end-use (application or sub-application).

All activity data has been provided at a Tier 2a sub-application level or is broken down to a sub-application level using ratios from detailed reporting in previous data years or through in-house research of the companies involved. More information on the received data, the applications and sub-applications, the disaggregation methodology, and the extrapolation methodologies are available in section A3.3.3.

The full list of HFCs and the activity data years in which they appeared are shown in Table 4–18.

Table 4–19 shows the breakdown of 2023 bulk HFC import data by HFC type and by assigned application.

Table 4–18 HFCs Used in Canada and Years of Appearance in Activity Data			
HFC Type	Years	HFC Type	Years
HFC-125	1995–2015, 2017–2023	HFC-23	1995–2004, 2008–2015, 2017–2023
HFC-134	2008–2009, 2015, 2017–2023	HFC-236fa	1996–1998, 2000–2004, 2008, 2010, 2012–2013, 2020–2021
HFC-134a	1995–2015, 2017–2023	HFC-245fa	2001–2015, 2017–2023
HFC-143	2013 and 2023	HFC-32	1995–2015, 2017–2023
HFC-143a	1995–2015, 2017–2023	HFC-365mfc	2008–2015, 2017–2020
HFC-152a	1995–2015, 2017–2023	HFC-41	1999–2000 and 2010
HFC-227ea	1995–2015, 2017–2023	HFC-4310mee	1998–2015, 2018–2020

Table 4–19 2023 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%	-	-	-	-	1.2%	0.0%
HFC-32	16.7%	-	0.0%	-	99.9%	98.6%	11.7%
HFC-125	29.8%	-	100.0%	-	0.0%	-	22.3%
HFC-134	-	0.1%	-	-	-	-	0.0%
HFC-134a	46.6%	11.8%	-	8.1%	0.1%	0.2%	34.4%
HFC-143	-	-	-	-	0.0%	-	0.0%
HFC-143a	6.9%	-	-	-	-	-	4.6%
HFC-152a	-	88.1%	-	91.9%	-	-	26.9%
HFC-227ea	0.0%	-	-	-	-	-	0.0%
HFC-245fa	-	-	-	-	0.0%	-	0.0%
Application share of total bulk imports	67.5%	15.1%	2.2%	14.8%	0.0%	0.4%	
<b>Notes:</b> 2023 bulk HFC import quantities were obtained through reporting under the Ozone-depleting Substances and Halocarbon Alternatives Regulations. Data was disaggregated to applications and sub-applications at the company and gas level using ratios from detailed reporting in previous data years or through in-house research. See Annex 3.3.3 for more details on the data disaggregation methodology. Totals may not add up due to rounding. “-” indicates that there were no imports of the HFC type assigned to the application. 0.0% indicates that imports were assigned to the application, but were small and are truncated due to rounding.							

23 Lists of HFC consumption allowance holders by calendar year can be accessed here: <https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/permits/authorizations-ozone-depleting-substances.html>.

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.<sup>24</sup> PureSphera in Bécancour, Quebec may also recover and/or destroy HFCs from end-of-life refrigeration equipment.<sup>25</sup> However, no data is publicly available on the amount of HFCs destroyed or reclaimed in Canada.

## Emission Factors

Surveys were performed in 2012 to document practices in HFC use and disposal in the refrigeration and air-conditioning industry to support the development of country-specific emission factors that are representative of Canada's circumstances (Environmental Health Strategies Inc. [EHS], 2013; Environment and Climate Change Canada [ECCC], 2015). Additional information on survey results and quality control procedures can be found in section A3.3.3.3. The country-specific emission factors were applied for the entire time-series.

For the aerosols, foam blowing, fire extinguishing, solvents, and other applications, default Tier 1 emission factors from Volume 3, Chapter 7 (IPCC, 2006) were used. All emission factors are presented with references in Annex 6.

## Estimation Methodology

Because the actual numbers of the various types of equipment are not available for Canada, the IPCC Tier 1a/2a approach (IPCC, 2006) was used with the annual quantities of HFC consumed by application and sub-application, as discussed in Volume 3, Chapter 7, section 7.1.2.1 (IPCC, 2006). Tier 2a methods were used for the refrigeration and air conditioning applications, applying country-specific emission factors (IPCC, 2006). Tier 1a methods were used for all other applications, where sub-application-level activity data were multiplied by default emission factors for the application (IPCC, 2006). For the calculation of the net consumption of each HFC in each sub-application, Equation 7.1 from Volume 3, Chapter 7 (IPCC, 2006) has been adapted to the Canadian context and used. Refer to section A3.3.3 for additional details on methodology.

The lifecycle of each HFC is tracked by sub-application and year, and annual emissions are estimated for each applicable lifecycle stage (assembly of the product, in-service operation of the product and end-of-life decommissioning). The annual quantity of each HFC that remains in products (in stock) after assembly, during the in-service life of the product, and at the end-of-life decommissioning stage is also calculated. In this way, the mathematically expanded version of the method discussed in Volume 3, Chapter 7, section 7.1.2.2 (IPCC, 2006) and subsequent sections are applied. Emissions for each lifecycle stage are estimated for each sub-application by multiplying the HFC quantity in that stage by its corresponding emission factor. The HFC emission estimation equations applied for each unique application or sub-application are explained in more detail in section A3.3.3.

### 4.17.3. Uncertainty Assessment and Time-series Consistency

A Monte Carlo uncertainty assessment was performed for the consumption of HFCs. It took into account the uncertainties associated with all sub-applications, such as commercial refrigeration, mobile air conditioning, etc. Uncertainties related to activity data (Cheminfo Services, 2005c) and emission factors from Volume 3, Chapter 7 (IPCC, 2006) were used to determine the uncertainty for each sub-application. 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 change from year-to-year. The uncertainty associated with the category as a whole was  $\pm 11\%$ .

### 4.17.4. QA/QC and Verification

HFC emissions from Product Uses as Substitutes for Ozone-Depleting Substances is a key category that has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Volume 1, Chapter 6 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

### 4.17.5. Recalculations

There are downward recalculations for this category for 2011–2022 from the use of updated proxy variables in extrapolating manufactured item imports and exports from 2010 onwards and to extrapolate 2016 bulk imports from 2015. The maximum impact of these recalculations is -42 kt CO<sub>2</sub> eq (-0.4%) in 2019.

<sup>24</sup> Czajko, C., Larsen, N. Personal communication (Microsoft Teams meeting discussion between Czajko, C., Larsen, N., and Industry Section of the Pollutant Inventories and Reporting Division of ECCC dated April 12, 2021). Heating, Refrigeration and Air Conditioning Institute of Canada – Refrigerant Management Canada.

<sup>25</sup> PureSphera's recovery process is described here: <https://www.puresphera.com/en/technologies-propres>.

#### 4.17.6. **Planned Improvements**

A data gap exists with the manufactured item (MI) import and export data, for which the last completely surveyed year is 2010. Quantities from 2010 along with some incomplete 2011–2015 data are extrapolated forward using proxy variables to complete the time-series. To fill in the data gap and to address a 2023 in-country review comment, investigation is being carried out on existing statistical data on the imports, exports and sales of MIs that can contain HFCs. As well, surveys to be sent to importers are being developed, so that information necessary for integration into the inventory can be obtained.

The end-of-life disposal loss factors for the refrigeration and air-conditioning application were selected using the results of a 2012 study and an in-house review (EHS, 2013; ECCC, 2015). For all other applications, Tier 1 default disposal loss factors from Volume 3, Chapter 7 are used (IPCC, 2006). To validate (or update) these factors and to address a 2023 in-country review comment, searches and communication with various stakeholders, such as refrigerant management programs and reclamation and destruction facilities are being made.

### 4.18. **Product Uses as Substitutes for Ozone-Depleting Substances (CRT Category 2.F, PFCs)**

#### 4.18.1. **Category Description**

Perfluorocarbon (PFC) consumption in Canada began in 1995. Like Hydrofluorocarbons (HFCs), PFCs are also used as substitutes for Ozone-Depleting Substances (ODS) being phased out under the Montreal Protocol (IPCC, 2006). However, the uses of PFCs are very limited compared to HFCs in Canada. Canadian applications that have used PFCs as Substitutes for ODS over the time series include Refrigeration and Air Conditioning, Foam Blowing Agents, and Solvents.

PFC releases contributed to about 8.0 kt CO<sub>2</sub> eq in 2023, a 296% increase from 2005.

#### 4.18.2. **Methodological Issues**

The 2006 IPCC Tier 1a/2a methodologies were used to estimate emissions from the consumption of PFCs in various applications for the years 1995 onwards. Details of the methods are found in the following subsections. The 1995–2000 activity data was obtained through the 1998 and 2001 PFC surveys conducted by Environment Canada. As 2001 and 2002 data was unavailable, emission estimates were developed based on the assumption that the use quantities in various applications stayed constant after 2000. Environment Canada conducted a voluntary collection of 2003–2007 PFC use data from major distributors in 2008 and 2009. The data from the major distributors was then integrated with existing PFC use data. The 2008 and 2009 PFC use data from major distributors was voluntarily collected in 2009 and 2010. 2014–2020 PFC data was collected from gas distributors in 2019, 2020 and 2021 voluntary surveys. 2020 use quantities were held constant for 2021–2023 in the absence of 2021–2023 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 2017–2023 HFC/PFC blend activity data was collected through mandatory HFC surveys in 2018 onwards. 2016 HFC/PFC blend activity data was interpolated between the 2015 and 2017 activity data. The PFC component of the blend activity data was disaggregated using IPCC 2006, Volume 3, Table 7.8.

Emission factors applied for the use of PFCs as ODS Substitutes are presented in Table A6.2–13.

#### **Refrigeration and Air Conditioning (CRT Category 2.F.1, PFCs)**

The IPCC Tier 2a methodology, i.e., equations 12, 13 and 14 from Volume 3, Chapter 7, section 7.5 of the 2006 IPCC Guidelines, was used to estimate the emissions from the assembly, operation and disposal of the following sub-applications: commercial refrigeration and stationary air conditioning systems. No other refrigeration and air conditioning sub-applications have been reported in surveys throughout the time series.

The assembly losses (k values) and annual operating leakage rates (x values) used were chosen from a range of values that were provided for each sub-application in the 2006 IPCC Guidelines. Loss and leakage rates by sub-application can be seen in Table A6.2–13.

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 ( $\text{CF}_4$ ), perfluoroethane ( $\text{C}_2\text{F}_6$ ), and perfluoropropane ( $\text{C}_3\text{F}_8$ ) have been used as commercial refrigerants or in commercial refrigerant blends, and as of 2020, a small quantity of  $\text{C}_2\text{F}_6$  continues to be imported annually in R-508B blends for the service and maintenance of commercial refrigerators.

In addition,  $\text{C}_2\text{F}_6$  (or blends containing it) have been used in stationary air-conditioning. Use was last reported in 2008, although in-service and end-of-life emissions continue to occur.

Uses of PFCs in commercial refrigeration and stationary air-conditioning contribute a total of 5.4 kt  $\text{CO}_2$  eq in 2023.

### **Foam Blowing Agents (CRT Category 2.F.2, PFCs)**

The use of perfluoropentane ( $\text{C}_5\text{F}_{12}$ ) in closed-cell foam was reported in the 1995–1997 activity data collection that took place in 1998. A facility used  $\text{C}_5\text{F}_{12}$  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-227<sup>a</sup>. 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  $\text{C}_5\text{F}_{12}$  used as a closed-cell foam blowing agent expired in 2011.

### **Fire Protection (CRT Category 2.F.3, PFCs)**

Uses of PFCs in Fire Protection applications has never been reported in any data collection. Therefore, emissions from this source are expected to be negligible.

### **Aerosols (CRT Category 2.F.4, PFCs)**

Uses of PFCs as aerosol propellants has never been reported in any data collection. Therefore, emissions from this source are expected to be negligible. Emissions from PFCs imported in aerosol cans that are used as solvents are reported in the Solvents category.

### **Solvents (CRT Category 2.F.5, PFCs)**

Uses of  $\text{CF}_4$ ,  $\text{C}_2\text{F}_6$ , perfluorocyclobutane ( $\text{c-C}_4\text{F}_8$ ),  $\text{C}_5\text{F}_{12}$  and perfluorohexane ( $\text{C}_6\text{F}_{14}$ ) 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 2023, emissions from the uses of  $\text{CF}_4$  and  $\text{C}_2\text{F}_6$  in solvent applications contributed 2.6 kt  $\text{CO}_2$  eq.

## **4.18.3. Uncertainty Assessment 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  $\pm 9\%$  to  $\pm 23\%$ . The current year uncertainty is assumed to be 23%, equal to the highest and most recent (2008) uncertainty in the range assessed. The base year uncertainty is zero since the use of PFCs as ODS substitutes did not begin until 1995.

#### 4.18.4. QA/QC and Verification

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

In addition, checks have been performed to ensure that there is no double-counting between the same-year activity data from the voluntary surveys of PFCs collected from gas distributors and the mandatory surveys on HFC/PFC blends.

#### 4.18.5. Recalculations

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

#### 4.18.6. Planned Improvements

Voluntary data surveys for 2021–2023 were not collected, and 2021–2023 use levels were held constant at 2020 levels for most applications. A voluntary data collection of 2021–2023 data is planned for 2025 to obtain updated PFC distribution and use data.

#### Solvents (CRT Category 2.F.5, PFCs)

Some of the recent (2014–2020) voluntary data surveys completed by gas distributors are annual sales reports with company names and the quantities sold and no additional information on end-use. A large portion of the quantity of PFCs attributed to use as solvents is based on research conducted by inventory compilers. Given the wide variety of possible uses of solvents (and PFCs), the categorical allocation and emissions profiles of solvent uses have a high degree of uncertainty. Users of PFCs as solvents will be contacted to confirm the categorical allocation and emissions profile of their solvent use (if possible).

### 4.19. Other Product Manufacture and Use (CRT Category 2.G)

#### 4.19.1. Category Description

The Other Product Manufacture and Use category includes emissions from the use of Sulphur Hexafluoride (SF<sub>6</sub>) in electrical equipment (CRT category 2.G.1), Nitrous Oxide (N<sub>2</sub>O) emissions from medical applications (CRT category 2.G.3.a), N<sub>2</sub>O emissions from use as a propellant (CRT category 2.G.3.b) and Perfluorocarbon (PFC) Emissions from Other Contained Product Uses (CRT category 2.G.4) such as uses as an electrical insulator or as a dielectric coolant, which are not ODS substitutes or electronics industry-related.

In electric utilities, SF<sub>6</sub> 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<sub>6</sub> is primarily used in high-voltage circuit breakers and related equipment. Emissions during equipment use are a result of leakages during gas transfer and handling operations and leakages during normal operation of the equipment. To keep equipment properly charged and operational, utilities must fill their equipment to replace the amount that has escaped.

Nitrous Oxide of Canada (NOC) in Maitland, Ontario, is the only known producer of compressed N<sub>2</sub>O for commercial sales in Canada. It supplies N<sub>2</sub>O to two of the three primary N<sub>2</sub>O gas distributors that essentially account for the total commercial market in Canada. These companies sell cylinders of N<sub>2</sub>O 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<sub>2</sub>O in Canada, including dental offices, clinics, hospitals and laboratories (Cheminfo Services, 2006). In addition to domestic sales of N<sub>2</sub>O produced in Canada, a portion of N<sub>2</sub>O used is imported. Quantities of N<sub>2</sub>O imported were obtained by the 2006 Cheminfo study for 1990 to 1997; through Statistics Canada for 2008 to 2011; and linearly interpolated from 2012 onwards due to changes in the disaggregation of Statistics Canada information.

Of all applications in which N<sub>2</sub>O can be used in Canada, only anaesthetic and propellant uses of N<sub>2</sub>O are considered emissive. Anaesthetic use represents the largest type of N<sub>2</sub>O end use in Canada and it is assumed that none of the N<sub>2</sub>O 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<sub>2</sub>O in whipped cream being considered significant. N<sub>2</sub>O is not reacted during the anaesthetic and propellant processes; therefore, all N<sub>2</sub>O used is emitted to the atmosphere (Cheminfo Services, 2006).

Other areas where N<sub>2</sub>O 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<sub>2</sub>O 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 650 kt (<0.1%) to Canada's total emissions in 2023, a 27% increase from 2005.

#### 4.19.2. Methodological Issues

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

A modified Tier 3 method was used to estimate SF<sub>6</sub> emissions from electrical equipment in utilities for years 2006 onwards, in place of the previous top-down approach (which assumed that all SF<sub>6</sub> purchased from gas distributors replaces SF<sub>6</sub> lost through leakage). The SF<sub>6</sub> emission estimates by province for 2006 onwards 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<sub>6</sub> 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<sub>6</sub> injected into the equipment or contained in the cylinders. The national SF<sub>6</sub> estimate for each year during the 2006–2023 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<sub>6</sub> 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 Annexe 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<sub>6</sub> from these organizations only started in the 2006 data year. Hence, the application of the Protocol was not possible. Surveys of SF<sub>6</sub> distributors were used to obtain usage data prior to the application of the Protocol. To resolve this issue of data availability and to ensure a consistent time series, an overlap technique (IPCC 2006, Volume 1, Chapter 5) was applied. In this case, the overlap was assessed between four sets of annual estimates (2006–2009) derived from the distributor surveys and obtained under the Protocol.

Emissions at provincial/territorial levels were estimated based on the national emission estimates (obtained from the use of the overlap approach) and the percent of provincial shares (based on the reported 2006–2009 data).

##### Nitrous Oxide Emissions from Medical Applications (CRT Category 2.G.3.a) and Propellant Usage (CRT Category 2.G.3.b)

N<sub>2</sub>O 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<sub>2</sub>O emissions and covers more than one calendar year because both supply and use are assumed to be continuous over the year; for example, N<sub>2</sub>O 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<sub>2</sub>O sales pattern by application (Cheminfo Services, 2006). The sales patterns for 2006 onwards are assumed to be the same as that for 2005. The amounts of N<sub>2</sub>O sold for anaesthetic and propellant purposes are calculated from the total domestic sales volume and their respective share of sales.

Provincial and territorial estimates were developed by distributing the national-level estimates based on provincial/territorial population data (Statistics Canada, n.d.[d]).

## Perfluorocarbon Emissions from Other Contained Product Uses (CRT Category 2.G.4)

The activity data on PFCs used in Other Contained Products were collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRT category 2.F; refer to section 4.18). Over the time series, perfluoromethane (CF<sub>4</sub>), perfluoroethane (C<sub>2</sub>F<sub>6</sub>) and perfluorohexane (C<sub>6</sub>F<sub>14</sub>) have been used for electrical insulation within contained products and perfluoropropane (C<sub>3</sub>F<sub>8</sub>) and C<sub>6</sub>F<sub>14</sub> have been used as dielectric coolants within contained products.

The IPCC Tier 1 method for other contained applications of ODS substitutes (IPCC, 2006) is used to calculate PFC Emissions for Other Contained Product Uses. Since no emission factors are available in the 2006 IPCC Guidelines, default emission factors from the IPCC 2000 Good Practice Guidance document are used. They assume a leakage rate of approximately 1% during the manufacturing process and an annual leakage rate of 2% during the equipment lifetime of 15 years (IPCC, 2000). It is assumed that there are no recovery or recycling technologies in place and therefore 100% of the PFCs remaining in Other Contained Products are released once the end of the lifespan is reached. These emission factors are presented in Table A6.3–2 and are applied to the PFC data in accordance with Equation 7.19 of the 2006 IPCC Guidelines.

### 4.19.3. Uncertainty Assessment and Time-series Consistency

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

A Tier 1 uncertainty assessment was performed for the category of SF<sub>6</sub> from Electrical Equipment. It should be noted, however, that the uncertainty assessment was done using 2007 data. It is expected that emission estimates of this submission would have much lower uncertainty values. The uncertainty for the category was estimated at ±30.0%. Depending on the years, the data source and methodology used for SF<sub>6</sub> from electrical equipment could vary, as explained in section 4.19.2 (Methodological Issues).

#### Nitrous Oxide Emissions from Medical Applications (CRT Category 2.G.3.a) and Propellant Usage (CRT Category 2.G.3.b)

A Tier 1 uncertainty assessment was performed for the categories of N<sub>2</sub>O Emissions from Medical Applications and Propellant Usage. It considered the uncertainties associated with domestic sales, import, sales patterns and emission factors. The uncertainty for these combined categories was evaluated at ±20%. It is expected that the uncertainty for this sector would not vary considerably from year to year as the data sources and methodology applied are the same.

#### Perfluorocarbon Emissions from Other Contained Product Uses (CRT Category 2.G.4)

A Tier 1 uncertainty assessment was performed for the category of PFC Emissions from Other Contained Product Uses. Uncertainties related to the gas distributor and facility activity data are assumed to be 2% and the emission factor uncertainty was assessed to be 50% (Japan Ministry of the Environment, 2009). The current year uncertainty is 51%, and the base year uncertainty is zero since emissions of PFCs for these applications did not begin until 1995.

### 4.19.4. QA/QC and Verification

The categories of N<sub>2</sub>O 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<sub>6</sub> Consumption in Electrical Equipment has undergone informal quality control checks throughout the emission estimation process.

### 4.19.5. Recalculations

There was a recalculation for SF<sub>6</sub> emissions from electrical equipment for 2022 of -38 kt CO<sub>2</sub>e due to updated activity data.

#### 4.19.6. **Planned Improvements**

##### **Sulphur Hexafluoride Emissions from Electrical Equipment (CRT Category 2.G.1)**

As mentioned previously, SF<sub>6</sub> is used as an insulating and arc-quenching medium in electrical transmission and distribution equipment. To enhance performance in cold weather, SF<sub>6</sub> gas can be mixed with carbon tetrafluoride (CF<sub>4</sub>) gas. Currently, Canada only reports SF<sub>6</sub> from this source category (CRT category 2.G.1). There are plans to collect CF<sub>4</sub> emission data to report in future inventory submissions.

##### **Sulphur Hexafluoride and Perfluorocarbon Emissions from Other Product Use (CRT Category 2.G.2)**

This category is a catch-all for product uses of SF<sub>6</sub> and PFCs that are not covered under other CRT categories and is currently reported as “NE” in the CRT reporter. Historical sales data collected from gas suppliers through voluntary data surveys indicate some use of SF<sub>6</sub> and PFCs for applications mentioned in the 2006 IPCC Guidelines (Volume 3, section 8.3).

A 2023 in-country review comment also suggested to assess the category significance based on a top-down methodology using for example, import/export data. As such, a voluntary data collection survey is being planned.

##### **Nitrous Oxide Emissions from Medical Applications (CRT Category 2.G.3.a) and Propellant Usage (CRT Category 2.G.3.b)**

There are plans to validate the Canadian N<sub>2</sub>O sales pattern by application currently used and if necessary, to develop an updated version. Such update aim to help estimate more accurately N<sub>2</sub>O emissions from CRT categories 2.G.3.a and 2.G.3.b.

##### **Perfluorocarbon Emissions from Other Contained Product Uses (CRT Category 2.G.4)**

This category is country-specific. A 2023 in-country review comment recommended the reallocation of all activity data in this category to other categories to improve the comparability of the inventory. Legacy data sources are being examined to ensure that emissions estimates are reattributed to the correct category(ies).

# CHAPTER 5

## AGRICULTURE (CRT SECTOR 3)

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### 5.1. Overview

The contribution of the Agriculture sector was 7% of Canada's total greenhouse gas (GHG) emissions from 1990 until 2020, when the contribution rose to 8% through 2023 as a result of decreases in emissions in other sectors, while agricultural emissions remained constant. Emissions in the sector increased by 30% between 1990 and 2023. Emission source categories in the Agriculture sector include Enteric Fermentation (methane [CH<sub>4</sub>]) and Manure Management (nitrous oxide [N<sub>2</sub>O] and CH<sub>4</sub>), for emissions associated with livestock production and Agricultural Soils (N<sub>2</sub>O), and Field Burning of Agricultural Residues (CH<sub>4</sub> and N<sub>2</sub>O), for emissions associated with crop production. Carbon dioxide (CO<sub>2</sub>) emissions from liming and urea application are reported in the Agriculture sector; however, CO<sub>2</sub> 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,<sup>1</sup> llamas, alpacas, horses, goats, elk, deer, wild boars, foxes, minks, rabbits, and mules and asses, are produced for commercial purposes, but production is small.

Canadian agriculture is highly regionalized due to historical and climatic influences. Approximately 76% of beef cattle and more than 90% of wheat, barley and canola are produced in the Prairies, a semi-arid to sub-humid ecozone, while approximately 75% of the dairy cattle herd, 60% of swine and poultry and over 75% of corn and soybeans are produced in the humid Mixedwood Plains ecozone in eastern Canada.

In 1990, Canada had 10.5 million beef cattle, 1.4 million dairy cattle, 10 million swine, and 101 million poultry. The beef cattle and swine populations peaked in 2005 at 15 million head each.

Beef populations have decreased to 11 million head since 2005, while swine populations decreased to 12.5 million head in 2010, rebounded to 14 million head in 2016, and have since remained stable. Since 1990, poultry populations increased to 154 million by 2016 and subsequently decreased to 151 million by 2023, while dairy cattle populations have decreased until recently, with some fluctuations, stabilizing at just under 1 million head in 2023.

Cropping practices have changed in Canada over the years. Canola production increased by nearly a factor of 6 from 3.3 Mt in 1990 to 19 Mt in 2023. Corn production has roughly doubled, increasing from 7 Mt to 15 Mt, and soybean production has increased by a factor of 5 from 1.3 Mt to 7 Mt. From 1990 to 2002, wheat production fell off sharply, decreasing from 32 Mt to 16 Mt, but has increased in recent years and typically varies between 20 and 35 Mt. With the changes in crop production, inorganic nitrogen (N) fertilizer consumption has more than doubled from 1.2 Mt in 1990 to 3.0 Mt in 2023, while land under conservation tillage has increased by 17 million hectares (Mha).

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<sup>1</sup> In the Common Reporting Tables (CRT), bison emissions are reported under the Intergovernmental Panel on Climate Change (IPCC) category "Buffalo," although the species referred to is the North American bison (*Bison bison*), which is raised for meat using methods similar to those used for beef cattle. In the text of the NIR, this livestock category will be referred to as Bison.

As a result of these combined changes in livestock and crop production, Canada's GHG emissions from the Agriculture sector rose from 43 Mt CO<sub>2</sub> eq in 1990 to 55 Mt CO<sub>2</sub> eq in 2023 (Table 5–1). This 30% increase is mainly due to emissions associated with the greater use of inorganic N fertilizers (150% increase in N shipments), larger swine populations (37% increase), and changes in animal weight, feed and manure handling practices in the beef, dairy and swine industries.

Emissions of CH<sub>4</sub> from livestock accounted for 28 Mt CO<sub>2</sub> eq in 1990 and 31 Mt CO<sub>2</sub> eq in 2023, with an uncertainty range of -6% to +20% for the mean estimates. Over the 1990 to 2023 time series, mean CH<sub>4</sub> emissions are estimated to have increased by 3.0 Mt CO<sub>2</sub> eq, an 11% increase, which is associated with an uncertainty range of -10% to +17%. Emissions of N<sub>2</sub>O from agricultural soils and livestock represented 13 Mt CO<sub>2</sub> eq in 1990 and 21 Mt CO<sub>2</sub> eq in 2023, with an uncertainty range of approximately -27% to +29% of the mean estimates. Over the time series, mean N<sub>2</sub>O emissions increased by 7.9 Mt CO<sub>2</sub> eq, an increase of 62%.

Emissions from the Agriculture sector peaked in 2005 and decreased to 50 Mt CO<sub>2</sub> 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<sub>2</sub> eq in 2023.

Table 5–1 **Overview of Greenhouse Gas Emissions from the Agriculture Sector, Selected Years**

GHG Source Category		GHG Emissions (kt CO <sub>2</sub> eq)							
		1990	2005	2018	2019	2020	2021	2022	2023
<b>Agriculture TOTAL<sup>a</sup></b>		<b>43 000</b>	<b>56 000</b>	<b>54 000</b>	<b>54 000</b>	<b>56 000</b>	<b>55 000</b>	<b>56 000</b>	<b>55 000</b>
<b>Enteric Fermentation 3.A. (CH<sub>4</sub>)</b>		<b>25 000</b>	<b>35 000</b>	<b>27 000</b>	<b>27 000</b>	<b>27 000</b>	<b>27 000</b>	<b>27 000</b>	<b>26 000</b>
Dairy Cattle 3.A.1.a.		4 400	3 600	3 800	3 900	3 900	4 000	4 000	3 900
Beef cattle <sup>b</sup> 3.A.1.b.		20 000	29 000	22 000	22 000	22 000	22 000	22 000	21 000
Others <sup>c</sup> 3.A.2-4.		820	1 500	1 200	1 200	1 200	1 200	1 200	1 200
<b>Manure Management 3.B.</b>		<b>6 000</b>	<b>8 700</b>	<b>7 900</b>	<b>7 900</b>	<b>7 800</b>	<b>7 900</b>	<b>7 800</b>	<b>7 700</b>
Dairy Cattle 3.B.1.a.	CH <sub>4</sub>	480	760	1 000	1 100	1 100	1 100	1 100	1 100
	N <sub>2</sub> O	460	310	240	240	240	240	240	230
Beef cattle <sup>b</sup> 3.B.1.b.	CH <sub>4</sub>	910	1 400	1 100	1 100	1 100	1 100	1 100	1 100
	N <sub>2</sub> O	1 700	2 600	2 100	2 100	2 100	2 100	2 100	2 000
Swine 3.B.3.	CH <sub>4</sub>	1 100	2 000	1 900	1 900	1 900	1 900	1 900	1 900
	N <sub>2</sub> O	90	60	50	50	50	50	40	40
Poultry 3.B.4.g.	CH <sub>4</sub>	180	220	220	220	220	220	220	220
	N <sub>2</sub> O	380	480	530	530	520	510	510	510
Others <sup>d</sup> 3.B.4.	CH <sub>4</sub>	40	60	50	40	40	40	40	40
	N <sub>2</sub> O	80	150	100	100	100	90	90	90
Indirect Source 3.B.5.	N <sub>2</sub> O	520	640	540	540	540	530	530	530
<b>Agricultural Soils (N<sub>2</sub>O) 3.D.</b>		<b>10 000</b>	<b>12 000</b>	<b>16 000</b>	<b>16 000</b>	<b>18 000</b>	<b>17 000</b>	<b>18 000</b>	<b>18 000</b>
Direct sources 3.D.1.		7 800	8 900	13 000	13 000	14 000	13 000	15 000	14 000
Inorganic nitrogen fertilizers 3.D.1.a.		3 900	4 700	8 100	8 100	9 100	9 000	8 600	9 300
Organic nitrogen fertilizers 3.D.1.b.		1 000	1 300	1 300	1 300	1 300	1 300	1 300	1 300
Crop residue decomposition 3.D.1.d.		2 200	2 700	3 800	3 800	3 900	3 100	3 800	3 700
Cultivation of organic soils 3.D.1.f.		220	220	220	220	220	220	220	220
Mineralization of soil organic carbon 3.D.1.e.		200	170	180	260	410	420	1 400	540
Conservation tillage <sup>e,f</sup> 3.D.1.		-360	-1 000	-2 100	-2 200	-2 300	-2 100	-2 200	-2 200
Irrigation <sup>f</sup> 3.D.1.		490	690	1 000	1 100	1 200	1 000	1 100	1 100
Urine and dung deposited by grazing animals 3.D.1.c.		200	230	180	180	170	170	170	170
Indirect sources 3.D.2.		2 300	2 700	3 500	3 500	3 700	3 500	3 600	3 700
<b>Field Burning of Agricultural Residues (CH<sub>4</sub> &amp; N<sub>2</sub>O) 3.F.</b>		<b>240</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>60</b>	<b>40</b>	<b>50</b>	<b>50</b>
<b>Liming and Urea Application (CO<sub>2</sub>) 3.G.</b>		<b>1 200</b>	<b>1 400</b>	<b>2 600</b>	<b>2 700</b>	<b>3 000</b>	<b>3 100</b>	<b>2 900</b>	<b>3 100</b>

Notes:

- Totals may not add up due to rounding.
- Beef cattle include dairy heifers. This corresponds to the Non-Dairy Cattle category in the CRF tables.
- Others, Enteric Fermentation, includes bison, goats, horses, sheep, llamas/alpacas, swine, deer/elk, and wild boars.
- Others, Manure Management, includes bison, goats, horses, sheep (CRT - 3.B.2), llamas/alpacas, foxes, minks, rabbits, deer/elk, and wild boars.
- The negative values reflect reduced N<sub>2</sub>O emissions due to the adoption of conservation tillage.
- Applies to all 3.D.1. CRT subcategories categories from the application of N fertilizer or mineralization of organic N in croplands, except pastures and organic soils

In this submission, 1990 emissions were revised by +57 kt CO<sub>2</sub> eq; 2005 emissions by +43 kt CO<sub>2</sub> eq ; and 2022 emissions by -35 kt CO<sub>2</sub> eq compared to the previous submission, representing recalculations of +0.13%, +0.08%, and -0.06%, respectively (Table 5–2).

Recalculations are the result of (i) new activity data on drained organic soils under perennial production combined with a change to Tier 1 emission factors of soil N<sub>2</sub>O from the 2013 Wetland Supplement; and (ii) error corrections and minor revisions to activity data for crop residue specifically a minor correction made to the non-growing season ratio-factor within the soil N<sub>2</sub>O methodology, to assure consistency with the final value published in Pelster et al. (2024). 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<sub>4</sub> emissions. The prescribed burning of savannahs is not practiced in Canada.

This chapter provides a brief introduction to each emission source category, as well as a short description of methodological issues; uncertainties and time-series consistency; quality assurance / quality control (QA/QC) and verification processes; recalculations; and planned improvements. Detailed inventory methodologies and sources of activity data are described in Annex 3.4.

Table 5–2 **Summary of Recalculations for the Agriculture Sector, Selected Years**

GHG Source Category		GHG Emissions (kt CO <sub>2</sub> eq)							
		1990	2005	2017	2018	2019	2020	2021	2022
Agriculture									
Previous submission (2024 NIR)		42 485	56 242	53 008	54 157	54 299	56 016	55 061	55 947
Current submission (2025 NIR)		42 541	56 286	53 006	54 146	54 287	55 986	55 109	55 912
Change in Emissions	kt CO <sub>2</sub> eq	57	43	-2	-11	-12	-30	48	-35
	%	0.13	0.08	0.00	-0.02	-0.02	-0.05	0.09	-0.06
Agricultural Soils 3.D.1.f									
Previous submission (2024 NIR)		54	54	54	54	54	54	54	54
Current submission (2025 NIR)		218	218	218	218	218	218	218	218
Change in Emissions	kt CO <sub>2</sub> eq	164	164	164	164	164	164	164	164
	%	305	305	305	305	305	305	305	305
Agricultural Soils 3.D.1. <sup>a</sup>									
Previous submission (2024 NIR)		7 516	8 584	11 885	12 512	12 611	13 834	12 895	14 325
Current submission (2025 NIR)		7 409	8 464	11 718	12 337	12 435	13 640	12 764	14 125
Change in Emissions	kt CO <sub>2</sub> eq	-107	-121	-166	-175	-176	-194	-117	-199
	%	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.0	-1.4
Note: Totals may not add up due to rounding. a. No recalculations occurred in 3.D.1.c and the modification to 3.D.1.f is separate from this change resulting from an error correction to the N <sub>2</sub> O EF for mineral soils.									

Table 5–3 **Qualitative Summary of the Revisions to Methodologies, Corrections and Improvements Carried out for Canada's 2025 Submission**

Correction or Improvement	Recalculation Categories Affected	Years Affected
Revisions to emission factor and activity data from histosols	Agricultural Soils – Direct N <sub>2</sub> O Emissions	Complete time series
Activity Data Updates and Error Correction	Agricultural Soils – Direct N <sub>2</sub> O Emissions - Error Correction for Non-growing Season Soil N <sub>2</sub> O Ratio Factor	Complete time series

## 5.2. Enteric Fermentation (CRT Category 3.A)

### 5.2.1. Category Description

Methane is produced during the normal digestive process of enteric fermentation in herbivores including species raised in agricultural animal production. Micro-organisms in the gastrointestinal tract break down carbohydrates and proteins into simple molecules for absorption and CH<sub>4</sub> is produced as a by-product. This process results in an accumulation of CH<sub>4</sub> in the rumen emitted by eructation and exhalation. Some CH<sub>4</sub> 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<sub>4</sub>.

In Canada, animal production varies from region to region. In western Canada, beef cattle production dominates, combining intensive production systems with high animal densities finished in feedlots and low-density, pasturing systems for cow-calf operations. Most dairy production occurs in eastern Canada in high-production, high-density facilities, and production has intensified significantly since 1990, affecting both milk productivity and management approaches. Eastern Canada has also traditionally produced swine in high-density, intensive production facilities. Over the past 20 years, some swine production has shifted to western Canada. Other animals that produce CH<sub>4</sub> 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<sub>4</sub> 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<sub>4</sub> 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 1990–2023 time period, are reflected in a 24% increase in CH<sub>4</sub> emission factors from this animal category. As milk production increases, the requirement of energy for lactation (NE<sub>l</sub>) becomes greater and requires increased food consumption.

In beef cattle, changes in mature body weight influence maintenance and growth energy (NE<sub>m</sub> and NE<sub>g</sub>) requirements and, consequently, feed consumption. From 1990 to 2003, larger breeds became popular and emission factors increased by 7.4% during that period. Since then, beef cattle weights have remained relatively stable, while slaughter animal weights have continued to increase, at a lower rate. Emission factors have since decreased because of a combination of the stabilization of cattle weights and a shift in cattle subcategory populations. Since 2005, beef cow and replacement heifer populations have decreased substantially, while finishing animal populations (slaughter heifers and steers) have remained constant. As a result, the proportion of finishing animals in the national herd has increased from 17% to 20%. Since finishing animals have a lower emission factor, the overall emission factor for the Non-Dairy Cattle category has decreased from its peak in 2005.

For non-cattle animal categories, CH<sub>4</sub> 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. Uncertainty Assessment and Time-Series Consistency

An uncertainty analysis was performed on the methodology used to estimate CH<sub>4</sub> 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 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 2023, 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<sub>4</sub> emissions from the Enteric Fermentation category was similar in 1990 and 2023, and mean estimates in 2023 lie within a range of -14% to +17% (Table 5–4). Over the time series of 1990 to 2023, mean emissions are estimated to have increased by 2.1 Mt CO<sub>2</sub> eq, an 8.2% increase. The observed increase falls within an uncertainty range of +4.4% to +13%.

The uncertainty in emissions was mainly associated with the calculation of the emission factor. The range of uncertainty around the calculation of the Non-Dairy Cattle Tier 2 emission factors was the largest contributor to uncertainty. Calculations of uncertainty in emissions and emission factors were the most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular the methane conversion rate (Y<sub>m</sub>) and the factor associated with the estimation of the net energy of maintenance (C<sub>fi</sub>) (Karimi-Zindashty et al., 2012).

The methodology and parameter data used in the calculation of emission factors are consistent throughout the entire time series (1990–2023), except for milk production for dairy cattle. The time series of milk production from 1990 to 1998 is estimated. Two milk production data sets exist in Canada: (1) publishable records that represent production data for genetically elite animals within the Canadian herd from 1990 to present, and (2) management records that provide a more accurate estimate of production from the entire Canadian dairy herd from 1999 to present. An estimate of milk production for the entire Canadian herd from 1990 to 1998 was calculated based on the average ratio between the publishable and the management data from 1999 to 2007.

Table 5–4 **Uncertainty in the Estimates of CH<sub>4</sub> Emissions from Enteric Fermentation**

Livestock Category	Uncertainty Source		Mean Value <sup>a,b</sup>	2.5% Probability <sup>b</sup>	97.5% Probability <sup>b</sup>
Dairy Cattle	Population (1000 head)		965	915 (-5.2%)	1 016 (+5.2%)
	Tier 2 emission factor (kg/head/year)		146	124 (-15%)	174 (+19%)
	Emissions (Mt CO <sub>2</sub> eq)		3.9	3.3 (-16%)	4.7 (+20%)
Non-Dairy Cattle	Population (1000 head)		10 712	10 507 (-1.9%)	10 930 (+2.0%)
	Tier 2 emission factor (kg/head/year)		71	60 (-15%)	84 (+18%)
	Emissions (Mt CO <sub>2</sub> eq)		21	18 (-16%)	26 (+21%)
Other Livestock	Emissions (Mt CO <sub>2</sub> eq)		1.2	0.97 (-18%)	1.4 (+18%)
Total emissions	Emissions (Mt CO <sub>2</sub> eq)	1990	25	21 (-16%)	30 (+21%)
		2023	27	23 (-14%)	32 (+17%)
		Trend	1990–2023	2.1 (+8.2%)	0.99 (+4.4%)
					2.8 (+13%)

Notes:

a. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2023.

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 2023.

### 5.2.4. QA/QC 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 consider 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<sub>4</sub> emissions from wetland emissions, the top-down estimates were consistent with the bottom-up estimates in areas where wetland emissions were minimal.

### 5.2.5. Recalculations

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

### 5.2.6. Planned Improvements

In general, the enteric fermentation methodology is robust; improvements are mainly dependent on the ability to collect more complete data on the composition of the diet fed to livestock, as that will facilitate the development of parameters specific to animal subcategories within different regions of Canada. Dairy feed information is currently being processed to update the time series for changes to dairy feed in recent years.

A study undertaken with Canadian beef industry experts to update and improve the beef production model was carried out, to characterize the variability in animal management strategies in different regions across Canada. However, no immediate plans are in place to modify the emission method.

## 5.3. Manure Management (CRT Category 3.B)

In Canada, the animal waste management systems (AWMS) typically used in animal production include (1) liquid storage, (2) solid storage and drylot, and (3) pasture and paddock. To a lesser extent, AWMS also include other systems such as composting and biodigesters. No manure is burned as fuel.

Both CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> emissions but relatively low N<sub>2</sub>O emissions, whereas well-aerated systems generate high N<sub>2</sub>O emissions but relatively low CH<sub>4</sub> emissions.

Manure management practices vary regionally, by animal categories, and over time. Most dairy, swine and poultry production occurs in modern high-density production facilities in Canada. The dairy industry has experienced a shift in manure storage practices since 1990, with larger operations with liquid systems replacing smaller operations with solid systems. The swine industry produces large volumes of liquid manure, and there has been an increase in the use of liquid manure systems in swine production since 1990, while poultry manure is predominantly managed in solid form. Both swine and poultry manure are spread on a limited land base. Feedlot beef production results in large volumes of dry lot and solid manure, whereas low-density pasturing systems for beef result in widely dispersed manure in pastures and paddocks. Other animals, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boars, sheep, and mules and asses, are generally raised in pastured and/or medium-density production facilities producing mainly solid manure. Fur-bearing animals also produce solid manure.

### 5.3.1. CH<sub>4</sub> Emissions from Manure Management (CRT Category 3.B [a])

#### 5.3.1.1. Category Description

Shortly after manure is excreted, the decomposition process begins. In well-aerated conditions, decomposition is an oxidation process producing CO<sub>2</sub>. However, if little oxygen is present, carbon is reduced, resulting in the production of CH<sub>4</sub>. The quantity of CH<sub>4</sub> produced depends on manure characteristics and the type of manure management system. Manure characteristics are, in turn, linked to animal category and animal nutrition.

#### 5.3.1.2. Methodological Issues

Methane emissions from 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 to better capture trends in feeding practices and/or animal weights, as described in Annex 3.4. For dairy cattle, the digestibility (DE) of feed is responsive to animal diet, and for swine, volatile solids excreted in manure are adjusted based on trends in body weights and growth rates. Volatile solids (VS) were estimated using Equation 10.23 of the 2006 IPCC Guidelines and manure ash contents from Marinier et al. (2004). For all other livestock, parameters taken from Marinier et al. (2004) were used to calculate VS based on ash content and digestible energy derived from

expert consultations. Urinary energy (UE) coefficients were applied according to the 2006 IPCC Guidelines. VS for swine were corrected for animal mass as described in Annex 3.4. For sheep and poultry categories, different animal subcategory parameters were used based on animal size for lambs and adult sheep and turkeys, broilers and layers in the poultry category.

Emission factors were derived using the CH<sub>4</sub> producing potential (B<sub>0</sub>), CH<sub>4</sub> 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, considering regional differences in production practices and manure storage systems. For swine and dairy cattle, a manure storage system time series was developed 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 section A3.4.3.3.

Increases in cattle emission factors over the 1990–2023 period (see section A3.4.3) reflect higher gross energy intake for dairy cattle due to changes in feed, herd characteristics and increased milk productivity. Most importantly, emission factors for dairy also reflect trends in manure storage practices, primarily, a shift from solid systems to liquid systems. For non-dairy cattle, changes are due to changes in live body weights (see section 5.2.2). Changes in swine emission factors (see section A3.4.3.6) for sows are related to the shift in swine production from eastern to western Canada, and in the case of growing swine are a result of increases in growth rates and final carcass weights.

### 5.3.1.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty analysis of CH<sub>4</sub> emissions from agricultural sources using the Monte Carlo technique included CH<sub>4</sub> emissions from management of manure. The analysis used parameter estimates and uncertainty distributions from Marinier et al. (2004) supplemented with information from Karimi-Zindashty et al. (2012), and additional and updated parameters specific to this analysis. Details of this analysis can be found in section A3.4.3.8.

The CH<sub>4</sub> emission estimate of 4.3 Mt CO<sub>2</sub> eq from the management of livestock manure in Canada in 2023 lies within an uncertainty range of -28% to +23% (Table 5–5). The emission estimate for 1990, 2.8 Mt CO<sub>2</sub> eq, has a slightly larger uncertainty range, -44% to +36%, due to the greater uncertainty associated with the distribution of manure management system types in 1990. The estimate of a 57% increase in mean emissions between 1990 and 2023 lies within an uncertainty range of +45% to +66%.

As was the case with the Enteric Fermentation category, most uncertainty in the emission estimate is associated with the calculation of the emission factor. The uncertainty range around the mean emission factor is as high as 110% in the case of dairy cattle. The uncertainty in emissions is most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology; in particular, the MCF that is applied to all regions of Canada and all animal types, and the maximum B<sub>0</sub> (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

Table 5–5 **Uncertainty in the Estimates of CH<sub>4</sub> Emissions from Manure Management**

Livestock Category	Uncertainty Source		Mean Value <sup>a</sup>	2.5% Probability <sup>b</sup>	97.5% Probability <sup>b</sup>
Dairy Cattle	Population (1000 head)		965	915 (-5.2%)	1 016 (+5.2%)
	Tier 2 emission factor (kg/head/year)		40	22 (-45%)	54 (+37%)
	Emissions (Mt CO <sub>2</sub> eq)		1.1	0.6 (-45%)	1.46 (+37%)
Non-Dairy Cattle	Population (1000 head)		10 712	10 507 (-1.9%)	10 930 (+2.0%)
	Tier 2 emission factor (kg/head/year)		3.6	2.7 (-25%)	5.3 (+45%)
	Emissions (Mt CO <sub>2</sub> eq)		1.1	0.8 (-27%)	1.64 (+51%)
Swine	Population (1000 head)		13 858	13 529 (-2.4%)	14 193 (+2.4%)
	Tier 2 emission factor (kg/head/year)		4.9	2.2 (-54%)	7.1 (+45%)
	Emissions (Mt CO <sub>2</sub> eq)		1.9	1.0 (-49%)	2.70 (+42%)
Other Livestock	Emissions (Mt CO <sub>2</sub> eq)		0.25	0.17 (-31%)	0.29 (+14%)
Total Emissions	Emissions (Mt CO <sub>2</sub> eq)	1990	2.8	1.5 (-44%)	3.7 (+36%)
		2023	4.3	3.1 (-28%)	5.3 (+23%)
	Trend	1990–2023	1.6 (+57%)	1.1 (+45%)	1.6 (+66%)

Notes:

a. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2023.

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 2023.

models would have a large impact on national manure management uncertainty. However, the introduction of an AWMS time series for the dairy and swine sectors may play an important role in influencing the trend uncertainty for manure management emissions.

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2023), except for milk production for dairy cattle and bull weights. Milk production from 1990 to 1999 in Ontario and the western provinces, and bull carcass weights, were estimated as described in section 5.2.3.

#### 5.3.1.4. 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 methodologies are documented and archived in electronic format. The IPCC Tier 2 CH<sub>4</sub> emission factors for manure management practices by all animal categories derived from Marinier et al. (2004) have been reviewed by independent experts (Patni and Desjardins, 2004). These documents have been archived in electronic form.

Internal Tier 2 QC checks carried out in 2010–2011 included a complete review and rebuild of calculation methodology, input data and review and compilation of Canadian research on manure management (MacDonald and Liang 2011). No specific bias can be clearly identified in the IPCC Tier 2 model parameters due to the high variability in research results and the lack of supporting information for research carried out on manure storage installations. There is no clear standard for evaluating whether IPCC parameters are appropriate for estimating emissions from manure management systems in the Canadian context. More standardized and detailed research is required in Canada to improve upon the current Tier 2 methodology. Details of this review can be found in section A3.4.3.7.

#### 5.3.1.5. Recalculations

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

#### 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<sub>2</sub>O Emissions from Manure Management (CRT Category 3.B [b])

#### 5.3.2.1. Category Description

The production of N<sub>2</sub>O 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<sub>4</sub><sup>+</sup>) to nitrate (NO<sub>3</sub><sup>-</sup>), and denitrification is the reduction of NO<sub>3</sub><sup>-</sup> to N<sub>2</sub>O or N<sub>2</sub>. Manure from the non-dairy cattle, sheep, goats, horses, and other minor livestock categories is mostly handled in solid and dry-lot systems, which are the types of manure management systems that emit the most N<sub>2</sub>O. N<sub>2</sub>O emissions from urine and dung deposited by grazing animals are reported separately (see section 5.4.1.4).

#### 5.3.2.2. Methodological Issues

N<sub>2</sub>O 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<sub>2</sub>O emission factors are assigned to AWMS subsystems (section A3.4.3.3), and weighted AWMS N<sub>2</sub>O 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<sub>2</sub>O emission factors are assigned to AWMS subsystems (section A3.4.3.3), and weighted AWMS N<sub>2</sub>O 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<sub>2</sub>O for each type of AWMS.

#### 5.3.2.3. Uncertainty Assessment and Time-Series Consistency

An uncertainty analysis using the Monte Carlo technique was carried out to estimate emissions of N<sub>2</sub>O from agricultural sources (Karimi-Zindashty et al., 2014). For N<sub>2</sub>O 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<sub>4</sub> 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 section A3.4.6.

The estimate of direct N<sub>2</sub>O emissions of 2.9 Mt CO<sub>2</sub> eq from Manure Management in 2023 lies within an uncertainty range of 1.6 Mt CO<sub>2</sub> eq (-43%) to 4.4 Mt CO<sub>2</sub> eq (+51%) (Table 5–6). Most uncertainty is associated with the IPCC Tier 1 emission factor (±100% uncertainty). Due to the size of the N<sub>2</sub>O model, the initial uncertainty analysis was limited to providing sound estimates of uncertainty for emission source categories and a basic sensitivity analysis. A complete analysis of the trend uncertainty has not yet been completed due to limitations in software capabilities. An uncertainty analysis of the dairy and swine models has not yet been performed.

The same methodology, emission factors and data sources are used for the entire time series (1990–2023).

#### 5.3.2.4. 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, 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<sub>2</sub>O emission database.

There are very few published data on N<sub>2</sub>O emissions from manure management and storage in Canada or in regions with practices and climatic conditions comparable to those of Canada. More standardized and detailed research is required in Canada to improve on the current methodology.

#### 5.3.2.5. Recalculations

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

#### 5.3.2.6. Planned Improvements

Data from direct measurements of N<sub>2</sub>O emissions from manure management in Canada are scarce. Recent scientific advances in analytical techniques allow direct measurements of N<sub>2</sub>O emissions from point sources. However, it will likely take several years before N<sub>2</sub>O emissions can be reliably measured and verified for various manure management systems in Canada.

As noted in section 5.3.1.6, implementing an AWMS time series is the main source of improvement available for this emission source. Improvements to dairy and swine have been implemented based on Statistics Canada farm environmental management surveys, and plans are in place to incorporate this analysis for other livestock categories.

Furthermore, as noted in section 5.2.6, data have been collected to develop a time series that accounts for changes in animal nutrition and country-specific nitrogen excretion rates. These data have been integrated for dairy cattle, but a similar analysis is still to be completed for swine. For select other livestock categories, changes will be incorporated over the medium term.

Further uncertainty analyses will be carried out to establish trend uncertainty and consider changes in the livestock models over the medium term.

### 5.3.3. Indirect N<sub>2</sub>O Emissions from Manure Management (CRT Category 3.B.5)

#### 5.3.3.1. Category Description

The production of N<sub>2</sub>O from manure management can also occur indirectly through NH<sub>3</sub> volatilization and leaching of N during storage and handling of animal manure. A fraction of the nitrogen in stored manure is transported off-site through volatilization in the form of NH<sub>3</sub> and NO<sub>x</sub> and subsequent redeposition. Furthermore, solid manure exposed to rainfall will be prone to loss of N through leaching and runoff. The nitrogen transported from the manure storage site in this manner is assumed to undergo subsequent nitrification and denitrification elsewhere in the environment and, consequently, produce N<sub>2</sub>O.

#### 5.3.3.2. Methodological Issues

Indirect emissions of N<sub>2</sub>O 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<sub>2</sub>O 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<sub>3</sub> and NO<sub>x</sub> during storage is estimated using a revised version of the Canadian NH<sub>3</sub> 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<sub>3</sub> 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<sub>2</sub>O 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<sub>2</sub>O 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. Uncertainty Assessment and Time-Series Consistency

A full uncertainty analysis using a Monte Carlo technique has not been carried out on the estimation of N<sub>2</sub>O emissions from manure management. The uncertainties associated with livestock populations, manure N excretion rates, AWMS, N leaching and NH<sub>3</sub> volatilization fractions, and indirect N<sub>2</sub>O 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 (1990–2023).

#### 5.3.3.4. QA/QC and Verification

This category underwent Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) following the 2006 IPCC Guidelines. The activity data, methodology and databases have been documented and archived in electronic form.

#### 5.3.3.5. Recalculations

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

#### 5.3.3.6. Planned Improvements

As noted in section 5.3.1.6, country-specific NH<sub>3</sub> volatilization fractions and N leaching coefficients, stratified by livestock subcategory and AWMS, are being developed for beef cattle. Non-Dairy Cattle Tier 2 parameters might be revised based on recent information.

## 5.4. N<sub>2</sub>O Emissions from Agricultural Soils (CRT Category 3.D)

N<sub>2</sub>O emissions from agricultural soils occur in direct and indirect forms: directly from anthropogenic N inputs to soils and indirectly through various pathways. Changes in crop rotations and management practices, such as tillage and irrigation, affect direct N<sub>2</sub>O emissions by altering the mineralization rates of organic nitrogen, nitrification and denitrification. Indirect emissions occur through two pathways: (1) the volatilization of nitrogen from inorganic fertilizer and manure applied to fields as NH<sub>3</sub> and NO<sub>x</sub> 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<sub>2</sub>O Emissions from Managed Soils (CRT Category 3.D.1)

Direct sources of N<sub>2</sub>O 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 based on nitrogen inputs from the application of organic and inorganic nitrogen fertilizers and crop residue nitrogen.

#### 5.4.1.1. Inorganic Nitrogen Fertilizers (CRT Category 3.D.1.a)

##### 5.4.1.1.1. Category Description

Inorganic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen undergoes transformations such as nitrification and denitrification that can release N<sub>2</sub>O. 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<sub>2</sub>O emissions from inorganic nitrogen fertilizer application on agricultural soils, which considers moisture regimes, soil texture, nitrogen sources, cropping systems, and topographic conditions. Emissions of N<sub>2</sub>O 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. Uncertainty Assessment and Time-Series Consistency

The uncertainty analysis, using the Monte Carlo technique on the methodology used to estimate emissions of N<sub>2</sub>O from agricultural sources noted in section 5.3.2.3, includes all direct and indirect emissions from soils (Table 5–6). For N<sub>2</sub>O emissions from fertilizer, the analysis considers the uncertainty in the parameters defined in the previous country-specific methodology (Rochette et al., 2008a) used to develop N<sub>2</sub>O 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<sub>2</sub>O emission factors. The quantification of uncertainty is expected to be improved due to the larger and more complete dataset for quantifying emission factors. Consequently, uncertainty analysis will rely less on expert judgement to establish probability distributions for factors used in deriving regional emission factors.

Based on past analysis, it is estimated that N<sub>2</sub>O emissions of 9.3 Mt CO<sub>2</sub> eq from the application of inorganic fertilizers on agricultural soils in 2023 lies within a range of 6.1 Mt CO<sub>2</sub> eq (-35%) to 13 Mt CO<sub>2</sub> eq (+43%) (Table 5–6).

The same methodology and emission factors were used for the entire time series (1990–2023).

Table 5–6 **Uncertainty in the Estimates of N<sub>2</sub>O Emissions from Manure Management and Agricultural Soils in 2023**

Emission Source		Mean Value <sup>a</sup>	2.5% Probability <sup>b</sup>	97.5% Probability <sup>b</sup>
		Mt CO <sub>2</sub> eq		
MANURE MANAGEMENT (N <sub>2</sub> O)				
Direct emissions		2.9	1.6 (-43%)	4.4 (+51%)
Indirect emissions		0.53	0.21 (-60%)	0.89 (+70%)
AGRICULTURAL SOILS (N <sub>2</sub> O)		18	11 (-36%)	27 (+52%)
Direct N <sub>2</sub> O emissions from managed soils		14	10 (-28%)	19 (+34%)
	Inorganic N fertilizers	9.3	6.1 (-35%)	13 (+43%)
	Organic N fertilizers	1.3	0.89 (-33%)	1.9 (+41%)
	Crop residues	3.7	2.4 (-35%)	5.3 (+45%)
	Cultivation of organic soils	0.22	0.046 (-79%)	0.43 (+96%)
	Mineralization associated with loss of soil organic matter	0.54	0.35 (-35%)	0.79 (+45%)
	Urine and dung deposited by grazing animals	0.17	0.067 (-60%)	0.29 (+75%)
	Soil N mineralization/immobilization	-1.2	-0.65 (-44%)	-1.8 (+55%)
Indirect N <sub>2</sub> O emissions from managed soils		3.7	1.5 (-60%)	6.3 (+70%)
	Atmospheric Deposition	0.91	0.23 (-75%)	1.9 (+110%)
	Leaching and runoff	2.8	0.56 (-80%)	5.6 (+100%)
Notes:				
a. Mean value reported from database.				
b. Values in parentheses represent the uncertain percentage of the mean.				

#### 5.4.1.1.4. 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, 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<sub>2</sub>O associated with inorganic fertilizer nitrogen applications on agricultural soils in Canada vary on a site-by-site basis. There is, however, an agreement between the previous IPCC default emission factor of 1% (IPCC, 2006), the revised humid environment emission factor of 1.6% (IPCC, 2019), the measured emission factor of 1.2% in eastern Canada, excluding emissions during the spring thaw period (Gregorich et al., 2005; Desjardins et al., 2010), and the range of emission factors developed in this methodology.

#### 5.4.1.1.5. Recalculations

A minor correction was made to the non-growing season ratio-factor to assure consistency with the final value published in Pelster et al. (2024) that had a minor impact on soil N<sub>2</sub>O emissions.

Emissions were revised downward by 57 kt CO<sub>2</sub> eq in 1990, 67 kt CO<sub>2</sub> eq in 2005, and by 123 kt CO<sub>2</sub> eq in 2022 (Table 5–7). The recalculations resulted in no change in the short-term and long-term emission trends (84% and 122%, respectively).

#### 5.4.1.1.6. Planned Improvements

The current method does not account for mitigation measures that reduce soil N<sub>2</sub>O 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.

**Table 5–7 Recalculations of N<sub>2</sub>O Emission Estimates and Their Impact on Trends in Greenhouse Gas Emissions from Fertilizer Application, Crop Residue Decomposition and Histosols**

Emission Source	Year	Submission Year	Category Emissions (kt CO <sub>2</sub> eq)	Change in Emissions (kt CO <sub>2</sub> eq)	Relative Change in Category Emissions (%)
Inorganic N fertilizers	1990	2024	3 926	57	-1.5
		2025	3 869		
	2005	2024	4 722	67	-1.4
		2025	4 655		
	2022	2024	8 701	123	-1.4
		2025	8 578		
Organic N fertilizers	1990	2024	1 014	16	-1.5
		2025	1 029		
	2005	2024	1 322	20	-1.5
		2025	1 302		
	2022	2024	1 362	21	-1.5
		2025	1 341		
Crop Residue and Mineralization Associated with Loss of Soil Organic Matter	1990	2024	2 225	31	-1.4
		2025	2 194		
	2005	2024	2 734	37	-1.4
		2025	2 696		
	2022	2024	3 886	53	-1.4
		2025	3 833		
Cultivation of Organic Soils	1990	2024	54	164	305
		2025	218		
	2005	2024	54	164	305
		2025	218		
	2022	2024	54	164	305
		2025	218		

#### 5.4.1.2. Organic Nitrogen Fertilizers Applied to Soils (CRT Category 3.D.1.b)

##### 5.4.1.2.1. Category Description

The application of organic nitrogen sources as fertilizer to agricultural soils can increase the rate of nitrification and denitrification and result in enhanced N<sub>2</sub>O emissions. Emissions from this category include (i) all manure managed by dry lot, liquid and other AWMSs; and (ii) human biosolids managed by municipal wastewater treatment plants.

##### 5.4.1.2.2. Methodological Issues

As is the case for N<sub>2</sub>O emissions from inorganic nitrogen fertilizers, a Tier 2 methodology is used to estimate N<sub>2</sub>O emissions from organic manure applied to agricultural soils using country-specific emission factors that consider moisture regimes (long-term growing season precipitation and potential evapotranspiration), soil texture, N sources, cropping systems, and topographic conditions. Emissions are calculated by multiplying the amount of organic N applied to agricultural soils by a weighted emission factor calculated for each ecodistrict, summed at the provincial and national levels. All manure handled by AWMSs, except for the urine and dung deposited by grazing animals, is assumed to be subsequently applied to agricultural soils after accounting for N losses during storage. Nitrogen in biosolids is applied to specific crop types per ecodistrict based on provincial regulations and crop requirements, and subsequent emissions are calculated using the country-specific Tier 2 emission factors for organic N.

##### 5.4.1.2.3. Uncertainty Assessment and Time-Series Consistency

In the case of N<sub>2</sub>O emissions from the application of organic nitrogen fertilizer, the uncertainty analysis considers the uncertainty associated with the parameters used to produce estimates of manure N, as noted in section 5.3.2.3, as well as the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) previously used to develop N<sub>2</sub>O emission factors, as noted in section 5.4.1.1.3. An updated Monte Carlo uncertainty analysis is planned, to quantify the uncertainty in the updated country-specific soil N<sub>2</sub>O 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.

Based on past analyses, it is estimated that N<sub>2</sub>O emissions of 1.3 Mt CO<sub>2</sub> eq from application of organic nitrogen fertilizers in 2023 lie within an uncertainty range of 0.9 Mt CO<sub>2</sub> eq (-33%) to 1.9 Mt CO<sub>2</sub> eq (+41%) (Table 5–6). 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<sub>2</sub>O 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 (1990–2023).

#### 5.4.1.2.4. 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, methodologies and changes to methodologies have been documented and archived in electronic form.

#### 5.4.1.2.5. Recalculations

A minor correction was made to the non-growing season ratio-factor to assure consistency with the final value published in Pelster et al. (2024) that had a minor impact on soil N<sub>2</sub>O emissions from organic fertilizer application. Emissions were revised downward by 16 kt CO<sub>2</sub> eq in 1990, 20 kt CO<sub>2</sub> eq in 2005, and 21 kt CO<sub>2</sub> eq in 2022 (Table 5–7). These recalculations resulted in no change in either short-term (3%) or long-term trend (32%).

#### 5.4.1.2.6. Planned Improvements

The current method does not account for mitigation measures that reduce soil N<sub>2</sub>O emissions, such as the timing of organic N applications. Canada plans to develop more robust ratio factors to account for mitigation measures over the medium term of three to five years.

### 5.4.1.3. Crop Residues (CRT Category 3.D.1.d)

#### 5.4.1.3.1. Category Description

When a crop is harvested, a portion is left in the field to decompose. This remaining plant matter serves as a source of N, which subsequently undergoes nitrification and denitrification and can thus contribute to N<sub>2</sub>O 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. Uncertainty Assessment and Time-Series Consistency

For N<sub>2</sub>O emissions from crop residue decomposition, the uncertainty analysis considers the uncertainty in crop production, as well as the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N<sub>2</sub>O emission factors as noted in section 5.4.1.1.3.

The estimate of N<sub>2</sub>O emissions of 3.7 Mt CO<sub>2</sub> eq from crop residue decomposition in 2023 is associated with an uncertainty range of -35% to +45%, or 2.4 Mt CO<sub>2</sub> eq to 5.3 Mt CO<sub>2</sub> eq respectively (Table 5–6). 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<sub>2</sub>O emission factors, and the emission factor modifiers for texture (RF\_TX) and tillage (RF\_TILL). An updated Monte Carlo uncertainty analysis is planned, to account for the uncertainty in the updated country-specific soil N<sub>2</sub>O emission factors, including the ratio factor used for organic nitrogen.

The same methodology and emission factors are used for the entire time series (1990–2023).

#### 5.4.1.3.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) following the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

#### 5.4.1.3.5. Recalculations

A minor correction was made to the non-growing season ratio-factor to assure consistency with the final value published in Pelster et al. (2024) that had a minor impact on soil N<sub>2</sub>O emissions. Minor modifications to yield data also had a minor impact on emissions in 2021 with an upward revision of roughly (≈60 kt CO<sub>2</sub> eq).

Emissions were revised downward by 31 kt CO<sub>2</sub> eq in 1990, 37 kt CO<sub>2</sub> eq in 2005 and 53 kt CO<sub>2</sub> eq in 2022, respectively (Table 5–7). There was no impact on the long-term (75%) or short-term emission trend (42%) as a result of these changes.

#### 5.4.1.3.6. Planned Improvements

Future improvements will focus on differentiating organic nitrogen fertilizers from crop residue N over the medium term (i.e. three to five years).

### 5.4.1.4. Urine and Dung Deposited by Grazing Animals (CRT Category 3.D.1.c)

#### 5.4.1.4.1. 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<sub>2</sub>O can be emitted.

#### 5.4.1.4.2. Methodological Issues

N<sub>2</sub>O emissions from manure excreted by grazing animals are calculated using a country-specific IPCC Tier 2 method that was derived from field flux measurements (Rochette et al., 2014; Lemke et al., 2012). Details of these new emission factors can be found in section A3.4.5. Emissions are calculated for each animal category by multiplying the number of grazing animals for that category by the appropriate nitrogen excretion rate and by the fraction of manure nitrogen available for conversion to N<sub>2</sub>O.

#### 5.4.1.4.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty associated with the new estimates of N<sub>2</sub>O emissions from urine and dung deposited by grazing animals is estimated based on the previous uncertainty analysis using the parameters and uncertainty distributions defined in the Tier 1 methodology in the 2006 IPCC Guidelines, except for new emission factors. Livestock populations, the proportion of animals on pasture systems and their characterizations are identical to those used in the analysis of CH<sub>4</sub> 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<sub>2</sub>O emissions of 0.17 Mt CO<sub>2</sub> eq from pasturing Canadian livestock in 2023 lies within an uncertainty range of -60% to +75%, or 0.067 Mt CO<sub>2</sub> eq to 0.29 Mt CO<sub>2</sub> eq, respectively (Table 5–6).

The same methodology and emission factors are used for the entire time series (1990–2023).

#### 5.4.1.4.4. QA/QC and Verification

The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form. QC checks and cross-checks have been carried out to identify data entry errors and calculation errors.

#### 5.4.1.4.5. Recalculations

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

#### 5.4.1.4.6. Planned Improvements

No improvements are currently planned for this category. Further uncertainty work will be carried out to consider changes made to the pasture, range and paddock (PRP) model and to establish trend uncertainty over the medium term.

### 5.4.1.5. Mineralization Associated with Loss of Soil Organic Matter (CRT Category 3.D.1.e)

#### 5.4.1.5.1. Category Description

Carbon loss in soils because of changes in land management practices, crop productivity, and manure application is accounted for in the Cropland category of the LULUCF sector (Chapter 6). Nevertheless, N mineralization associated with the loss of soil organic carbon contributes to the overall N balance of agricultural lands. This nitrogen, once in an inorganic form, is prone to loss in the form of N<sub>2</sub>O during either nitrification or denitrification and consequently must be considered because of its contribution to soil N<sub>2</sub>O emissions.

#### 5.4.1.5.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of N in soil organic matter that is lost because of changes in cropland management practices, crop productivity and/or manure application, multiplied by the emission factor at the ecodistrict level, and scaled up to the provincial and national levels.

The quantity of soil organic carbon loss at an ecodistrict level from 1990 to 2023 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<sub>2</sub>O 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<sub>2</sub>O emission factors (EF\_BASE) are the same as those used to estimate emissions from the application of organic fertilizer on annual crops. Emission factors are based on climatic and soil characteristics in the individual ecodistrict in which organic matter mineralization occurs.

#### 5.4.1.5.3. Uncertainty Assessment and Time-Series Consistency

Uncertainty parameters are based on the standard deviation for the soil database, uncertainty estimates of carbon loss and the uncertainty surrounding ecodistrict-based emission factors. Impacts on the uncertainty associated with agricultural soils will be re-evaluated during the next full round of uncertainty assessments when they are renewed. Owing to its small contribution to total emissions, this source would not likely affect overall emission uncertainty. Currently, uncertainty estimates for this category are considered the same as those for emissions from crop residue decomposition. According to these assumptions, the estimate of N<sub>2</sub>O emissions of 0.54 Mt CO<sub>2</sub> eq from mineralization associated with the loss of soil organic matter in 2023 lies within an uncertainty range of -35% to +45%, or 0.35 Mt CO<sub>2</sub> eq to 0.79 Mt CO<sub>2</sub> eq, respectively (Table 5–6).

#### 5.4.1.5.4. 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, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

#### 5.4.1.5.5. Recalculations

A minor correction was made to the non-growing season ratio-factor to assure consistency with the final value published in Pelster et al. (2024) that had a minor impact on soil N<sub>2</sub>O emissions.

Emissions were revised downward by 3 kt CO<sub>2</sub> eq in 1990, 3 kt CO<sub>2</sub> eq in 2005 and 19 kt CO<sub>2</sub> eq in 2022, respectively. There was no impact on the long-term or short-term emission trend as a result of these changes.

#### 5.4.1.5.6. Planned Improvements

As is the case for crop residue N, future improvements in this category will focus on differentiating N<sub>2</sub>O emission factors for organic and inorganic N sources. The uncertainty for this category will be calculated in the next round of uncertainty analyses.

### 5.4.1.6. Cultivation of Organic Soils (CRT Category 3.D.1.f)

#### 5.4.1.6.1. Category Description

Cultivation of organic soils (histosols) for crop production usually involves drainage, lowering the water table and increasing aeration, which enhances the decomposition of organic matter and nitrogen mineralization. The enhancement of decomposition upon the cultivation of histosols can result in greater denitrification and nitrification and thus in higher N<sub>2</sub>O production (Mosier et al., 1998).

#### 5.4.1.6.2. Methodological Issues

The IPCC Tier 1 methodology is used to estimate N<sub>2</sub>O emissions from cultivated organic soils. Emissions of N<sub>2</sub>O are calculated by multiplying the area of cultivated histosols by the IPCC default emission factor.

Areas of cultivated histosols at a provincial level are not surveyed in the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada have resulted in an estimated area of 16 kha and 30 kha of cultivated organic soils for annual and perennial crop production in Canada, a constant level for the period 1990–2023 (Liang et al., 2004a).

#### 5.4.1.6.3. Uncertainty Assessment and Time-Series Consistency

For N<sub>2</sub>O emissions from organic soils, the uncertainty analysis considers the uncertainty in cultivated organic soils and in the default emission factors.

The N<sub>2</sub>O emission estimate of 0.22 Mt CO<sub>2</sub> eq from organic soils in 2023 lies within an uncertainty range of -79% to +96%, or 0.05 Mt CO<sub>2</sub> eq to 0.43 Mt CO<sub>2</sub> eq, respectively (Table 5–6). The main source of uncertainty is the IPCC Tier 1 default emission factors.

The same methodology and emission factors are used for the entire time series (1990–2023).

#### 5.4.1.6.4. 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, methodologies, and changes to methodologies are documented and archived in paper and electronic form.

#### 5.4.1.6.5. Recalculations

The inclusion of cultivated histosols for perennial crop production combined with the revision of IPCC Tier 1 N<sub>2</sub>O EFs from the 2013 Wetland Supplement results in significant increased emissions in 1990, 2005 and 2023 by 164 kt CO<sub>2</sub> eq (305%) (Table 5–7). This change did not alter the long-term or short-term trend.

#### 5.4.1.6.6. Planned Improvements

No improvements are currently planned for this category. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

### 5.4.1.7. Changes in N<sub>2</sub>O Emissions from Adoption of No-Till and Reduced Tillage

#### 5.4.1.7.1. Category Description

Emissions in this category are not derived from additional N inputs (i.e., fertilizer, manure or crop residues). Rather, it is implemented as a modification to N<sub>2</sub>O 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-till, as well as reduced tillage, results in changes to several factors that influence N<sub>2</sub>O 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<sub>2</sub>O emissions for the Prairies (Malhi and Lemke, 2007) and can increase N<sub>2</sub>O emissions for the non-Prairie regions of Canada (Liang et al., 2020; Rochette et al., 2008b) but results were highly variable on a more broad analysis (Pelster et al. 2023). Following an expert review process with Canadian agricultural research scientists, the tillage factor for prairie regions from Liang et al. (2020) is implemented, while the factor for non-prairie regions is not implemented, pending further analysis. The net result across the country is a reduction in emissions. This reduction is reported separately as a negative estimate (Table 5–1).

Changes in N<sub>2</sub>O emissions resulting from the adoption of NT and RT are estimated through the modification of soil N<sub>2</sub>O emission factors and applied to inorganic fertilizers, organic nitrogen applied to cropland, and crop residue nitrogen decomposition. This subcategory is kept separate from the fertilizer and crop residue decomposition source categories to preserve transparency in reporting. However, this separation causes negative emissions to be reported. An empirically derived tillage factor (RF\_TILL), defined as the ratio of mean N<sub>2</sub>O fluxes on NT or RT to mean N<sub>2</sub>O fluxes on intensive tillage (IT) ( $N_{2O_{NT}}/N_{2O_{IT}}$ ), represents the effect of NT or RT on N<sub>2</sub>O emissions (see Annex 3.4).

#### 5.4.1.7.3. Uncertainty Assessment and Time-Series Consistency

For N<sub>2</sub>O emissions from the adoption of conservation tillage practices, the uncertainty analysis considers the uncertainty in tillage practice areas, manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N<sub>2</sub>O emission factors as noted in section 5.4.1.1.3.

The estimate of N<sub>2</sub>O emission reductions of 2.2 Mt CO<sub>2</sub> eq from conservation tillage practices in 2023 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 5–6). 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 (1990–2023).

5.4.1.7.4. **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, methodologies and changes to methodologies are documented and archived in paper and electronic form.

5.4.1.7.5. **Recalculations**

A minor correction was made to the non-growing season ratio-factor to assure consistency with the final value published in Pelster et al. (2024) that had a minor impact on soil N<sub>2</sub>O emissions. This change led to an upward recalculation in N<sub>2</sub>O emissions of 5 kt CO<sub>2</sub> eq in 1990, 13 kt CO<sub>2</sub> eq in 2005 and 28 kt CO<sub>2</sub> eq in 2022. These recalculations resulted in no change in the long-term (520%) or short term (110%) trend (Table 5–8).

Table 5–8 Recalculations of N <sub>2</sub> O 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 <sub>2</sub> eq)	Change in Emissions (kt CO <sub>2</sub> eq)	Relative Change in Category Emissions (%)
Conservation tillage practices	1990	2024	-360	4.5	-1.3
		2025	-355		
	2005	2024	-1 059	13	-1.2
		2025	-1 046		
	2022	2024	-2 233	28	-1.2
		2025	-2 205		
Irrigation	1990	2024	494	-4.6	-0.93
		2025	490		
	2005	2024	694	-6.6	-0.95
		2025	688		
	2022	2024	1 151	-11	-1.0
		2025	1 140		

5.4.1.7.6. **Planned Improvements**

Work is ongoing to develop level and trend uncertainty estimates using the IPCC Tier 2 method. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.8. **N<sub>2</sub>O Emissions from Irrigation**

5.4.1.8.1. **Category Description**

As in the case of tillage practices, the effect of irrigation on N<sub>2</sub>O emissions is not derived from additional nitrogen input but rather reflects changes in soil conditions that affect N<sub>2</sub>O emissions. Higher soil water content under irrigation increases the potential for N<sub>2</sub>O emissions through increased anaerobic biological activity, reducing soil aeration (Jambert et al., 1997) and thus enhancing denitrification.

5.4.1.8.2. **Methodological Issues**

The methodology used is country-specific and is based on the assumptions that (i) irrigation water stimulates N<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O emissions is also reported separately from other source categories.

#### 5.4.1.8.3. Uncertainty Assessment and Time-Series Consistency

For N<sub>2</sub>O emissions from irrigation, the uncertainty analysis considers the uncertainty associated with irrigated areas and the manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, as well as the uncertainty defined in the previous country-specific methodology (Rochette et al., 2008a) used to develop N<sub>2</sub>O 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<sub>2</sub>O emission factors and the irrigation emission factor included in this submission.

The estimate of N<sub>2</sub>O emissions of 1.1 Mt CO<sub>2</sub> eq from irrigated land in 2023 has an uncertainty range of -44% to +55%, based on the uncertainty range of the combined emissions from tillage, irrigation and summer fallow practices (Table 5–8). 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<sub>2</sub>O emission factors included in this submission.

The same methodology and emission factors are used for the entire time series (1990–2023).

#### 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. A minor correction was made to the non-growing season ratio-factor to assure consistency with the final value published in Pelster et al. (2024) that had a minor impact on soil N<sub>2</sub>O emissions. Emissions were revised downward by 5 kt CO<sub>2</sub> eq in 1990, 7 kt CO<sub>2</sub> eq in 2005 and 11 kt CO<sub>2</sub> eq in 2022, respectively. There was no impact on the long-term or short-term emission trend (Table 5–8).

#### 5.4.1.8.6. Planned Improvements

No improvements are currently planned for this category. Further uncertainty work will be carried out to establish an updated level and trend uncertainty estimate over the medium term.

### 5.4.2. Indirect N<sub>2</sub>O Emissions from Managed Soils (CRT Category 3.D.2)

A fraction of the nitrogen from organic and inorganic fertilizers applied to agricultural fields is transported off-site through leaching, runoff or volatilization in the form of NH<sub>3</sub> and NO<sub>x</sub> and subsequent re-deposition. This nitrogen that is transported off-site from agricultural fields results in eventual nitrogen accumulation in other ecosystem sites and subsequently undergoes nitrification or denitrification to produce N<sub>2</sub>O.

#### 5.4.2.1. Atmospheric Deposition of Nitrogen (CRT Category 3.D.2.a)

##### 5.4.2.1.1. Category Description

When organic or inorganic fertilizer is applied to cropland, a portion of the nitrogen is lost through volatilization in the form of NH<sub>3</sub> or NO<sub>x</sub>, which can then be redeposited elsewhere and undergo further transformation, resulting in off-site N<sub>2</sub>O emissions. The quantity of this volatilized nitrogen depends on several 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 determine N<sub>2</sub>O emissions from atmospheric deposition of NH<sub>3</sub> and NO<sub>x</sub>. 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<sub>2</sub>O 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<sub>2</sub>O-N kg<sup>-1</sup> N for wet climates and 0.005 kg N<sub>2</sub>O-N kg<sup>-1</sup> 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<sub>3</sub> following application is estimated using a revised version of the Canadian NH<sub>3</sub> 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<sub>3</sub>.

#### 5.4.2.1.3. Uncertainty Assessment and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N<sub>2</sub>O emissions from the atmospheric deposition of N considers 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<sub>3</sub>.

The estimate of N<sub>2</sub>O emissions of 0.91 Mt CO<sub>2</sub> eq from volatilization and redeposition in 2023 has an uncertainty range of -75% to +110%, or 0.23 Mt CO<sub>2</sub> eq to 1.9 Mt CO<sub>2</sub> eq respectively (Table 5–6). Most of the uncertainty is associated with the IPCC Tier 1 emission factor of 1% (uncertainty range, 0.2% to 5%). An updated uncertainty analysis will be carried out at a future date; however, the replacement of the default IPCC emission factor from the 2006 IPCC Guidelines, with the climate-specific factors from the 2019 IPCC guidelines, is expected to decrease uncertainty based on the smaller range of uncertainty for the new factors.

The same methodology and emission factors are used for the entire time series (1990–2023).

#### 5.4.2.1.4. 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, methodologies and changes to methodologies are documented and archived in paper and electronic form.

#### 5.4.2.1.5. Recalculations

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

#### 5.4.2.1.6. Planned Improvements

No improvements are currently planned for this category.

### 5.4.2.2. Nitrogen Leaching and Runoff (CRT Category 3.D.2.b)

#### 5.4.2.2.1. Category Description

When organic and inorganic fertilizers, and crop residues, are added to cropland, a portion of the nitrogen from these sources is lost through leaching and runoff. The magnitude of this loss depends on several factors, such as the application rate and method, crop type, soil texture, rainfall and landscape. This portion of lost nitrogen can undergo further transformations, such as nitrification and denitrification, and can produce off-site N<sub>2</sub>O emissions.

#### 5.4.2.2.2. Methodological Issues

There are few published scientific data that determine N<sub>2</sub>O emissions from leaching and runoff in Canada. As in the case of N<sub>2</sub>O emissions from volatilization and deposition of NH<sub>3</sub> and NO<sub>x</sub>, 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<sub>2</sub>O emissions from leaching and runoff of fertilizers, manure, and crop residue nitrogen from agricultural soils. Indirect N<sub>2</sub>O 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<sub>LEACH</sub>), multiplied by the amount of inorganic and organic nitrogen, and by an emission factor of 0.0075 kg N<sub>2</sub>O-N kg<sup>-1</sup> N (IPCC, 2006).

The default value for FRAC<sub>LEACH</sub> in the Revised 1996 Guidelines is 0.3. However, FRAC<sub>LEACH</sub> can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration, such as in the Prairies (IPCC, 2006). Accordingly, it is assumed that FRAC<sub>LEACH</sub> 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<sub>LEACH</sub> value of 0.3 recommended by the 2006 IPCC Guidelines is assigned. The minimum FRAC<sub>LEACH</sub> value of 0.05 is assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts, FRAC<sub>LEACH</sub> is estimated by the linear extrapolation of the two end-points described above.

#### 5.4.2.2.3. Uncertainty Assessment and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N<sub>2</sub>O emissions from nitrogen leaching and runoff considers 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<sub>2</sub>O emissions of 2.8 Mt CO<sub>2</sub> eq from nitrogen leaching and runoff in 2023 lies within an uncertainty range of -80% to +100%, or 0.56 Mt CO<sub>2</sub> eq to 5.6 Mt CO<sub>2</sub> eq respectively (Table 5–6). 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 (1990–2023).

#### 5.4.2.2.4. 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, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

#### 5.4.2.2.5. Recalculations

There were no recalculations to this category in this submission. However, updates to crop residue data in 2021 had a minor impact on emissions (≈10 ktCO<sub>2</sub> eq).

#### 5.4.2.2.6. Planned Improvements

No improvements are currently planned for this category.

### 5.5. CH<sub>4</sub> and N<sub>2</sub>O Emissions from Field Burning of Agricultural Residues (CRT Category 3.F)

#### 5.5.1. Category Description

Crop residues are sometimes burned in Canada, as a matter of convenience and for disease control through residue removals. However, this practice has declined in recent years because of concerns over soil quality and environmental issues. Field burning of agricultural residues is a net source of CH<sub>4</sub>, CO, NO<sub>x</sub>, and N<sub>2</sub>O (IPCC, 2006).

#### 5.5.2. Methodological Issues

There are no published data on emissions of N<sub>2</sub>O and CH<sub>4</sub> 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<sup>2</sup> and on expert consultations (Coote et al., 2008).

Crop-specific parameters required for estimating the amount of crop residue burned, such as moisture content of the crop product and ratio of above-ground crop residue to crop product, were obtained from Janzen et al. (2003) and are consistent with the values used to estimate emissions from crop residue decomposition.

#### 5.5.3. Uncertainty Assessment and Time-Series Consistency

The uncertainties associated with CH<sub>4</sub> and N<sub>2</sub>O emissions from field burning of agricultural residues are determined using an IPCC Tier 1 method (IPCC, 2006).

The uncertainties associated with CH<sub>4</sub> and N<sub>2</sub>O emissions from field burning of agricultural residues are the amount of field crop residues burned and emission factors. Based on the area of specific seeded crop, the uncertainty in the amount of crop residues burned is estimated to be ±50% (Coote et al., 2008). The uncertainties associated with the emission factors are not reported in the 2006 IPCC Guidelines, but are assumed to be similar to those associated with burning of Savanna and grassland: ±40% for CH<sub>4</sub> and ±48% for N<sub>2</sub>O (IPCC, 2006). The level uncertainties for CH<sub>4</sub> and N<sub>2</sub>O emission estimates are ±64% and ±69%, respectively.

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

#### 5.5.4. 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 methodologies are documented and archived in paper and electronic form.

#### 5.5.5. Recalculations

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

#### 5.5.6. Planned Improvements

No improvements are currently planned for this category.

### 5.6. CO<sub>2</sub> Emissions from Liming (CRT Category 3.G)

#### 5.6.1. Category Description

In Canada, agricultural limestone is sometimes used in the production of certain crops, such as alfalfa, to neutralize acidic soils, increase the availability of soil nutrients, particularly phosphorus, reduce the toxicity of heavy metals, such as aluminum, and improve the crop growth environment. During this neutralization process, CO<sub>2</sub> 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<sub>2</sub>. Methods and data sources are outlined in Annex 3.4.

#### 5.6.3. Uncertainty Assessment and Time-Series Consistency

The 95% confidence limits for data on annual lime consumption in each province are estimated to be  $\pm 30\%$ . This uncertainty is assumed to include the uncertainty in lime sales, uncertainty in when lime sold is actually applied, and uncertainty in the timing of emissions from applied lime. The uncertainty in the emission factor is considered to be  $-50\%$  based on the 2006 IPCC Guidelines (IPCC, 2006). The overall mean and uncertainties were estimated to be  $0.17 \pm 0.14$  Mt CO<sub>2</sub> eq for the level uncertainty.

The same methodology is used for the entire time series of emission estimates (1990–2023).

#### 5.6.4. QA/QC 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

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

#### 5.6.6. Planned Improvements

It is planned to implement the Technical Expert Review Teams (TERTs) recommendation on including the impurity of limestone in estimates in the next inventory submission.

## 5.7. CO<sub>2</sub> Emissions from Urea Application (CRT Category 3.H)

### 5.7.1. Category Description

When urea [CO(NH<sub>2</sub>)<sub>2</sub>] or urea-based nitrogen fertilizers are applied to soil to augment crop production, CO<sub>2</sub> is released when the urea undergoes hydrolysis. According to the 2006 IPCC Guidelines, the quantity of CO<sub>2</sub> released into the atmosphere should be accounted for as an emission. In addition to urea, Canadian farmers also use significant amounts of urea ammonium nitrate (28-0-0) with a mixture of 30% CO(NH<sub>2</sub>)<sub>2</sub>.

### 5.7.2. Methodological Issues

Emissions associated with urea application were calculated from the amount of urea or urea-based fertilizers applied annually, and the quantity of carbon contained in the urea released as CO<sub>2</sub> after hydrolysis. Methods and data sources are outlined in Annex 3.4.

### 5.7.3. Uncertainty Assessment and Time-Series Consistency

The 95% confidence limit for data on the annual urea or urea-based fertilizer consumption are estimated to be ±15%. The uncertainty estimate associated with the emissions is based on simple error propagation using survey uncertainty and an uncertainty of -50% associated with the emission factor specified in the 2006 IPCC Guidelines. The overall mean and uncertainties are estimated to be 2.9 ± 1.4 Mt CO<sub>2</sub> eq for the level of uncertainty.

The same methodology and data sources are used for the entire time series of emission estimates. Urea consumption in Canada increased significantly from 1990 to 2023 with a relatively high inter-annual variability in a range of up to ±25% annually. Although we cannot identify specific factors that result in inter-annual variability, urea-based fertilizer shipments in Canada vary due to price fluctuations, climate factors influencing crop production, and other factors.

### 5.7.4. QA/QC and Verification

This category has undergone Tier 1 QC checks (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 this category for the current inventory edition. The long-term and short-term trends remain unchanged at +266% and +138%.

### 5.7.6. Planned Improvements

No improvements are currently planned for this category.

# CHAPTER 6

## LAND USE, LAND-USE CHANGE AND FORESTRY (CRT SECTOR 4)

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### 6.1. Overview

The Land Use, Land-Use Change and Forestry (LULUCF) sector reports greenhouse gas (GHG) fluxes between the atmosphere and Canada's managed lands, as well as fluxes associated with land-use changes and emissions from harvested wood products (HWP) derived from these lands. This assessment includes emissions and removals of carbon dioxide (CO<sub>2</sub>) associated with carbon (C) stock changes; additional emissions of CO<sub>2</sub>, methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O) and carbon monoxide (CO)<sup>1</sup> due to controlled biomass burning; CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions from drained organic forest soils and wetland drainage and rewetting for peat extraction purposes; and N<sub>2</sub>O released following land conversion to cropland.

The estimated net GHG flux in the LULUCF sector, calculated as the sum of CO<sub>2</sub><sup>2</sup> fluxes and non-CO<sub>2</sub> emissions and CO<sub>2</sub> removals, amounted to net emissions of 50 Mt in 1990, 66 Mt in 2005 and 4.2 Mt in 2023.<sup>3</sup> When applied to the national totals, the net flux estimates result in an increase of 8.2% in 1990, 8.7% in 2005 and 0.6% in 2023 in total Canadian GHG emissions. [Table 6–1](#) provides the net flux estimates for the major LULUCF categories and subcategories for 1990, 2005 and more recent years. The full time series of LULUCF sector estimates is available in Table 10 of the common reporting table (CRT) series.

The Forest Land, Cropland and Harvested Wood Products categories had the greatest influence on the totals for the sector. Positive net fluxes (i.e., C emissions) were reported in the LULUCF sector during all years of the time series.<sup>4</sup> Carbon emissions increased from 1990 to 2005 by 16 Mt and subsequently declined due to the downward trend in net emissions in the Forest Land category, though the trend is impacted by interannual variability in the Cropland category.

Emissions and removals from the forest sector in Canada consist of the net fluxes from forest stands that are of harvest origin or commercially mature stands that have recovered from natural disturbances, and the corresponding net change in global storage of carbon in HWP extracted from Canadian forests that results from new products and the disposal of products that have either reached their end of useful life or have been combusted for bioenergy. Forest management

1 Emissions of CO are reported as CO in CRT Table 4, but are not included in the sectoral totals, and are instead reported as indirect CO<sub>2</sub> in CRT Table 6. Unless otherwise indicated, all emissions and removals reported for the LULUCF sector do not include emissions of indirect CO<sub>2</sub> from CO.

2 Unless otherwise indicated, all emissions and removals are shown in CO<sub>2</sub> equivalents (CO<sub>2</sub> 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/>.

resulted in an increase in net emissions from 74 Mt to 140 Mt during the 1990–2005 period in the Forest Land category. This increase in emissions reflects the influence of forest harvest and, to a lesser extent, increased insect-related mortality which, together, resulted in a net reduction in C removals from the atmosphere by the anthropogenic component of the managed forest. Net emissions by forest land have then returned to and fallen below earlier levels, reaching a minimum value of 22 Mt in 2022, mainly due to reduced harvest levels relative to rates observed in the early 2000s and evolving Forest age-class structure.

Net flux in the Harvested Wood Products category,<sup>5</sup> which is closely linked to the Forest Land category and the rate of use and disposal of existing products, have ranged between -61 Mt and +1 Mt during the reported 1990–2023 period. The minimum value (-61 Mt) was recorded in 2004 corresponding with peak harvest rates, while the maximum value (+1 Mt) occurred in 2009 when harvest rates were at their minimum (Table 6–1 and Figure 6–2). Emissions are influenced primarily by the trend in forest harvest rates during the reporting period, and the long-term impact of harvesting levels before 1990, as some of the C in HWP harvested prior to 1990 is emitted during the reporting period (Table 6–1) and forest stands harvested in the past recover and increase their rates of CO<sub>2</sub> removals.

The combined net flux from the Forest Land and Harvested Wood Products categories—the latter including HWP from forest conversion activities and firewood harvest from non-forest lands since 1990—amounted to net emissions of 34 Mt in 1990 and 18 Mt in 2023, peaking at 80 Mt in 2005.

Emissions and removals from stands recovering from natural disturbances beyond the control of human intervention are tracked separately from those tracked in the anthropogenic component. Nonetheless, natural disturbances can result in substantial emissions and subsequent removals of GHGs within the managed forest and display large interannual variability that masks the role of forest management activities (see section 6.3.1.2 for more details) on forest carbon. Since 1990, the net flux from lands impacted by natural disturbances has ranged from removals of 130 Mt in 1992 to peak emissions of 1000 Mt in 2023 (peak wildfire year in the reporting period). Emissions and removals have tended to be higher since the

Table 6–1 **Overview of Net Greenhouse Gas Flux Estimates in the Land Use, Land-Use Change and Forestry Sector, Selected Years**

Sectoral Category	Net GHG Flux (kt CO <sub>2</sub> eq) <sup>b</sup>							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>LAND USE, LAND-USE CHANGE AND FORESTRY TOTAL<sup>a</sup></b>	<b>50 000</b>	<b>66 000</b>	<b>24 000</b>	<b>15 000</b>	<b>25 000</b>	<b>15 000</b>	<b>51 000</b>	<b>4 200</b>
<b>Forest Land 4.A.</b>	<b>73 000</b>	<b>140 000</b>	<b>60 000</b>	<b>40 000</b>	<b>40 000</b>	<b>34 000</b>	<b>22 000</b>	<b>24 000</b>
Forest Land Remaining Forest Land 4.A.1	74 000	140 000	60 000	40 000	40 000	34 000	22 000	24 000
Land Converted to Forest Land 4.A.2	- 950	-890	-320	-290	-240	-170	-130	-130
<b>Cropland 4.B.</b>	<b>5 500</b>	<b>-20 000</b>	<b>-20 000</b>	<b>-15 000</b>	<b>-13 000</b>	<b>-16 000</b>	<b>25 000</b>	<b>-22 000</b>
Cropland Remaining Cropland 4.B.1	-7 700	-25 000	-25 000	-21 000	-18 000	-21 000	20 000	-27 000
Land Converted to Cropland 4.B.2	13 000	5 300	4 900	5 200	4 800	5 000	5 300	5 300
<b>Grassland 4.C.</b>	<b>0.7</b>	<b>0.9</b>	<b>1.3</b>	<b>1.3</b>	<b>1.3</b>	<b>1.3</b>	<b>1.3</b>	<b>1.3</b>
Grassland Remaining Grassland 4.C.1	0.7	0.9	1.3	1.3	1.3	1.3	1.3	1.3
Land Converted to Grassland 4.C.2	NO	NO	NO	NO	NO	NO	NO	NO
<b>Wetlands 4.D.</b>	<b>5 100</b>	<b>2 700</b>	<b>2 500</b>	<b>2 700</b>	<b>2 900</b>	<b>2 800</b>	<b>2 600</b>	<b>2 600</b>
Wetlands Remaining Wetlands 4.D.1	1 200	2 200	2 300	2 300	2 300	2 300	2 300	2 400
Land Converted to Wetlands 4.D.2	4 000	510	250	430	570	460	280	250
<b>Settlements 4.E.</b>	<b>4 800</b>	<b>4 700</b>	<b>5 400</b>	<b>5 300</b>	<b>5 300</b>	<b>5 500</b>	<b>5 200</b>	<b>5 000</b>
Settlements Remaining Settlements 4.E.1	-3 900	-4 100	-4 100	-4 100	-4 100	-4 100	-4 100	-4 100
Land Converted to Settlements 4.E.2	8 700	8 800	9 500	9 400	9 400	9 600	9 300	9 200
<b>Other Land 4.F.</b>	<b>NE, NO</b>	<b>NE, NO</b>	<b>NE, NO</b>	<b>NE, NO</b>	<b>NE, NO</b>	<b>NE, NO</b>	<b>NE, NO</b>	<b>NE, NO</b>
<b>Harvested Wood Products 4.G.</b>	<b>-38 000</b>	<b>-57 000</b>	<b>-24 000</b>	<b>-18 000</b>	<b>-10 000</b>	<b>-12 000</b>	<b>-4 000</b>	<b>-5 100</b>
Forest conversion <sup>c</sup>	25 000	17 000	17 000	17 000	17 000	17 000	17 000	17 000
Indirect CO <sub>2</sub> <sup>d</sup>	660	880	690	590	550	550	470	470
Natural disturbances <sup>e</sup>	-120 000	12 000	250 000	160 000	2 700	290 000	87 000	1 100 000

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<sub>2</sub> from the atmosphere.

c. Not a reporting category; it overlaps with the Land Converted to Cropland, Land Converted to Wetlands, and Land Converted to Settlements subcategories.

d. Indirect emissions of CO<sub>2</sub> from the atmospheric oxidation of CO that results from controlled biomass burning, reported in CRT Table 6.

e. Not a reporting category; this line is provided solely for transparency purposes and shows the net balance of emissions/removals resulting from natural disturbances in managed forests, including indirect emissions of CO<sub>2</sub> due to the atmospheric oxidation of CO that results from wildfires.

<sup>5</sup> Includes HWP from managed forests and deforested lands (forest conversion) and firewood harvested from non-forest lands.

mid-2000s than in the early part of the inventory reporting period (Table 6–1) due to the increased frequency of wildfires and insect disturbances. Since 2018, on average, emissions from lands impacted by natural disturbances, both wildfire and insect disturbance, are estimated to be 290 Mt and have been a net source of emissions since the early 2000s. Wildfire impacts have steadily increased in Canadian Forest Land over the reporting period, culminating in 2023 with a total area burned of 7.9 Mha in the managed forest, the largest area burned since national records have been maintained.

Changes in agricultural land management practices in Western Canada, such as the extensive adoption of conservation tillage practices combined with the reduced use of summer fallow and increasing crop yields—in turn, increasing C input to soils—have resulted in an increase in net removals of CO<sub>2</sub> in the Cropland category during the 1990–2006 period. This trend was further augmented by reductions in the conversion of other lands to cropland over the same period. However, since 2006, a decrease in the conservation tillage adoption rate, a trend towards the conversion of perennial crops to annual crops and, most recently, some increases in the conversion of Forest Land and Grassland to Cropland, have resulted in a levelling off and decline in Cropland removals. This trend is somewhat attenuated by higher annual crop yields. However, periodic crop failures and exceptional yields, due mainly to weather variations, increase interannual variability in soil C inputs and, therefore, in emissions and removals. Examples include the peak emissions in the years 2002 (4.9 Mt), 2003 (8.6 Mt) and 2022 (23 Mt), associated with the drought in Western Canada, and the peak removals in 2009 (36 Mt) and 2014 (44 Mt), associated with high crop yields. As a result, short-term trends must be interpreted with care.

Over the 1990–2023 period, net emissions in the Wetlands category (peat extraction and flooded lands) ranged from a peak of 5.2 Mt (1993) to a low of 2.5 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 (reservoirs) accounted for 39% of all emissions in the Wetlands category in 2023, compared to 88% in 1990. Emissions from the conversion of Forest and Other Land during expansions of peat extraction and the development of reservoirs (in the Land Converted to Wetlands category) mainly in the early part of the time series, decreased from 4.0 Mt to 0.2 Mt over the reporting period.

Net emissions reported in the Settlements category fluctuated between 4.1 Mt (1997) and 6.0 Mt (2013), driven mainly by rates of conversion of forested land, which accounted for 9.0 Mt of emissions in 2023. Relatively steady removals of around 4.0 Mt per year from the growth of urban trees offset these emissions on average by 70% over the reporting period.

Forest conversion is not a reporting category per se since it overlaps with the Land Converted to Cropland, Land Converted to Wetlands, and Land Converted to Settlements categories. Considering these categories together, the emissions due to forest conversion decreased from 25 Mt in 1990 to 17 Mt in 2023. This decline in emissions consists of decreases of 4.4 Mt and 1.9 Mt in immediate and residual emissions from the conversion of forest to cropland and wetlands, respectively; and an increase of 0.4 Mt in these emissions from the conversion of forest to settlements.

To avoid double counting, the estimates of C stock changes in CRT tables 4.A to 4.E exclude C emissions emitted as CO<sub>2</sub>, CH<sub>4</sub> and CO, due to biomass burning, and CO<sub>2</sub> and CH<sub>4</sub> emissions, due to the drainage and rewetting of organic soils. Carbon emissions from biomass burning emitted as CO<sub>2</sub> and CH<sub>4</sub> are reported in CRT Table 4(V) along with N<sub>2</sub>O emissions. Carbon emissions in the form of CO<sub>2</sub> and CH<sub>4</sub>, from the drainage of organic forest soils and wetland drainage, and rewetting for peat extraction purposes are reported in CRT Table 4(II) along with emissions of N<sub>2</sub>O. Carbon emissions in the form of CO are reported as such in CRT Table 4, but are not included in the sectoral totals, and are instead reported as indirect CO<sub>2</sub> in CRT Table 6. Emissions and removals of CO<sub>2</sub> and emissions of CH<sub>4</sub>, N<sub>2</sub>O and CO are automatically tallied in CRT Table 4.

To address the most recent Technical Expert Review Team (TERT) recommendations, this year's submission includes significant revisions in the approach to reporting estimates for Forest Land and Harvested Wood Products. Further recalculations were implemented as a result of the most recent TERT review that impact reported changes of biomass in lands undergoing land use change, specifically Cropland and Forest Land during afforestation. Continuous improvements were also made to the Wetland category with the implementation of new and updated country-specific science into the estimation methodology for peat extraction that resulted in a downward revision of 0.3, 0.4 and 0.7 Mt CO<sub>2</sub> eq for the years 1990, 2005 and 2022 respectively and an upward revision was implemented in Croplands based on additions to the area of Wetland converted to Cropland. Other minor refinements were made to activity data used for Forest Land and some parameter refinements in the Harvested Wood Products model.

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.

The HWP revisions stem from the change in the location of reporting of biomass carbon stocks transferred to Harvested Wood Products. In this submission, biomass carbon stocks harvested for the production of Harvested Wood Products are reported in the contributing land category as a flux out of the land-use category's carbon pool. The change mainly affects Forest Land, but also Croplands, Settlements, and to a lesser extent Wetlands. Previously we did not report the transfer of carbon out of the contributing Land-Use category and reported the gross emissions from the HWP pool.

Consistent with the TERT's recommendation, Harvested Wood Products are now reported as the net carbon stock change (annual domestic harvest minus the annual flux associated with the disposal of Harvested Wood Products originating from domestically harvested wood). Contributing land categories are reported as the net flux resulting from the difference between CO<sub>2</sub> removals from the atmosphere, emissions from decomposition, and fluxes of carbon to the Harvested Wood Products pool. This change does not result in a recalculation at the overall LULUCF sector level but transfers reported gains and losses from Harvested Wood Products to each of the affected land use categories. As such, the downward recalculations of -170, -200 and -140 Mt CO<sub>2</sub> eq in years 1990, 2005 and 2022 respectively are entirely compensated for by the upward recalculations of fluxes observed in Forest Land, Cropland, Settlement and to a lesser extent Wetland. This revised reporting approach improves the comparability of Canada's HWP reporting with other countries and better captures the immediate impact of harvest on Forest Land carbon stocks and the important role of Harvested Wood Products as a significant global carbon store.

The combined impact of recalculations in the LULUCF sector (Table 6–2) were upward recalculations of 0.58 Mt CO<sub>2</sub> eq in 1990 and downward revisions of 0.40 and 0.66 Mt CO<sub>2</sub> eq in 2005 and 2022 respectively, though internally reporting among land use categories and HWP have changed significantly.

See sections 6.3 to 6.9, Table 6–3 and Chapter 8 for additional details on the changes implemented.

Table 6–2 Summary of Recalculations in Reported Estimates for the Land Use, Land-Use Change and Forestry Sector, Selected Years								
Sectoral Category		1990	2005	2018	2019	2020	2021	2022
<b>LAND USE, LAND-USE CHANGE AND FORESTRY TOTAL<sup>a</sup></b>	<b>kt</b>	<b>660</b>	<b>- 21</b>	<b>1 000</b>	<b>1 000</b>	<b>- 640</b>	<b>1 200</b>	<b>- 660</b>
	<b>%</b>	<b>1.3%</b>	<b>0%</b>	<b>5%</b>	<b>7%</b>	<b>-3%</b>	<b>9%</b>	<b>-1.3%</b>
<b>Forest Land 4.A.</b>	<b>kt</b>	<b>160 000</b>	<b>200 000</b>	<b>160 000</b>	<b>140 000</b>	<b>140 000</b>	<b>140 000</b>	<b>130 000</b>
	<b>%</b>	<b>-180%</b>	<b>-310%</b>	<b>-160%</b>	<b>-140%</b>	<b>-140%</b>	<b>-130%</b>	<b>-120%</b>
Forest Land Remaining Forest Land 4.A.1	kt	160 000	200 000	160 000	140 000	140 000	140 000	130 000
	%	-180%	-320%	-160%	-140%	-140%	-130%	-120%
Land Converted to Forest Land 4.A.2	kt	120	60	12	13	- 0.4	4.3	-0.3
	%	-11%	-6.3%	-3.7%	-4.4%	0.1%	-2.4%	0.3%
<b>Cropland 4.B.</b>	<b>kt</b>	<b>5 200</b>	<b>2 500</b>	<b>2 900</b>	<b>3 100</b>	<b>2 700</b>	<b>2 800</b>	<b>3 100</b>
	<b>%</b>	<b>1700%</b>	<b>-11%</b>	<b>-13%</b>	<b>-17%</b>	<b>-17%</b>	<b>-15%</b>	<b>14%</b>
Cropland Remaining Cropland 4.B.1.	kt	1 700	1 400	1 500	1 400	1 400	1 400	1 400
	%	-18%	-5.1%	-5.9%	-6.4%	-7.2%	-6.1%	7.6%
Land Converted to Cropland 4.B.2	kt	3 500	1 200	1 300	1 700	1 300	1 400	1 700
	%	36%	29%	38%	49%	38%	41%	48%
<b>Grassland 4.C.</b>	<b>kt</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
	<b>%</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
Grassland Remaining Grassland 4.C.1	kt	-	-	-	-	-	-	-
	%	-	-	-	-	-	-	-
<b>Wetlands 4.D.</b>	<b>kt</b>	<b>- 270.0</b>	<b>- 440</b>	<b>- 250</b>	<b>- 380.0</b>	<b>- 630.0</b>	<b>- 410</b>	<b>- 720</b>
	<b>%</b>	<b>-5.0%</b>	<b>-14%</b>	<b>-9.2%</b>	<b>-12%</b>	<b>-18%</b>	<b>-13%</b>	<b>-21%</b>
Wetlands Remaining Wetlands 4.D.1	kt	- 310.0	- 450.0	- 260.0	- 400.0	- 640.0	- 420.0	- 710
	%	-21%	-17%	-10%	-15%	-22%	-15%	-23%
Land Converted to Wetlands 4.D.2	kt	37	5.4	1.9	18.0	7.7	13	-8.1
	%	0.6%	0.1%	0.0%	0.3%	0.1%	0.2%	-0.1%
<b>Settlements 4.E.</b>	<b>kt</b>	<b>3 000</b>	<b>3 000</b>	<b>3 100</b>	<b>3 100</b>	<b>3 000</b>	<b>3 300</b>	<b>3 000</b>
	<b>%</b>	<b>160%</b>	<b>170%</b>	<b>130%</b>	<b>140%</b>	<b>130%</b>	<b>150%</b>	<b>130%</b>
Settlements Remaining Settlements 4.E.1	kt	300	310	310	310	310	310	310
	%	-7.1%	-7.0%	-7.0%	-7.0%	-7.0%	-7.0%	-7.0%
Land Converted to Settlements 4.E.2	kt	2 700	2 700	2 800	2 700	2 700	3 000	2 700
	%	44%	44%	42%	42%	39%	45%	40%
<b>Harvested Wood Products 4.G.</b>	<b>kt</b>	<b>-170 000</b>	<b>-200 000</b>	<b>-160 000</b>	<b>-150 000</b>	<b>-150 000</b>	<b>-140 000</b>	<b>-140 000</b>
	<b>%</b>	<b>-130%</b>	<b>-140%</b>	<b>-120%</b>	<b>-110%</b>	<b>-110%</b>	<b>-110%</b>	<b>-100%</b>
Forest conversion <sup>b</sup>	kt	6 100	3 800	4 000	4 300	3 800	4 300	4 200
	%	33.0%	28.0%	31.0%	33.0%	29.0%	33.0%	33.0%
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.								

Environment and Climate Change Canada (ECCC) has established governance mechanisms for LULUCF reporting through memoranda of understanding with Agriculture and Agri-Food Canada (AAFC) and the Canadian Forest Service of Natural Resources Canada (NRCan-CFS) for planning, coordinating and developing estimates in the Forest Land and Cropland categories. In addition, the Department collaborates with many groups of scientists and experts across various levels of government and research institutions to produce estimates for other land-use categories.

Planned improvements include continued refinements and improved transparency of communication of anthropogenic emissions and removals resulting from forest management, continued refinements to the HWP model structure and activity data, the completion of uncertainty estimates for all LULUCF categories, and the gradual integration of missing land-use and land-use change categories. More details can be found in sections 6.3 to 6.9 and in Chapter 8, section 8.3.1 and Table 8–5.

The remainder of this chapter provides more detail on each LULUCF category. Section 6.2 gives an overview of how managed lands are defined and represented; section 6.3 provides a short description of the Forest Land category; section 6.4 describes the Harvested Wood Products category; sections 6.5 to 6.8 describe the Cropland, Grassland, Wetlands and Settlements categories; and section 6.9 focuses on the cross-category estimates of forest conversion.

Detailed inventory methodologies and sources of activity data are described in Annex 3.5 and a compilation of emission factors and other parameters used to develop and report the LULUCF estimates is provided in section A6.5.

Table 6–3 Summary of Changes in the Land Use, Land-Use Change and Forestry Sector		
List of Changes	Change Category	Years Affected
<b>Forest Land</b>		
Computing architecture modifications and code refinements	Continuous improvement	Complete time series
Updates to British Columbia slash-burning data and harvest prioritization criteria	Continuous improvement	Complete time series
Update Spruce budworm parameters in Quebec	Continuous improvement	Complete time series
Afforestation /reforestation activity updates and revisions	Activity data updates	2019; 2021–2022
Residential Firewood activity data refinements	Activity data updates	Complete time series
Updated harvest data	Activity data updates	2015–2022
Transfers of carbon to the HWP pool now reported in the source Land category	TERT Recommendation	Complete time series
<b>Cropland</b>		
Updated activity data on drained organic soils under perennial crop production	Activity data updates	Complete time series
Revised IPCC Tier 1 emission factors of soil organic C losses from the 2013 Wetland Supplement	Continuous improvement	Complete time series
Transfers of carbon to the HWP pool now reported in the source Land category	TERT Recommendation	Complete time series
<b>Wetlands</b>		
Updated time series on different activity data, updated EF information with Canadian Science, for peat extraction	Activity data updates	Complete time series
Transfers of carbon to the HWP pool now reported in the source Land category	TERT Recommendation	Complete time series
<b>Settlements</b>		
Activity data update for 2020 and new Emission Factors for GLSL estimates	Continuous improvement	Complete time series
Transfers of carbon to the HWP pool now reported in the source Land category	TERT Recommendation	Complete time series
<b>Harvested Wood Products</b>		
Revised reporting approach - gains and losses in the HWP pool calculated as annual carbon domestic harvest minus annual release of carbon to the atmosphere from HWP that came from wood harvested domestically	TERT Recommendation	Complete time series
Revisions to HWP transfers (from forests)	Activity data updates	Complete time series
Residential bionergy activity update and Emission Factors	Activity data updates	Complete time series
Updated HWP commodity conversion parameters based on latest FAO statistics	Continuous improvement	Complete time series
Updated waste incineration activity data	Activity data updates	Complete time series

## 6.2. Land Category Definitions and Representation of Managed Lands

To harmonize all land-based estimates, common working definitions of land categories were developed and adopted by all groups involved in estimate preparation. Definitions are consistent with the IPCC (2006) land categories, while remaining relevant to land management practices, prevailing environmental conditions and available data sources in Canada. This framework applies to all LULUCF estimates reported under the United Nations Framework Convention on Climate Change (UNFCCC).

The Forest Land category includes all treed areas of 1 ha or more, with a minimum tree crown cover of 25% and trees of 5 m in height, or having the potential to reach this height. Not all Canadian forests are under the direct influence of human activities, prompting the non-trivial question of what areas properly embody managed forests. For the GHG inventory, managed forests are those managed for timber and non-timber resources (including parks) or subject to fire protection. Section A3.5.2 provides more details on the implementation of the managed forests definition.

Agricultural land includes both the Cropland and Grassland (for agricultural use) categories. Cropland includes all land in annual crops, summer fallow and perennial crops (mostly forage, but also including berries, grapes, nursery crops, vegetables, and fruit trees and orchards). Grassland used for agriculture is defined as unimproved pasture or rangeland exclusively used for grazing domestic livestock. It occurs only in geographical areas where the grassland would not naturally regrow to forest if abandoned, i.e., natural shortgrass prairies in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. All agricultural land that is not classified as grassland is classified de facto as cropland, including unimproved pastures where the natural vegetation would be forest (Eastern Canada and most of British Columbia).

Vegetated areas that do not meet the definition of Forest Land or Cropland are generally classified as Grassland. Extensive areas of tundra in the Canadian North are considered unmanaged grassland.

Wetlands are areas where permanent or recurrent saturated conditions allow the establishment of vegetation and the development of soils typical of these conditions and that 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.

Because of the land categorization scheme, some land-use transitions cannot occur—for example, the conversion of forest to agricultural grassland, since, by definition, the Grassland category excludes areas where forests can grow naturally. Since grassland is defined as native grassland, 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 2023. The diagonal cells related to the Forest Land category show the total area of managed forest associated with each of two components (anthropogenic or natural disturbance impacts). Therefore, the Forest Land category includes all managed forest areas with anthropogenic impacts (GHG estimates for these areas are reported in CRT tables 4.A, 4[II] and 4[V]), as well as forest areas with natural disturbance impacts (see section 6.3.1.2 and Table 6–5 for more details on the approach used by Canada to isolate the effect of anthropogenic activities on managed forests). The diagonal cells related to the Cropland category refer to total land-use areas; the diagonal cells related to the Grassland category to total managed agricultural grassland; and the diagonal cells related to the Wetlands and Settlements categories only to areas where activities causing GHG emissions or CO<sub>2</sub> 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 CRT for each land category. The full time series of the land-use and land-use change matrix is available in Table 4.1 (Land Transition Matrix) of the CRT series.

The LULUCF framework includes the conversion of unmanaged forests, grassland and lands with previously undefined land use to other land categories. In all cases, unmanaged land converted to any use is subsequently considered managed land. Parks and protected areas are included in managed lands.

The LULUCF estimates, as reported in the CRT tables, are attached spatially to reporting zones (Figure 6–1). These reporting zones are essentially the same as Canada’s terrestrial ecozones (Marshall and Shut, 1999), with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into eastern and western components to form four reporting zones, and the Prairies ecozone is divided into semi-arid and sub-humid components. Estimates are reported for 17 of the 18 reporting zones. The only exception is the Arctic Cordillera ecozone, the northernmost ecozone in Canada, where no direct human-induced GHG emissions or removals have been detected for the LULUCF sector. More details on the spatial estimation and reporting framework can be found in section A3.5.1.

Table 6–4 **Land Use and Land-Use Change Matrix for the 2023 Inventory Year**

Initial Land Use	Final Land Use (kha)						
	Forest Land <sup>a</sup>		Cropland	Grassland <sup>b</sup>	Wetlands <sup>c</sup>	Settlements <sup>c</sup>	Other
	Anthropogenic component	Natural disturbance component					
Forest Land <sup>a</sup>	162 777	62 626	22	NO	0.01	26	NO
<i>Anthropogenic component</i>	165 562	695	22	NO	0.01	26	NO
<i>Natural disturbance component</i>	-2 785	61 930	NO	NO	NO	NO	NO
Cropland	1.8	NO	45 649	NO	NE	11	NO
Grassland	NO	NO	0.10	7 067	NE	2.8	NO
Wetlands <sup>c</sup>	NO	NO	NE	NO	497	NE	NO
Settlements <sup>c</sup>	NO	NO	NE	NO	NO	995	NO
Other	NO	NO	NO	NO	0.13	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.

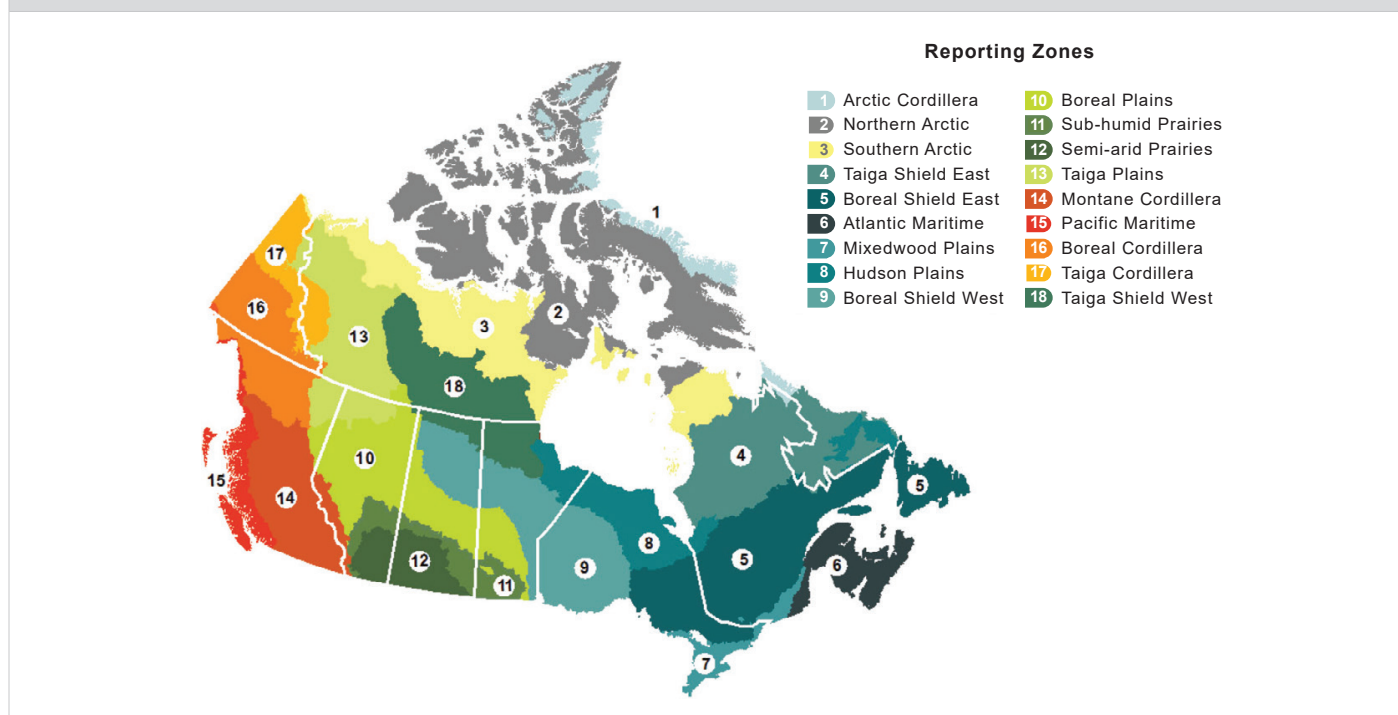
Areas presented in this table are not rounded to keep consistency within the table between numbers with different orders of magnitude, and with areas reported in the CRT tables. However, caution is advised when interpreting these estimated areas due to the uncertainty associated with these values.

a. Includes all managed forest areas subject to either anthropogenic or natural disturbances.

b. Only includes areas of agricultural grassland.

c. Only includes areas for which estimates are reported in the CRT.

Figure 6–1 **Reporting Zones for Land Use, Land-Use Change and Forestry Sector Estimates**



The land areas reported in the CRT tables represent those used for annual estimate development, but not always the total land area of a land category or subcategory in a specific inventory year. For example, the area of land converted to flooded land (reservoirs) represents 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 CRT sectoral background tables refer to the cumulative total land area converted over the last 20 years (10 years for reservoirs) and should not be confused with annual rates of land-use change. The trends observed in the CRT land conversion categories (e.g., Land Converted to Forest Land and Land Converted to Cropland) result from the balance between the area of land newly converted to a category and the transfer of lands converted more than 20 years ago (10 years for reservoirs) 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 CRT Table 4.1 for the first time in this submission and the remaining unmanaged land area reported in this CRT Table 4.1 includes both unmanaged and managed non-forest land for which there are no estimates of emissions and removals. These areas are reported in this table to fulfill the requirement of the UNFCCC Reporting Guidelines to report the total land mass area of the country (see section A3.5.1 for more details).

### 6.3. Forest Land (CRT Category 4.A)

Forests and other wooded lands cover 410 million hectares (Mha) of Canadian territory; forest lands alone occupy 360 Mha.<sup>6</sup> 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 2023, the net GHG balance reported for the anthropogenic component of the managed Forest Land (see section 6.3.1.2) amounted to emissions of 24 Mt (Table 6–1 and CRT Table 4).

The estimate for the Forest Land category includes net emissions and removals of CO<sub>2</sub>, as well as N<sub>2</sub>O and CH<sub>4</sub> emissions from slash burning and prescribed burning and drained organic forest soils. For the purposes of UNFCCC reporting, the Forest Land category is divided into Forest Land Remaining Forest Land (anthropogenic component) (160 Mha, net emissions of 24 Mt in 2023) and Land Converted to Forest Land (0.03 Mha, net removals of 0.1 Mt in 2023) subcategories. The Forest Land estimates for the natural component of the carbon monitoring system are reported in this chapter (see Table 6–1) but are not compiled with the anthropogenic component reported in the LULUCF total.

#### 6.3.1. Forest Land Remaining Forest Land (CRT Category 4.A.1)

##### 6.3.1.1. Category Description

As trees grow, they absorb CO<sub>2</sub> from the atmosphere through photosynthesis, storing some of this C in vegetation (biomass), dead organic matter (DOM) and soils. Carbon dioxide and other GHGs are returned to the atmosphere through respiration and the decay and burning of organic matter. Human interactions with the land can directly alter the magnitude and rate of these natural exchanges of GHGs over both the immediate and long term. Past land-use changes and land-use practices still affect current GHG fluxes to and from managed forests. This long-term effect is a unique characteristic of the LULUCF sector that distinguishes it from the other inventory sectors.

Forest management practices (including harvesting, silvicultural treatments and regeneration) are the primary direct human influences on emissions and removals in forests. Harvesting transfers C to HWP (see section 6.4) and produces harvest residues (branches, foliage and non-commercial species), which are left on site to decay or are burned. Clear-cut harvesting resets the stand age to 0, which changes the rate of C accumulation in biomass, as young trees accumulate little biomass in the first 30 to 40 years. The combination of GHG emissions and removals in the Forest Land category and the carbon change in the Harvested Wood Products pool associated with annual forest product production represents the net annual flux of carbon between managed forests and the atmosphere (Figure 6–2).

Estimated net emissions reported in the Forest Land category from the management of forests also include net fluxes from forest stands that are either of harvest origin or have recovered from natural disturbances and transfers to Harvested Wood Products. The impact of non-anthropogenic disturbances (i.e., natural disturbances such as wildfires, insect infestations and windthrow) in the managed forest is also presented (Table 6–5).<sup>7</sup> Net emissions in the Forest Land category increased from 73 Mt in 1990 to 140 Mt in 2005 and have gradually returned to, and then fell below earlier levels, reaching a minimum value of 22 Mt of emissions in 2022. Harvest rates increased nationally from 1990 to 2004 resulting in increasing emissions.

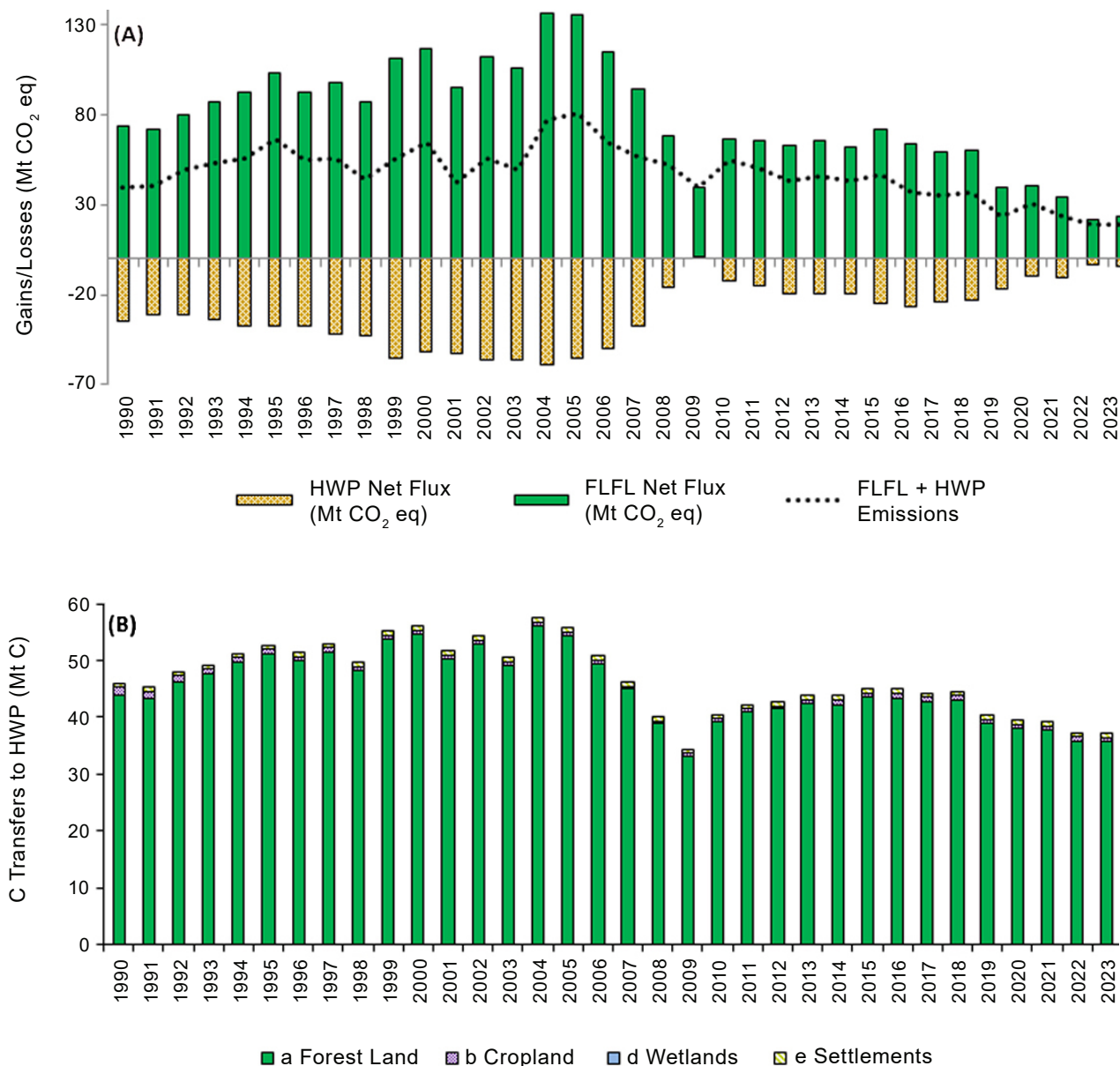
6 Canada's statistical data – forest inventory. Natural Resources Canada. [Accessed 2023 Jan 25]. Available online at: <https://cfs.nrcan.gc.ca/statsprofile>.

7 Impacts of natural disturbances with greater than 20% tree mortality.

The shift in the trend from increasing to decreasing emissions coincides with a sharp decline in harvest rates between 2004 and 2009 (Figure 6–2), which was largely due to changes in export markets. Harvest levels never returned to levels observed in 2004 and 2005. As such the trend of decreasing emissions, from a maximum of 140 Mt in 2005 to a minimum of 22 Mt in 2022 was maintained for the rest of the reporting period as areas that were harvested prior to peak harvest rates in 2004 shift from a net source of emissions to a net removal with the regrowth of the harvested stand (Figure 6–2).

The increase in emissions that occurred prior to 2005 (Figure 6–2) is mainly due to trends in the Montane Cordillera and Boreal Plains reporting zones. In the Montane Cordillera zone, steadily increasing rates of harvest in combination with insect infestations, that occurred between 2000 and 2005, and subsequent salvage harvesting of infested stands resulted in a shift in the average age of the forests of this region to younger age classes. Freshly harvested stands act as a net source of emissions as the DOM pool is increased on these sites and it takes time for the rate of carbon uptake in biomass<sup>8</sup> to recover.

Figure 6–2 a) Gains and Losses of Carbon from Forest Land and HWP, and b) Annual Transfers of HWP by Contributing Land Categories



8 Average age of the forest in this context refers to the age-class structure of the forest and carbon uptake refers to net primary production.

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

Subcategories	GHG	1990	2005	2018	2019	2020	2021	2022	2023
<b>TOTAL MANAGED FOREST AREA (kha)</b>		<b>230 000</b>	<b>230 000</b>	<b>230 000</b>	<b>230 000</b>	<b>230 000</b>	<b>230 000</b>	<b>230 000</b>	<b>230 000</b>
Areas with anthropogenic impacts		140 000	150 000	160 000	170 000	170 000	170 000	170 000	160 000
Areas with natural disturbance impacts		88 000	72 000	61 000	60 000	59 000	60 000	59 000	63 000
<b>NET FLUX – REPORTED AND NOT REPORTED (kt CO<sub>2</sub> eq)<sup>a, b</sup></b>		<b>-48 000</b>	<b>150 000</b>	<b>310 000</b>	<b>200 000</b>	<b>43 000</b>	<b>330 000</b>	<b>110 000</b>	<b>1 100 000</b>
<b>Reported estimates<sup>c</sup></b>		<b>74 000</b>	<b>140 000</b>	<b>60 000</b>	<b>40 000</b>	<b>40 000</b>	<b>34 000</b>	<b>22 000</b>	<b>24 000</b>
Anthropogenic Component, Past Forest Management Activities		240 000	300 000	200 000	180 000	170 000	160 000	150 000	150 000
Net Flux – Forest Products Transferred to HWP <sup>d</sup>	CO <sub>2</sub>	160 000	200 000	160 000	140 000	140 000	140 000	130 000	130 000
Net Flux – Ecosystem	CO <sub>2</sub>	83 000	94 000	39 000	33 000	30 000	25 000	18 000	14 000
	CH <sub>4</sub>	340	740	550	420	390	390	280	300
	N <sub>2</sub> O	130	330	250	200	190	190	150	160
	CO <sup>e</sup>	240	630	460	340	320	320	220	240
Anthropogenic Component, Mature Stands of Natural Disturbance Origin	CO <sub>2</sub>	-170 000	-160 000	-140 000	-140 000	-130 000	-130 000	-130 000	-120 000
<b>Emissions/removals from lands impacted by natural disturbances</b>		<b>-120 000</b>	<b>12 000</b>	<b>250 000</b>	<b>160 000</b>	<b>2 700</b>	<b>290 000</b>	<b>87 000</b>	<b>1 100 000</b>
Wildfires – direct immediate emissions <sup>f</sup>		28 000	60 000	240 000	160 000	13 000	270 000	82 000	980 000
	CO <sub>2</sub>	24 000	52 000	200 000	130 000	11 000	230 000	71 000	850 000
	CH <sub>4</sub>	2 700	5 800	23 000	15 000	1 300	26 000	8 000	96 000
	N <sub>2</sub> O	1 100	2 300	9 200	6 100	520	10 000	3 200	38 000
Wildfires – indirect immediate CO <sub>2</sub> emissions <sup>f</sup>	CO	2 400	5 200	20 000	13 000	1 100	23 000	7 100	85 000
Post-wildfire CO <sub>2</sub> emissions and removals <sup>f</sup>	CO <sub>2</sub>	-150 000	-92 000	-27 000	-24 000	-29 000	-15 000	-17 000	35 000
Insects – emissions and removals <sup>g</sup>	CO <sub>2</sub>	240	39 000	21 000	19 000	17 000	16 000	15 000	13 000
Other natural disturbances – emissions and removals <sup>h</sup>	CO <sub>2</sub>	NO	NO	NO	NO	NO	NO	NO	NO

**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<sub>2</sub> 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<sub>2</sub> and emissions of CH<sub>4</sub>, N<sub>2</sub>O and CO.

c. Includes emissions/removals of CO<sub>2</sub> and emissions of CH<sub>4</sub> and N<sub>2</sub>O, from forest stands in the anthropogenic component differentiating stands with past forest management activities from mature stands of natural disturbance origin. Not including CO emissions.

d. This transfer from forest land remaining forest land to the harvested wood products (HWP) C pool includes salvage logging after natural disturbances.

e. Indirect emissions of CO<sub>2</sub> from the atmospheric oxidation of CO that result from slash burning and prescribed burning activities after forest harvest are reported in CRT Table 6.

f. Immediate emissions include direct and indirect CO<sub>2</sub> and direct non-CO<sub>2</sub> emissions resulting from the immediate impact of wildfires. Post-wildfire CO<sub>2</sub> 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<sub>2</sub> are associated with natural stand regeneration following wildfire.

g. Includes emissions due to insect infestations, mainly residual, and removals associated with subsequent natural stand regeneration.

h. Includes the remnant impact in emissions of Hurricane Juan on Nova Scotia forests in 2003 and removals from subsequent natural stand regeneration.

At the same time, low-level insect infestations increased tree mortality over large areas, resulting in increased emissions from decomposition. In the Boreal Plains Reporting Zone, increased harvest rates also resulted in a shift in the average age of forests. Insect infestations and fire caused a reduction in 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 increased reported emissions in these regions an impact that may continue over the next few decades.

The total net flux in managed forests shown in Table 6–5 is the sum of estimates of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions and CO<sub>2</sub> removals affected by human activities (including CO emissions from controlled biomass burning reported as indirect CO<sub>2</sub>), 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 50 Mt in 1990, net emissions of 140 Mt in 2005 and 1100 Mt in 2023. Variations in net fluxes largely depend on the occurrence of natural disturbances in a given year (Figure 6–3) which have been increasing over the reporting period, particularly in the latter half of the time series, culminating with the unprecedented 2023 wildfire year in which emissions from wildfires surpassed all anthropogenic emissions from all Sectors in Canada.

Emissions and removals reported from the forest sector, without the natural disturbance component but also considering fluxes of carbon to the Harvested Wood Products category, demonstrate that the Canadian Forest sector acts as a net source of carbon transferred to the atmosphere and to the global waste stream as a result of short- and long-term impacts of human management (Figure 6–2).

### 6.3.1.2. Methodological Issues

Canada uses a Tier 3 methodology to estimate GHG emissions from, and removals by, managed forests. The country's National Forest Carbon Monitoring, Accounting and Reporting System (NFCMARS)<sup>9</sup> incorporates a model-based approach (Carbon Budget Model of the Canadian Forest Sector, or CBM-CFS3) (Kull et al., 2019; Kurz et al., 2009). This model integrates forest inventory data and yield curves with spatially referenced activity data on forest management and natural disturbances to estimate forest C stocks, C stock changes, and CO<sub>2</sub> emissions and removals. The model uses regional ecological and climate parameters to simulate C transfers between pools in the forest ecosystem as well as to the HWP pool and the atmosphere. A more detailed description of forest C modelling is provided in section A3.5.2.1.

Prior to the 2017 submission, emissions and removals reported in the Forest Land category displayed large interannual variability due to the impact of natural disturbances that masked the impacts of forest management activities. The IPCC has recognized that the issue of reporting emissions from natural disturbances in some countries is problematic and encouraged countries that use Tier 3 methodologies to work towards developing new approaches that can improve the isolation of anthropogenic impacts (IPCC, 2010). In addition, the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (hereafter referred to as the 2019 Refinement to the 2006 IPCC Guidelines) (IPCC, 2019) provides examples of approaches that countries (including Canada) have used to resolve this issue. Since the 2017 submission, Canada has implemented a Tier 3 approach to isolate the effects of anthropogenic activities on managed forests. This approach involves the separate monitoring and compilation of emissions and removals from forest stands impacted by anthropogenic and natural drivers (referred to as the anthropogenic and natural disturbance components respectively). The anthropogenic component includes emissions and removals associated with (i) stands that have been directly affected by past forest management activities (e.g., clear-cutting and partial harvesting, commercial and pre-commercial thinning, and salvage logging); (ii) mature stands affected by natural disturbances causing biomass mortality of 20% or less (i.e., insect defoliation) or having greater than 20% mortality at a point during the reporting period but have recovered to their pre-disturbance biomass since; and (iii) mature stands affected by stand-replacing natural disturbances in the past that have reached a regionally-determined minimum operable age (i.e., that have reached commercial maturity and are actively monitored in forest management practice to serve the public interest). The natural disturbance component includes emissions associated with natural disturbances, such as wildfires or insect outbreaks causing more than 20% biomass mortality and the removals that occur as the stands regrow back to maturity or attain pre-disturbance biomass, respectively. To ensure transparency, all emissions and removals are presented here (Table 6–5; Figure 6–3), but reporting is based on the anthropogenic component in an effort to better capture the emissions and removals more closely linked to land management and to better inform stakeholders in the forest sector. A full accounting of natural disturbances and the C balance in managed forests can also be found in the State of Canada's Forests report (NRCan, 2023). Additional information on the estimation approach is provided in section A3.5.2.6, in Kurz et al. (2018) and Kurz et al. (2024).

Carbon stock changes in the anthropogenic component of managed forests are reported by reporting zone in CRT Table 4.A. For any given pool, C stock changes include not only exchanges of GHG with the atmosphere, but also C transfers to and from pools, for example, the transfer of C from living biomass to DOM upon stand mortality. Therefore, individual C stock changes give no indication of the net fluxes between C pools in managed forests and the atmosphere. In addition, to meet transparency reporting requirements, areas included in the natural disturbance component of managed forests are reported separately, by reporting zone, in CRT Table 4.A.

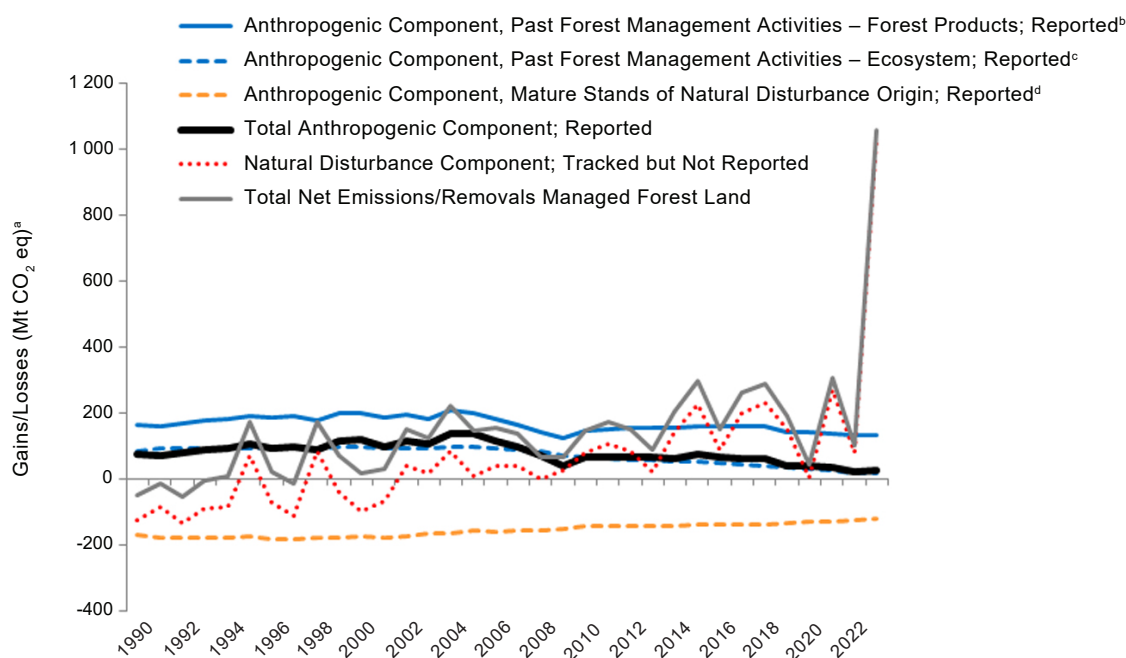
Harvesting wood from managed forests not only results in a transfer of C from the Forest Land category to the Harvested Wood Products category (Figure 6–2; Table 6–5), but also produces debris or residues that remain on-site and decompose. The fate of the C embedded in the wood transported off-site is transferred to and tracked in the HWP pool. Transfers are reported in the Forest Land category and the Harvested Wood Products category reports the change in this pool resulting from annual carbon input and annual carbon emission and disposal. The emissions from the C that decomposes on-site are also reported in the Forest Land category. In the current version of the CRT tables, transfers of wood to the HWP pool are reported in Table 4.A as additional information. The transfers are further included in the Net CO<sub>2</sub> Emissions/Removals columns. However, with the information provided as Additional Information, it is now possible to differentiate emissions to the atmosphere relative to transfers to the HWP pool, which was not the case in previous CRF Tables. More information on Canada's approach to HWP modelling is available in section A3.5.3.

Emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O from drained organic forest soils are reported in CRT Table 4(II). They are calculated using activity data obtained from a combination of historical documents, consultations and provincial statistics, using Tier 1 emission factors from the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC, 2014) (for more details, see section A3.5.2.4).

Based on calculations of direct and indirect soil N<sub>2</sub>O emissions from net soil organic carbon (SOC) losses in stands under anthropogenic influence aggregated at the reconciliation unit (RU) level, the potential emissions from this source can be considered insignificant in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. Emissions aggregated at the RU level were approximated to range from 55 kt in 1990 to 0 kt in recent years.

<sup>9</sup> Canada's forest carbon reporting system: <https://natural-resources.canada.ca/climate-change/forest-carbon/canada-s-forest-carbon-reporting-system>.

Figure 6–3 Gains and Losses of Carbon in Forest Land Remaining Forest Land, by Component



Notes:

- a. Not including indirect CO<sub>2</sub>
- b. Transfers to HWP
- c. Clear-cut and partial harvests, commercial and pre-commercial thinning, and salvage logging.
- d. Stands that have reached minimum operable age (either commercial maturity or pre-disturbance biomass threshold) and are eligible to be scheduled for harvest.

### 6.3.1.3. Uncertainty Assessment and Time-Series Consistency

#### Uncertainty Assessment

Numerical techniques are used to quantify the uncertainties surrounding the CBM-CFS3 outputs (Metsaranta et al., 2017). The modelling of Canada's managed forests is not done in a single run, but in separate project runs whose outputs are subsequently assembled. For each project, 100 Monte Carlo runs are conducted using the base input data for the GHG estimates. Confidence intervals are obtained for each inventory year by randomly sampling 10 000 combinations of all the project runs for that year. Separate uncertainty estimates are produced for each GHG. In years when no substantial changes occur, such as in this submission, a Monte Carlo simulation is not performed (the most recent one was for the 2024 submission and covered the entire 1990–2022 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<sub>2</sub> estimates was 72 Mt in 1990, 91 Mt in 2005 and 85 Mt in 2023 (Table 6–6). On average, the uncertainty range was ±37 Mt of the annual median result produced by the Monte Carlo runs over the entire time series. Non-CO<sub>2</sub> emissions contribute little to the total uncertainty. Probability distributions for the net flux estimate are asymmetrical and skewed to the lower bound (greater sink), which is representative of the nature of the distributions of the activity data and parameters tested in the Monte Carlo analysis as expressed in the model. More information on the general approach used to conduct this analysis is provided in section A3.5.2.9, 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 use consistent methodologies and data. However, the forest inventory data incorporated in the analyses were not all collected in the same year across the country. Section A3.5.2.5 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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O Fluxes in the Forest Land Remaining Forest Land Category, with 2.5th and 97.5th Percentiles, Selected Years**

Gas	Inventory Year	Net Flux (Mt)	2.5th Percentile (Mt)	% Uncertainty <sup>a</sup> (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
CO <sub>2</sub>	1990	73	4	-94	77	5.0
	2005	135	75	-44	166	23
	2023	23	-37	-260	49	113
CH <sub>4</sub>	1990	0.3	0.2	-25	0.7	99
	2005	0.7	0.6	-22	1.2	64
	2023	0.3	0.2	-41	0.5	84
N <sub>2</sub> O	1990	0.1	0.1	-23	0.3	148
	2005	0.3	0.2	-17	0.6	99
	2023	0.1	0.1	-37	0.2	131

Note:

a. Uncertainty ranges remain relatively constant throughout the time series. As a result, as the absolute value of emissions and removals decreases, the proportional error increases. Uncertainty ranges reported in section A2.3 are taken from the error associated with the proportional error for 2023.

#### 6.3.1.4. QA/QC and Verification

Systematic and documented quality assurance / quality control (QA/QC) procedures are performed in four areas: workflow checks (manual), model checks (automated), benchmark checks (manual) and external reviews. The check results are systematically documented, and an issue-logging system identifies each issue and facilitates tracking and resolution management. Tier 2 QC checks (White and Dymond, 2008; Dymond, 2008) specifically address estimate development in the Forest Land category.

Environment and Climate Change Canada uses its own QA/QC procedures for estimates developed internally (see section 1.3, Chapter 1) and implements category-specific Tier 2 checks for estimates obtained from its partners, as well as for all estimates and activity data compiled in the LULUCF data warehouse (Blondel, 2022) and subsequently entered into the CRT Reporter software. These procedures and their outcomes are fully documented in the centralized archives.

Shaw et al. (2014) compared the C stock values predicted by the CBM-CFS3 with ground plot-based estimates of ecosystem C stocks from Canada's new National Forest Inventory (NFI). Carbon stock data sets from the NFI were entirely independent of the input data used for model simulations for each ground plot. The mean error in total ecosystem stocks (representing the comparison between model predictions and ground-plot measurements) was 1%, while the biases in the above-ground biomass, deadwood, litter and mineral soil C pools were 7.5% (4.3 t/ha), -30.8% (-4.5 t/ha), 9.9% (5 t/ha) and 8.4% (8.1 t/ha), respectively; the contribution of the soil pool was the largest in absolute value. The errors in the above-ground biomass and deadwood pools compared favourably to the standards proposed in the IPCC's *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC, 2003) for these pools (8% and 30% respectively). These results point to important pool-, region- and species-specific variations that require further study.

Following Shaw et al. (2014), a national-scale calibration study for soil and DOM C modelling parameters was conducted (Hararuk et al. 2017), using a more comprehensive database of upland forest soil C observations (Shaw et al. 2018). An improved calibration of DOM-related parameters – base decay rates and their sensitivity to temperature, proportions of C released to the atmosphere, root turnover and snag fall rates – resulted in faster C cycling in woody debris and the soil organic layer (litter) and distinct C dynamics in hardwood and softwood dominated stands. Those improvements didn't lead to substantial improvements of global model performances, however, but provided indications for future improvements.

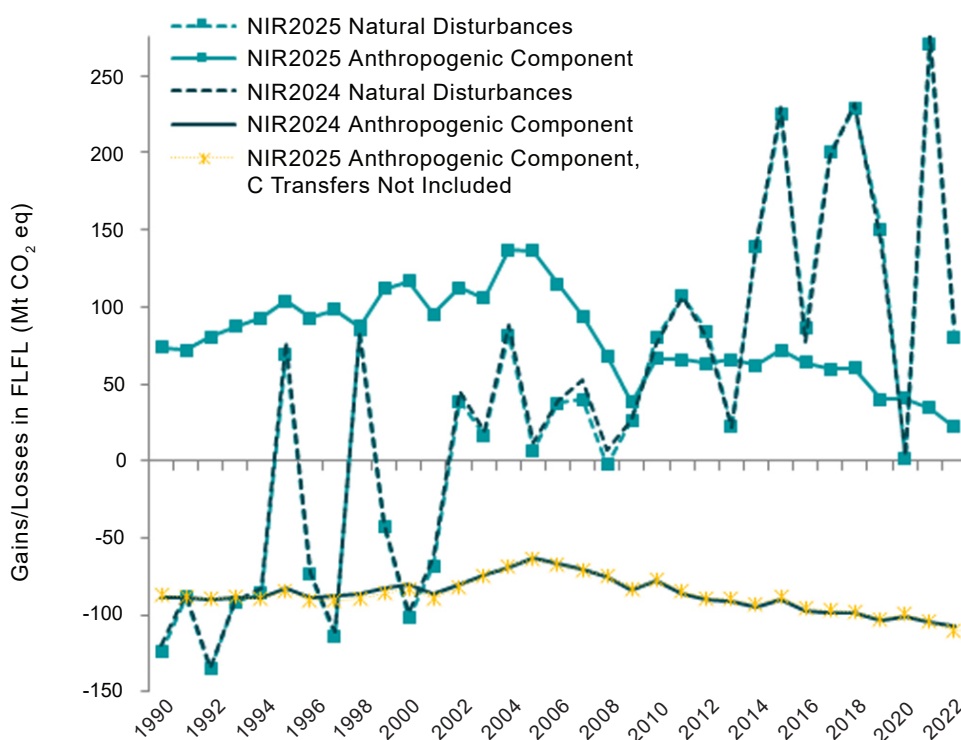
Additional analyses have been conducted at the site-scale, comparing hybrid biometric-model estimates derived using a combination of tree-ring observations and the CBM-CFS3 against eddy covariance derived estimates (e.g., Metsaranta et al. 2018; 2021), and at provincial scales (e.g. Hagemann et al. 2010; Heffner et al. 2021) to compare estimates against provincial forestry plot data. In general, like Shaw et al. (2014), these studies demonstrated that there is good agreement between estimates for some C stocks such as live biomass, and that the most gain in model performance would be obtained from improvements to how DOM dynamics are represented. Those studies also suggest further exploration of spatial variations driven by species composition, soil types, microbial activities and bryophyte abundance. As part of quality assurance (QA) efforts, the approach used in the 2017 National Inventory Report (NIR) for estimating anthropogenic emissions and removals was reviewed by an international panel of forest scientists convened by ECCC in October 2016. The panel found that the new approach effectively isolates anthropogenic emissions and removals due to forest management from the impacts of natural disturbances. The panel also stated that the criterion used to classify stands impacted by insect infestations as being under anthropogenic or natural influence was justifiable. However, it recommended that the threshold used to differentiate anthropogenic from natural emissions and removals after stand-replacing natural disturbances should be regionally specific to incorporate variations in forest ecology. Changes were implemented in the 2018 submission and provincial forest experts reviewed and approved the revised approach.

### 6.3.1.5. Recalculations

Recalculations occurred in the Forest Land category that resulted from relatively minor methodological changes this year (Fisher et al., 2024). They include (i) activity data revisions in conventional harvest and commercial thinning in recent years and residential firewood activity over the time series; (ii) updated slash-burning data and harvest algorithms in British Columbia; and (iii) the update of recent reforestation and afforestation activity data; and (iv) revised parameters for insect disturbance in Quebec. These changes had variable impacts on estimates throughout the time series ranging from downward revisions of -2.0 Mt CO<sub>2</sub> eq in 2015, to upward revisions of 3.2 Mt CO<sub>2</sub> eq in 1998. Recalculations in key reporting years resulted in downward revisions in removals from Forest Land of -0.74 Mt CO<sub>2</sub> eq in 1990 and upward revisions to removals of 0.20 Mt CO<sub>2</sub> eq and 2.2 Mt CO<sub>2</sub> eq in reporting years, 2005 and 2022 respectively (Figure 6-4).

The largest change in Forest Land estimates is a result in the change to HWP reporting to resolve the TERT recommendation on completeness in which transfers of carbon to the HWP pool are now reported in the source Land category from which the HWP is being supplied. Because of this change, there is an apparent upward revision in the Forest Land flipping the FL emissions and removals from a net sink to a net source, with upward revisions of 161 Mt CO<sub>2</sub> eq, 200 Mt CO<sub>2</sub> eq and 132 Mt CO<sub>2</sub> eq in reporting years 1990, 2005 and 2022 respectively. Revisions to HWP reporting have no net impact to reported emissions and removals in the LULUCF sector (See section 6.4.5).

Figure 6-4 Recalculations in the Natural Disturbance Component and Anthropogenic Component of Forest Land Remaining Forest Land



### 6.3.1.6. Planned Improvements

Studies have been developed to explore the role of human actions and management on fire regimes, the relationship between trends in emissions and removals and key indicators of human management such as harvest rates and conservation areas as well as analyses of the consistency of carbon recovery intervals in forest landscapes with evolving age-class structures. Upon completion of these studies, revisions will be made to Canada's anthropogenic partitioning protocols.

During the period of this analysis continual improvements will continue such as (i) updates to baseline inputs (data, processes and parameters, e.g.: refinements to fire activity data) as well as continuous refinements to certain parameters in the CBM-CFS3 modelling framework; as well (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 as well as a gradual integration of increasing spatially explicit data and estimates in the modelling framework.

Additional details on planned improvements for Forest Land are outlined in Chapter 8, section 8.3.1 and Table 8–5, and further information may be found in the Improvement Plan for Forest and Harvested Wood Products Greenhouse Gas Estimates.<sup>10</sup>

## 6.3.2. Land Converted to Forest Land (CRT Category 4.A.2)

### 6.3.2.1. Category Description

This category includes all land converted to forest land by direct human activities. This does not include reforestation after harvesting or abandoned farmland where natural regeneration has been allowed to occur. More precisely, the category refers to the active establishment of forest on land where the previous land use was not forest (typically, abandoned farmland).

The total cumulative area reported in the Land Converted to Forest Land category declined from 170 kha in 1990 to 26 kha in 2023. Given that activity data after 2008 are only for Ontario and recent afforestation activities starting in 2021 (see section 6.3.2.2), the trend mainly reflects the gradual transfer of lands afforested more than 20 years ago to the Forest Land Remaining Forest Land category. Nearly 86% of all conversions of farmland to forest land in the last 20 years occurred in Eastern Canada (Atlantic Maritime, Mixedwood Plains and Boreal Shield East reporting zones), with 8% in the Prairie provinces (Boreal Shield West, Boreal Plains and Sub-humid Prairies reporting zones) and the remaining 5% in the most westerly ecozones (Pacific Maritime and Montane Cordillera reporting zones).

Net removals declined throughout the period, from 1.1 Mt in 1990 to 0.13 Mt in 2023. Net C accumulation largely occurred in living biomass (32 Gg C in 2022, CRT 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 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 2007–2019 obtained through a data-sharing agreement with Forests Ontario providing access to its database of tree planting activities.

For the year 2023, estimates associated with recent afforestation activities in Canada were prepared, as was the case in 2021, 2022 using a methodology specifically developed that incorporates site-specific pre-planting C stocks into the estimation of the initial and then subsequent C content for the new afforestation sites (see section 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 section A3.5.2.1. However, the biomass losses from croplands during the conversion year are estimated using historical yields, harvest index relationship and root-shoot ratio (see Annex 3, section A3.5.2.8). 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.

<sup>10</sup> <https://data-donnees.az.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/E-LULUCF/?lang=en>

### 6.3.2.3. Uncertainty Assessment and Time-Series Consistency

Significant challenges remain in estimating the uncertainty for this category due to the lack of a consistent national system for tracking afforestation and because a Monte Carlo simulation cannot currently be run using the model data input structure for this category. Given these limitations, initial uncertainty estimates were developed based on expert judgement. It was assumed that the 95% confidence intervals for this category could be estimated at 10% smaller or 200% larger than the reported value.

### 6.3.2.4. QA/QC and Verification

Tier 2 QC checks (Dymond, 2008) specifically address estimate development in the Forest Land category. Environment and Climate Change Canada, while maintaining its own QA/QC procedures for internally developed estimates (see section 1.3, Chapter 1), has implemented specific procedures for estimates obtained from its data partners, as well as for all estimates and activity data from the LULUCF data warehouse (Blondel, 2022) subsequently entered into the CRT Reporter software.

### 6.3.2.5. Recalculations

Recalculations occurred from inclusion of biomass losses from conversion of croplands to forestlands. This change caused an upward recalculation of 121 kt in 1990, 61 kt in 2005 and 7 kt in 2023.

### 6.3.2.6. Planned Improvements

Although access to information on afforestation activity remains limited, continued efforts are underway to obtain more data for recent years from provincial and territorial resource management agencies. Uncertainty estimates will be further refined as more information becomes available.

## 6.4. Harvested Wood Products (CRT Category 4.G)

### 6.4.1. Category Description

Gains and losses from the Harvested Wood Products category are reported using the Simple Decay Approach described in the annex to Volume 4, Chapter 12, Section 12A.3.2, 2019 Refinement of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (hereafter referred to as the 2019 Refinement of the 2006 IPCC Guidelines) (IPCC, 2019). The simple decay approach is similar to the Production Approach, tracking all fluxes of carbon associated with HWP from the Forest to HWP pools and to the end of its useful life, but differs by including bioenergy products and wood waste products that result from wood extracted from the forest. Wood harvested from the forest is reported as a carbon leaving the forest ecosystem and subsequently entering harvest wood products (more details provided in section A3.5.3).

Gains and losses associated with this category result from the use and disposal of HWP manufactured from wood obtained from industrial roundwood harvesting on forest land, residential firewood harvesting in forests and other wooded lands, and forest conversion activities in Canada and subsequently consumed either in Canada or abroad. Products disposed of at the end of their useful life are transferred to the waste stream in the country where the wood product was used. Due to the large proportion of Canadian wood that is exported, we are not able to accurately track the fate of that carbon.

Fluxes of carbon in this source are influenced by 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. The HWP category has acted as a carbon store throughout the time series with increasing storage of carbon in HWP by as much as 60 Mt CO<sub>2</sub> eq in 2004 (peak harvest year) with the exception of 2009 when reductions in storage of 0.78 Mt CO<sub>2</sub> eq occurred as harvest rates fell to their lowest level. In 2023, the HWP pool increased by 5.1 Mt CO<sub>2</sub> eq relative to 57 Mt CO<sub>2</sub> eq and 38 Mt CO<sub>2</sub> eq in 2005 and 1990 respectively (Table 6–7). In recent years less carbon has been stored in the HWP pool due to reduced harvest rates relative to the mid-2000s.

Table 6–7 Carbon Stocks in the Harvested Wood Products Pool and Losses Resulting from Their Use and Disposal

Source Subcategories / Commodities	Land Category	1990	2005	2018	2019	2020	2021	2022	2023
<b>Carbon Stocks and Fluxes (kt C)<sup>a</sup></b>									
<b>Inputs</b>		<b>46 000</b>	<b>56 000</b>	<b>45 000</b>	<b>40 000</b>	<b>40 000</b>	<b>39 000</b>	<b>37 000</b>	<b>37 000</b>
Conventional harvest <sup>b</sup>	Forest Land	40 000	51 000	39 000	36 000	35 000	35 000	33 000	33 000
Forest conversion <sup>b</sup>	Cropland	1 100	410	510	540	490	510	550	560
	Wetlands	3.0	5.9	0.4	3.1	3.6	3.0	-	-
	Settlements	690	700	720	710	720	790	690	670
Residential firewood <sup>c</sup>	Forest Land	4 100	3 100	3 600	3 200	2 800	2 500	2 700	2 500
	Cropland	230	130	190	150	130	110	110	110
	Settlements	82	83	84	84	84	84	84	84
Exports		19 000	31 000	21 000	20 000	18 000	18 000	16 000	16 000
Net stocks <sup>d</sup>		330 000	520 000	600 000	610 000	610 000	610 000	620 000	620 000
<b>Carbon Flux – Domestic Consumption from harvest</b>		<b>24 000</b>	<b>20 000</b>	<b>21 000</b>	<b>18 000</b>	<b>20 000</b>	<b>20 000</b>	<b>20 000</b>	<b>20 000</b>
Solid wood – sawnwood		1 500	2 100	2 700	2 700	2 700	2 800	2 800	2 800
Solid wood – wood panels		730	890	1 100	1 200	1 200	1 200	1 200	1 200
Other solid wood products		250	520	610	610	610	610	620	620
Pulp and paper market		2 300	200	890	820	760	700	650	620
Residential firewood and industrial fuelwood		14 000	16 000	15 000	13 000	13 000	13 000	14 000	14 000
Mill residue <sup>e</sup>		5 100	450	480	310	1 300	770	770	770
<b>Carbon Flux – Worldwide from Canadian harvest</b>		<b>12 000</b>	<b>20 000</b>	<b>17 000</b>	<b>17 000</b>	<b>17 000</b>	<b>17 000</b>	<b>16 000</b>	<b>16 000</b>
Solid wood – sawnwood		2 700	4 400	5 200	5 300	5 300	5 400	5 400	5 400
Solid wood – wood panels		210	1 200	1 600	1 700	1 700	1 700	1 700	1 700
Other solid wood products		14	14	17	18	18	18	19	19
Pulp and paper market		8 500	14 000	9 900	9 600	9 300	8 900	8 500	8 100
Mill residue <sup>e</sup>		130	580	570	510	550	560	570	570
<b>Net Flux (kt CO<sub>2</sub>)</b>		<b>-38 000</b>	<b>-57 000</b>	<b>-24 000</b>	<b>-18 000</b>	<b>-10 000</b>	<b>-12 000</b>	<b>-4 000</b>	<b>-5 100</b>

## Notes:

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 CRT Table 4.A under the Forest Land Remaining Forest Land category and in tables 4.B, 4.D and 4.D under subcategories related to forest conversion, if using the instant oxidation approach for HWP.

c. Includes the C in residential firewood harvested from forest, agricultural woody biomass and urban trees, and assumed to be burned in the year of harvest. This C would be reported as C losses in CRT tables 4.A under Forest Land Remaining Forest Land, 4.B under Cropland Remaining Cropland, and 4.E under Settlements Remaining Settlements, if using the instant oxidation approach for HWP.

d. Represents the quantity of C in the HWP pool at the end of the reporting year. Because inputs to the model consider the harvests since 1900, net stocks over the reporting period may include C harvested before 1990.

e. Assumed to be disposed of in the year of harvest.

For the entire reporting period, carbon in biomass transferred from the forest is reported as a carbon loss from the Forest ecosystem (dotted line in Figure 6–5), which was the value reported for submissions prior to the implementation of the HWP model in 2015. The carbon that is transferred from the Forest ecosystem to the HWP pool creates a pool of carbon that is stored in products in use. The differences between the transfers into and the losses from the HWP carbon pool from either product disposal or emission through combustion as bioenergy (bars in Figure 6–5) represent the reported emissions according to the simple decay method as defined in the *2019 Refinement of the 2006 IPCC Guidelines*. These differences represent the annual net increase or decrease of C storage in the HWP pool. Net stocks in the HWP pools have increased each year, except for 2009. In total, 620 Mt C have been transferred and stored in the HWP pool since 1990.

Harvested Wood Products gains and losses are inextricably linked to the emissions/removals reported in the Forest Land category: the sum of net emissions/removals reported in the Forest Land category and emissions reported in the Harvested Wood Products category provides an estimate of total net emissions/removals reported in managed forests (Figure 6–2).

## 6.4.2. Methodological Issues

A country-specific model, applying the IPCC simple-decay approach, the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP),<sup>11</sup> is used to monitor and quantify the fate of C that has been exported from Forest Land from the point of forest harvest, forest conversion or firewood collection from Forests, Cropland or Settlement areas. The model tracks HWP sub-pools and C flows between sub-pools throughout the life cycle of wood products (e.g. manufacturing, use, trade and disposal).

The simple decay approach (Section 12A.3.2, 2019 Refinement) excludes HWP imports and includes all HWP exports.<sup>12</sup> The approach quantifies all carbon exports from Land categories, including products that do not undergo storage, such as domestic bioenergy products. Carbon storage in short- and long-lived products is treated in the same way as in the Production Approach with losses calculated based on the half-lives of products entering the pool. The carbon loss either from the disposal of short- and long-lived products and the combustion of bioenergy products are reported as CO<sub>2</sub> in the HWP source category and CH<sub>4</sub> and N<sub>2</sub>O emissions from HWP combustion or decomposition are reported in the Energy and Waste sectors in the country of their use or disposal in accordance with the IPCC Guidelines (more details provided in Annex 3.5.3) in the country of their disposal. For HWP consumed and disposed of in Canada, CH<sub>4</sub> emissions were reported under the Waste sector, and emissions from methane recovery for energy purposes were included under the Energy sector, in accordance with the IPCC 2006 Guidelines (Ch 12, Section 12.1, Page 12.6).

The HWP model uses carbon transferred from harvest as inputs. These inputs (Table 6–7) include (i) the annual mass of C transferred to forest products that result from conventional, contemporary<sup>13</sup> and residential firewood harvesting on Forest Land and a relatively small amount from lands converted from forest to cropland, wetlands (hydroelectric reservoirs) and settlements (around 2.9% of all inputs in any year) transferred from the CBM-CFS3 model (see section 6.3.1.2); and (ii) an additional annual quantity of C from woody biomass harvested from cropland and from urban trees on land in the Settlements category and used for residential bioenergy (Table 6–7). Contemporary harvest data since 1990 were generated by Canada's country-specific forest ecosystem carbon dynamics model CBM-CFS3 and were available spatially by reconciliation units (RU) (see section 6.3.1.2). Historical harvests between 1941 and 1989 were at the aggregated national level from Statistics Canada and were used to extrapolate for the period between 1900 and 1940.

Data on annual volumes of residential firewood and industrial fuelwood are provided by the Energy sector (section A3.1.4.1.4). Residential firewood data were obtained from surveys of residential wood use for the years 1997, 2003, 2007, 2015, 2017 and 2019 (Statistics Canada 1997, 2003, 2007, 2015, 2017, 2019); and pellet and manufactured log consumption data were collected from surveys for the years 1996, 2006, 2012, 2017 and 2019 (Canadian Facts, 1997; TNS, 2006; TNS, 2012; Statistics Canada, 2017, 2019). Data on firewood consumption in the territories come from fuelwood and firewood harvest statistics in the National Forestry Database,<sup>14</sup> and data on industrial fuelwood come from the annual Report on Energy Supply and Demand in Canada (RESO). More information on the estimation methodology, data sources and parameters used in the model can be found in Annex 3.1 and section A3.5.3.

Activity data, annual estimates of C inputs, stock changes in the HWP pool and the resulting net emissions for each commodity are reported in CRT Table 4.G. In accordance with the Simple Decay Approach, the following assumptions were made in reporting HWP-related data in this table:

- **Column C (Gains):** corresponds to C inputs associated with C transferred from any wood-producing land category (e.g. Forest Land) to the HWP pools used domestically and exported; these C inputs would represent C transfers to the HWP pool, reported in Column U of Tables 4.A, 4.B, 4.D and 4.E.
- **Column D (Losses):** corresponds to C losses using decay Equation 12.1 in Volume 4, Chapter 12, of the 2006 IPCC Guidelines, for HWP with longer half-lives and from the annual combustion of firewood and the oxidation of milling waste.
- **Column F (Annual change in stocks):** calculated as the net interannual change in stocks in the HWP pool; the total annual values of these net stocks are reported in Table 6–7.
- **Column G (Net gains/losses from HWP in use, CO<sub>2</sub>):** values reported in this column correspond to the CO<sub>2</sub> emissions associated with the carbon change in the HWP pool calculated as  $44/12 \times (\text{annual carbon domestic harvest} - \text{annual release of carbon at the end of its useful life from HWP that came from wood harvested in the reporting country, including wood that is exported but excluding imports})$ .

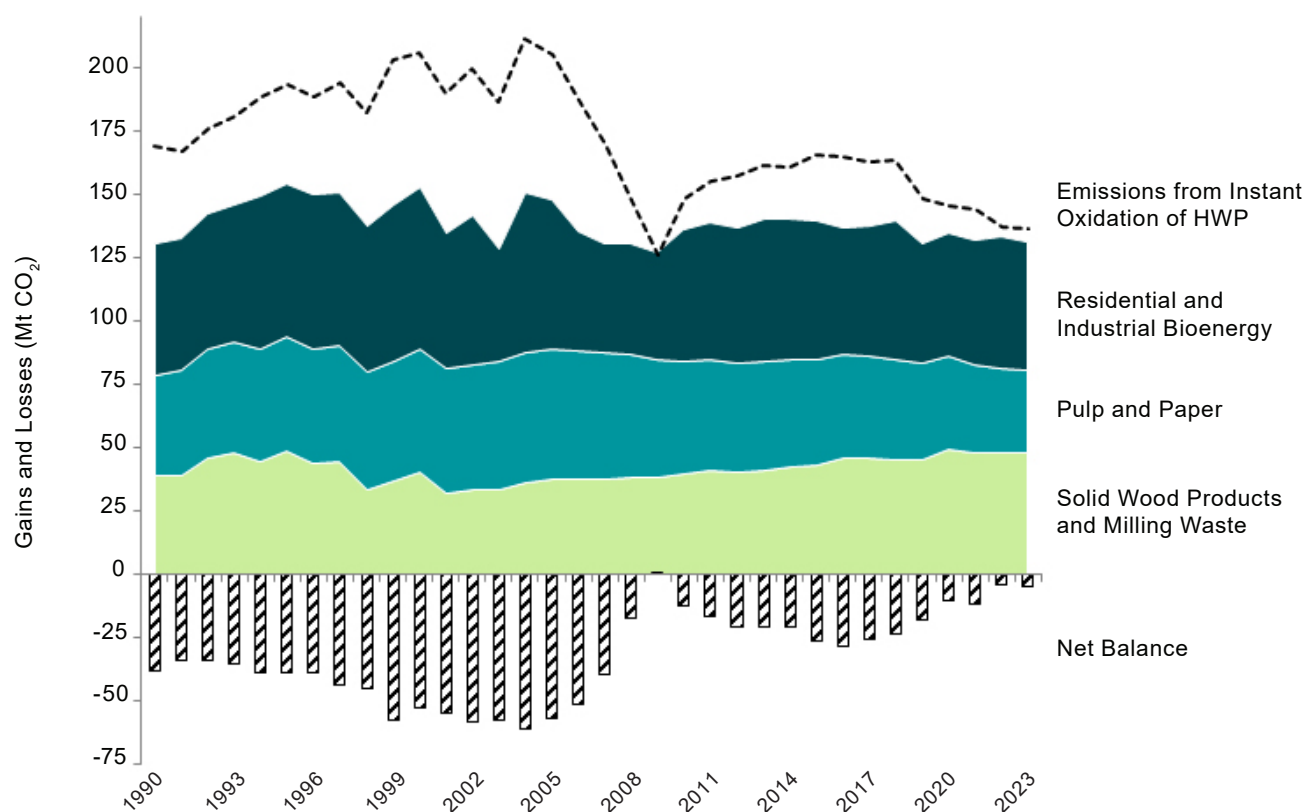
11 Canada's forest carbon reporting system: <https://natural-resources.canada.ca/climate-change/forest-carbon/canada-s-forest-carbon-reporting-system>.

12 Currently statistics on bioenergy exports are not available, bioenergy currently modelled is domestic.

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

14 National Forestry Database, available online at <http://nfdpr.ccfm.org/en/data/harvest.php>.

Figure 6–5 Gains and Losses from the Harvested Wood Products Pool Using the Simple Decay Approach



Notes:  
The net balance is the difference between the C transferred to the HWP pool and gross flux from the HWP pool, the value reported in the CRT tables representing the net flux to and from the HWP pool.  
This data series represents the carbon transferred annually from the forest and other land into the HWP C pool in units of CO<sub>2</sub>. It includes salvage logging after natural disturbances in forests.

### 6.4.3. Uncertainty Assessment and Time-Series Consistency

In the assessment of the uncertainty associated with the Harvested Wood Products category, model parameters are varied during Monte Carlo simulations. In addition, 100 HWP inputs are derived from the CBM-CFS3 (ecosystem) uncertainty analyses. These simulations are used to estimate the combined uncertainty associated with the two estimation systems (i.e. CBM-CFS3 and NFCMARS-HWP) for all C harvested since 1990 (Table 6–8). Additional parameters were used in the Monte Carlo analysis including the uncertainty distributions for historical inputs (pre-1990 harvest), contemporary inputs (harvests since 1990) and five allocation parameters related to bioenergy. Best practices for treatment of uncertainty for the new reporting approach is still under evaluation. In the current submission, confidence intervals are built around estimates of changes in carbon in HWP pools associated with conventional harvest and forest conversion. Confidence intervals are still considered to be accurate, however, the symmetry of the interval around the mean may be biased. More details are provided in section A3.5.3.

Table 6–8 **Estimates of CO<sub>2</sub> Gains and Losses from Harvested Wood Products, with 2.5th and 97.5th Percentiles, Selected Years**

Inventory Year	Source of C inputs	Gains/Losses (Mt CO <sub>2</sub> )	2.5th Percentile (Mt)	% Uncertainty (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
1990	Forest conversion – since 1990	-4.0	-3.1	-22	-4.5	13
	Conventional harvest – since 1990	-88	-115	32	-95	8
	Historical harvest – before 1990	53	41	-24	67	25
2005	Forest conversion – since 1990	-1.3	-1.3	-0.4	-1.7	37
	Conventional harvest – since 1990	-71	-94	32	-75	5.8
	Historical harvest – before 1990	15	12	-24	20	33
2023	Forest conversion – since 1990	-0.8	-0.9	4	-1.6	90.3
	Conventional harvest – since 1990	-14	-26	83.4	-21	49.0
	Historical harvest – before 1990	10	7.8	-23	11	11

#### 6.4.4. QA/QC and Verification

Environment and Climate Change Canada, while maintaining its own QA/QC procedures for internally developed estimates (see section 1.3, Chapter 1), has implemented specific procedures for estimates obtained from its data partners, as well as for all estimates and activity data compiled in the LULUCF data warehouse (Blondel, 2022) and subsequently entered into the CRT Reporter software.

#### 6.4.5. Recalculations

Recalculations occurred in the Harvested Wood Products category, due to (i) updated HWP model parameters based on the latest Food and Agriculture Organization (FAO) statistics on Canadian forest products;<sup>15</sup> (ii) Updated HWP commodity conversion parameters; ; (iii) updated waste incineration activity data; (iv) updated residential bioenergy activity data and emission factors; and (v) revisions to HWP transfers from Forests (see section 6.9.5).

The combined effect of these methodological and activity data changes resulted in small downward recalculations in total fluxes reported in this category early in the time series and upward recalculations later in the time series. Recalculations in key reporting years resulted in downward revisions in carbon storage in HWP of -0.36 Mt CO<sub>2</sub> eq in 1990 and -0.07 on 2005 and upward revisions to carbon storage of 1.4 Mt CO<sub>2</sub> eq in reporting year 2022.

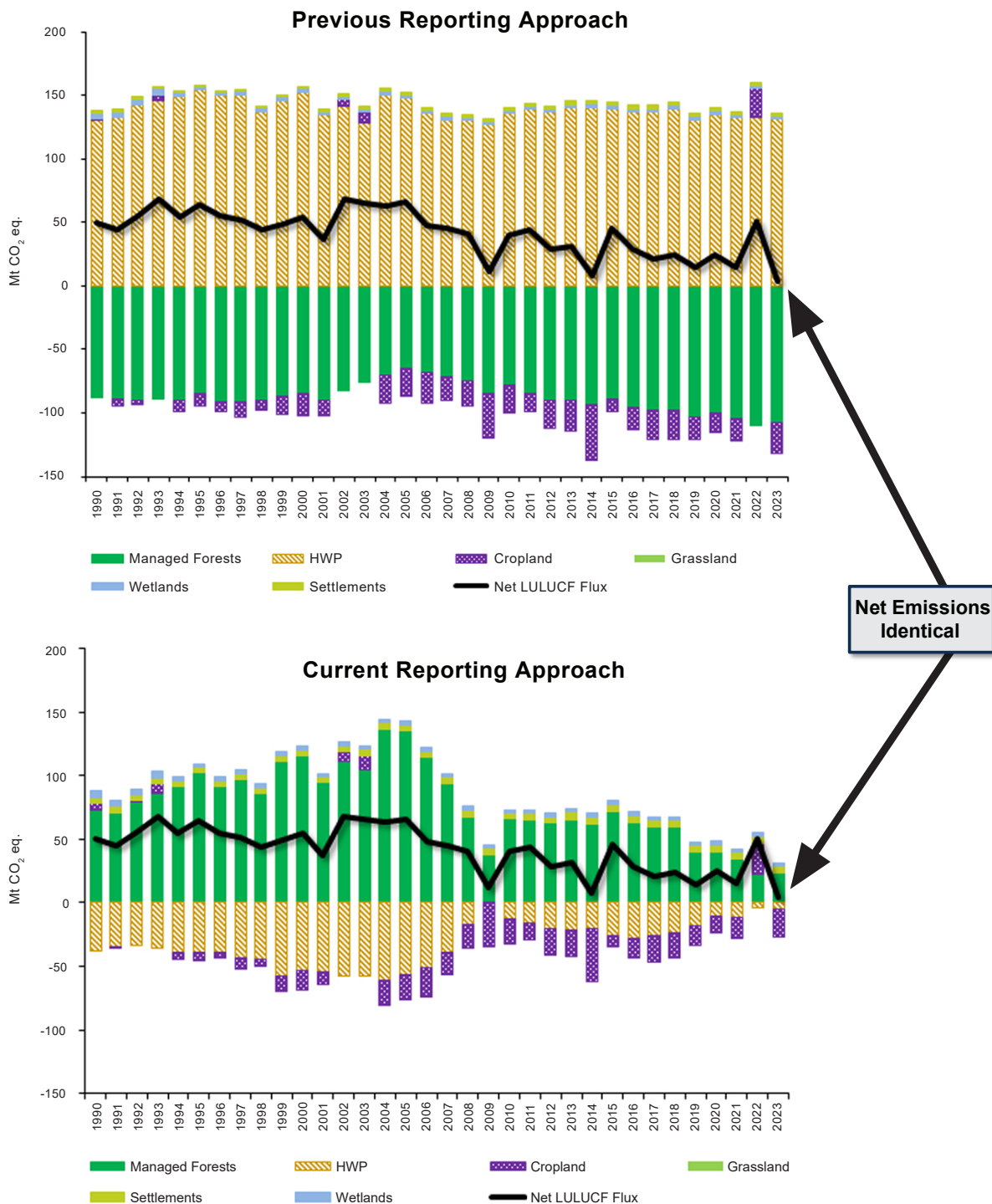
The important change in HWP estimates is a result of the change to the reporting framework to resolve the TERT recommendation on completeness in which transfers of carbon to the HWP pool are now reported as the difference between annual inputs of new products into the pool and outputs from the pool at the end of the products useful life. Because of this change, there is an apparent downward revision in the HWP category flipping the profile of HWP from being reported as a gross emission source to being reported as a net source of carbon storage that has grown on an annual basis throughout the time series. This change in reporting results in apparent downward revisions of -168 Mt CO<sub>2</sub> eq, -204 Mt CO<sub>2</sub> eq and -137 Mt CO<sub>2</sub> eq in reporting years 1990, 2005 and 2022 respectively flipping the reporting of HWP from a reported loss of carbon from the terrestrial ecosystem to a net gain of carbon as a result of inputs to the pool being greater than outputs from the pool. Revisions to HWP reporting have no net impact to reported gains and losses in the LULUCF sector (6) only in the location of where gains and losses are reported on the terrestrial landscape.

Modifications that occurred in the change from the CRF tables to the CRT format provides the ability to transparently report transfers from different land uses to HWP. Previously, emissions to the atmosphere from decomposition or combustion could not be clearly differentiated in the reporting tables from carbon transfers to HWP in Tables 4.A through 4.E of the CRF tables. Carbon transfers are now reported in the Forest Land category as a carbon loss from the Forest ecosystem (inversion of green bars in Figure 6–6), as are transfers that occur during Forest conversions. As such the downward revisions that occur in HWP, for example: -168 Mt CO<sub>2</sub> eq, -204 Mt CO<sub>2</sub> eq and -137 Mt CO<sub>2</sub> eq are fully offset by upward revisions to Forest Land (161 Mt CO<sub>2</sub> eq, 200 Mt CO<sub>2</sub> eq, and 132 Mt CO<sub>2</sub> eq) and in Forest Conversion in Cropland, Settlement and Wetland (7 Mt CO<sub>2</sub> eq, 4 Mt CO<sub>2</sub> eq, and 5 Mt CO<sub>2</sub> eq) in reporting years 1990, 2005 and 2022 respectively.

This reporting change in combination with the implementation of the new CRT allows reporting that avoids the harvest transfers being mistakenly considered instant oxidation and provides improved comparability between Canada's reporting and other countries that report using the Production Approach for HWP reporting and using the Stock Change approach for Forest Land reporting.

15 FAOSTAT Forestry Production and Trade, available online at <https://www.fao.org/faostat/en/#data/FT>.

Figure 6–6 **Recalculations of Gains and Losses from the Harvested Wood Products Pool Resulting from Revisions to the Reporting Approach**



#### 6.4.6. Planned Improvements

Research is in progress to improve the regional differentiation of HWP production and trade ensuring that the provincial/territorial summaries accurately reflect regional conditions and further work is aimed at the characterization of the biomass feedstocks used as fuel in the industry sector.

More details are provided in section 6.3.1.6 and in Chapter 8, section 8.3.1 and Table 8–5.

## 6.5. Cropland (CRT Category 4.B)

Cropland covers approximately 46 Mha of Canada's territory. In 2023, the net GHG balance in the Cropland category amounted to net removals of 22 Mt (Table 6–1). For UNFCCC reporting purposes, the Cropland category is divided into Cropland Remaining Cropland (net removals of 27 Mt in 2023) and Land (i.e. either forest or grassland) Converted to Cropland (net emissions of 5.3 Mt in 2023). The estimates of Land Converted to Cropland include net emissions and removals of CO<sub>2</sub>, as well as N<sub>2</sub>O and CH<sub>4</sub> emissions.

### 6.5.1. Cropland Remaining Cropland (CRT Category 4.B.1)

#### 6.5.1.1. Category Description

Cultivated agricultural land in Canada includes field crops, summerfallow, hayfields, and tame or seeded pastures, mainly located in the nine southernmost reporting zones. About 83% of Canada's cropland can be found in the interior plains of Western Canada, made up of the Semi-arid Prairies, Sub-humid Prairies and Boreal Plains reporting zones, while another 12% is in the Mixedwood Plains reporting zone of Eastern Canada.

The Cropland Remaining Cropland subcategory includes CO<sub>2</sub> emissions/removals from mineral soils; CO<sub>2</sub> emissions from the cultivation of organic soils; and CO<sub>2</sub> 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<sub>2</sub> emissions and removals in mineral soils, impacted by changes in tillage practices and perennial/annual crop conversion on an area basis. Since the 2022 submission, the IPCC Tier 2 Steady State approach (IPCC, 2019; Thiagarajan et al., 2022) is used to estimate the impact of crop productivity and subsequent crop residue C input on soil C storage. As a result, the explicit inclusion of area-based summerfallow factors is eliminated as a separate driver of changes in cropland soil C. Estimates of CO<sub>2</sub> removals associated with increases in C inputs to soils from reductions in summerfallow are based exclusively on changes in crop production to avoid double counting since regional estimates of production changes inherently include the reduction in summerfallow. In addition, a country-specific method using manure-induced C retention factors has been developed for estimating soil C storage as influenced by the application of manure to soils under annual crop production (Liang et al., 2021).

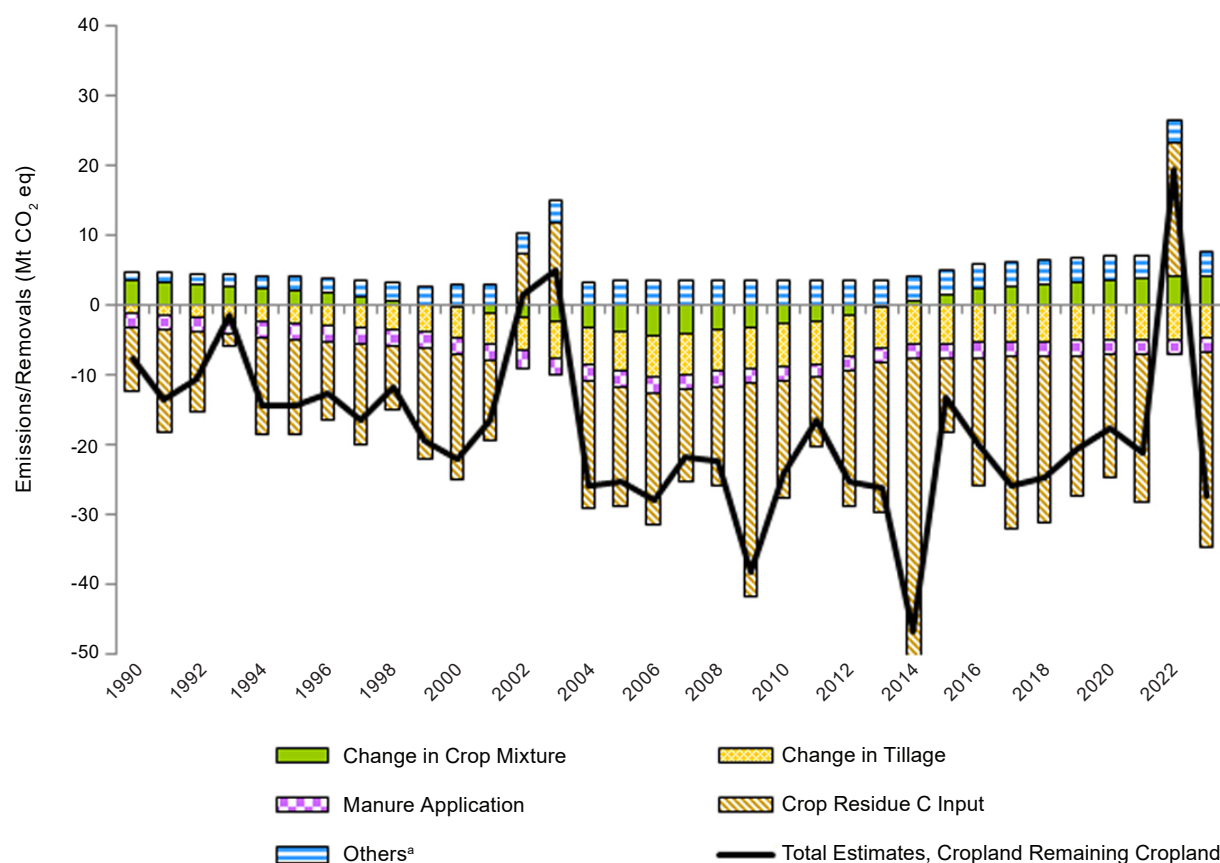
##### 6.5.1.1.1. CO<sub>2</sub> Emissions from, and Removals by, Mineral Soils

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<sub>2</sub> emissions to or removal from the atmosphere.

In 1990, changes to mineral soil management represented net CO<sub>2</sub> removals of 8.7 Mt (Table 6–9). CO<sub>2</sub> removals by soil increased to 27 Mt in 2005 and 29 Mt in 2023. Since 1990, on average, the yields of major field crops increased by 25% for barley, 68% for canola, 53% for corn, 19% for soybean and 78% for spring wheat. However, crop yields fluctuated by year, impacting C inputs to soils from crop residues, resulting in fluctuations in net removals of CO<sub>2</sub> by soils of 9 Mt in 1990, 17 Mt in 2005, and 28 Mt in 2023. Interannual variability tends to be high throughout the time series, reflecting weather-related impacts on crop production (Figure 6–7).

Conservation tillage increased significantly, from 11 Mha in 1990 to 28 Mha in 2023, and this trend results in CO<sub>2</sub> removals by soil of 1.3 Mt in 1990, 5.6 Mt in 2005 and then leveling off to 4.8 Mt in 2023 (Table 6–9; Campbell et al., 1996; Janzen et al., 1998; McConkey et al., 2003). Furthermore, the proportion of perennial crops relative to annual crops increased between 1990 and 2006, also observed in the net change in crop mixtures, which resulted in net emissions of 3.5 Mt in 1990, net removals of 3.8 Mt in 2005 and net emissions of 4.2 Mt in 2023. 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<sub>2</sub> removals by soils varying from 2.1 Mt to 2.5 Mt annually, reflecting changes in beef cattle, swine and poultry populations. As a result of these combined changes in management practices, since 2006, net removals by mineral soils have increased by roughly 2 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.

Figure 6–7 Emissions and Removals Related to Cropland Remaining Cropland



Note:  
a. "Others" include emissions/removals associated with perennial woody crops, harvest of woody biomass, and cultivation of histosols, and residual emissions from historic land conversion to cropland.

Table 6–9 Baseline and Recent-Year Emissions and Removals Associated with Various Land Management Changes in the Cropland Remaining Cropland Category

Categories	Land Management Change (LMC)	Emissions/Removals (kt CO <sub>2</sub> eq) <sup>a</sup>							
		1990	2005	2018	2019	2020	2021	2022	2023
TOTAL CROPLAND REMAINING CROPLAND		-7 700	-25 000	-25 000	-21 000	-18 000	-21 000	20 000	-27 000
Cultivation of histosols		1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200
Perennial woody crops		-1 000	41	-130	-9	88	130	130	61
Woody biomass transferred to HWP		840	490	680	540	460	410	410	400
Total mineral soils		-8 700	-27 000	-26 000	-22 000	-19 000	-23 000	18 000	-29 000
Crop mixture changes	Increase in perennial crops	-3 600	-12 000	-11 000	-11 000	-11 000	-11 000	-11 000	-12 000
	Increase in annual crops	7 100	8 500	14 000	15 000	15 000	15 000	16 000	16 000
Tillage changes	Conventional to reduced	-870	-1 000	-680	-650	-630	-600	-590	-580
	Conventional to no-till	-420	-3 700	-3 600	-3 500	-3 500	-3 500	-3 400	-3 400
	Other <sup>b</sup>	-0.5	-860	-940	-920	-900	-870	-850	-830
Crop residue C input		-9 000	-17 000	-24 000	-20 000	-18 000	-21 000	19 000	-28 000
Manure application		-2 100	-2 500	-2 200	-2 200	-2 200	-2 200	-2 100	-2 100
Land conversion – residual emissions <sup>c</sup>		200	1 800	1 800	1 800	1 800	1 700	1 700	1 700

Notes:  
a. A negative sign indicates the removal of CO<sub>2</sub> 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<sub>2</sub> emissions from the conversion of forest land and grassland to cropland occurring more than 20 years prior to the inventory year, including emissions from the decay of woody biomass and DOM.

### 6.5.1.2. Methodological Issues

According to the 2006 IPCC Guidelines, changes in SOC are driven by changes in soil management practices. When no change in management has occurred, it is assumed that mineral soils are neither sequestering nor losing C.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management practices on SOC, selecting the key management practices and management changes likely to cause changes in soil C stocks and on which activity data (time series of management practices) from the *Census of Agriculture* (COA) were available. Several management practices are known to increase SOC in cultivated cropland, including reduced tillage intensity, intensification of cropping systems, adoption of yield-promoting practices, and re-establishment of perennial vegetation (Janzen et al., 1997; Bruce et al., 1999). Other land management changes (LMCs), such as manure application and increased crop productivity, are also known to have positive impacts on SOC. Data on rates of annual biomass production can be determined from the yield estimates produced to estimate nitrous oxide emissions from crop residues (Thiagarajan et al., 2018), as can data on carbon input in manure. Estimates of CO<sub>2</sub> 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, making use of 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 section A3.5.1). The C emission/removal factors represent the rate of SOC change per year and per unit area of land that underwent a land management change.

The impact of LMCs on SOC varies with the initial conditions. Therefore, to obtain the most accurate estimates of soil C stock changes, the cumulative effects of the long-term management history of each piece of land or farm field should be considered. This inventory relies mainly on the COA for the estimated area of LMCs (i.e., changes in tillage and crop mixtures), which are not spatially explicit. The area of LMCs was determined individually in the 3475 SLC polygons where agricultural activities occur, each one with an agricultural area between roughly 1000 and 1 000 000 ha. This is the finest resolution possible for activity data linked to an ecological land stratum. The COA provides information on the area of each practice in each census year, so only the net area of change for each land management practice can be estimated. Estimates of these LMCs are as close to the gross area of LMCs as is feasible for regional or national analyses.

The validity of the COA-based LMC estimates relies on two key assumptions: the additivity and the reversibility of area-based C factors. Additivity assumes that the combined effects of different LMCs or of LMCs at different times would be the same as the sum of the effect of each individual LMC. Reversibility is the assumption that the C effects of an LMC in one direction (e.g. converting annual crops to perennial crops) are the opposite of the C effects of the LMC in the opposite direction (e.g. converting perennial crops to annual crops).

The various C factors associated with each specific area-based tillage practice and perennial/annual crop mixture in space and time were derived using the CENTURY model (Version 4.0), by comparing the output from scenarios with and without the management change in question.

Crop productivity has continued to increase in Canada, likely due to higher fertilization rates and improvements in crop genetics (Fan et al., 2019). The 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019) provides a Tier 2 Steady State approach for estimating the change in SOC storage as impacted by crop productivity. This method was applied using crop biomass input data consistent with estimates of crop residue nitrogen (N) used to estimate nitrous oxide emissions in [Chapter 5](#).

A country-specific method using a manure-induced C retention factor (Liang et al., 2020) was developed to estimate the soil C sink resulting from manure application to cropland soils. Estimates of SOC change were limited to the application of manure on annual cropping systems. Applications of manure on perennial cropping systems were 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 section A3.5.4.1.

### 6.5.1.3. Uncertainty Assessment and Time-Series Consistency

Uncertainty was estimated analytically using a Tier 1 approach. The uncertainties associated with estimates of CO<sub>2</sub> emissions and removals were assessed by taking account of the uncertainties surrounding the area of management changes (i.e. changes in tillage practices and annual/perennial crop mixtures), and the associated C factors (McConkey et al., 2007).

The uncertainty associated with the area of a given management practice in an ecodistrict was found to vary inversely with the relative proportion of that practice regarding the total area of agricultural land in that ecodistrict. The relative uncertainty associated with the area of a management practice (expressed as the standard deviation for an assumed normal population) decreased from 10% to 1.25% of the area as the relative area of that practice increased (McConkey et al., 2007).

The uncertainties associated with C change factors for tillage and annual/perennial crop mixtures were attributed to two main sources: (i) the process uncertainty inherent in C change due to inaccuracies in predicting C change even when the management practice is defined perfectly; and (ii) the situational uncertainty in C change due to variations in the location or timing of the management practice. Further details on estimating processes and situational uncertainties can be found in section A3.5.4.1. Uncertainty estimates associated with emissions/removals of CO<sub>2</sub> from mineral soils were developed by McConkey et al. (2007), who reported uncertainty values of  $\pm 19\%$  for the level and  $\pm 27\%$  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<sub>2</sub> estimates is ensured through the use of the same methodology for the entire time series of estimates.

### 6.5.1.4. QA/QC and Verification

Tier 1 QC checks implemented by AAFC specifically address estimate development in the Cropland Remaining Cropland subcategory. 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 the CRT Reporter software. In addition, activity data, methodologies, and changes have been documented and archived in paper and electronic form.

In February 2009, Canada convened an international team of scientists and experts from Denmark, France, Japan, Sweden, the Russian Federation, and the United States to conduct a QA assessment of its methods. Some limitations in the current system were found regarding activity data, which could possibly create some bias in the current C stock change estimates. In particular, the lack of a complete and consistent set of land-use data and issues with the concept and application of pseudo-rotations were cited.

Carbon change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). The comparison showed that empirical data on changes in SOC, in response to no-till seeding, were highly variable, particularly in Eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. Liang et al. (2020) compiled soil C stock change data under conventional, reduced and no-till practices on agricultural soils in Canada, and reported that climate, soil texture, and management duration are the main drivers of soil C change in no-till systems. The analysis suggested that estimates of tillage impacts could be improved through the addition of more recent and more comprehensive data. For the change from annual to perennial cropping, the mean empirical factor was 0.59 Mg C ha<sup>-1</sup> yr<sup>-1</sup>, which compares favourably with the range of 0.46–0.56 Mg C ha<sup>-1</sup> yr<sup>-1</sup> 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<sup>-1</sup> yr<sup>-1</sup> empirical versus 0.74–0.77 Mg C ha<sup>-1</sup> yr<sup>-1</sup> 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 can use measured crop yields as C inputs in simulations were tested in the national C assessment analysis. These models were also used for simulations of soil C storage with varying degrees of success against field observations (Thiagarajan et al., 2022). These models' estimates of national soil C change varied significantly. For comparability purposes among Developed countries, the IPCC Tier 2 Steady State approach is used for estimating the change in soil C storage as impacted by crop productivity and crop residue C input. The results of this approach were observed to be roughly equivalent to the mean of the other models.

As part of QA and continuous improvement efforts, methodologies for estimating soil C storage, as impacted by changes in crop productivity / crop residue C input and manure application on annual cropland soils, were reviewed by a panel of researchers and scientists from ECCC and AAFC (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.

#### 6.5.1.5. Recalculations

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

#### 6.5.1.6. Planned Improvements

An integrated modelling approach is planned to simulate the change in soil C storage as impacted by crop productivity, tillage practices and crop mixtures. The model parameters will be adapted to Canadian conditions through Bayesian optimization. Currently, multiple models are being assessed, including the IPCC Tier 2 Steady State approach. In addition, a complete formal analysis and calculation of uncertainty including that associated with tillage practices, annual/perennial crop mixtures, crop productivity and crop residue C input and manure application are also planned in the medium term, within three to five years.

More details are provided in Chapter 8, [Table 8–5](#).

#### 6.5.1.7. CO<sub>2</sub> Emissions from the Cultivation of Organic Soils

##### 6.5.1.7.1. Category Description

In Canada, the cultivation of organic soils is defined as the conversion of organic soils to annual crop production, normally accompanied by artificial drainage, cultivation and liming. Organic soils used for agricultural production in Canada include peaty-phase gleysols, fibrisols over 60-cm thick, and mesisols and humisols over 40-cm thick (Soil Classification Working Group, 1998).

##### 6.5.1.7.2. Methodological Issues

Emissions from the cultivation of organic soils were calculated by multiplying the total area of cultivated histosols by the default emission factor of 7.9 Mg C ha<sup>-1</sup> yr<sup>-1</sup> for cropland, and 5.7 Mg C ha<sup>-1</sup> yr<sup>-1</sup> for grassland (IPCC, 2014).

The COA does not provide information on the area of cultivated histosols, and area estimates were based on the expert opinion of soil and crop specialists across Canada (Liang et al., 2004). The estimated total area of cultivated organic soils in Canada (constant for the period 1990–2023) was 16 kha for annual crops and 30 kha for perennial crops. Nearly 90% of cultivated histosols are in the Boreal Shield East, Mixedwood Plains and Boreal Plains reporting zones.

##### 6.5.1.7.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties surrounding the area estimates for cultivated histosols and the emission factor. The uncertainty associated with the 95% confidence limit for the area estimate of cultivated histosols was assessed at ±50% (Hutchinson et al., 2007). The uncertainty associated with the 95% confidence limit for the default emission factor is estimated at ±90% (IPCC, 2014). The overall mean and uncertainties associated with this source of emissions were estimated to be 1.1 ± 0.3 Mt for the level uncertainty and 0 ± 0.13 Mt for the trend uncertainty (McConkey et al., 2007).

The same methodology and emission factors were used for the entire time series of emission estimates.

##### 6.5.1.7.4. QA/QC and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines. The activity data, methodologies, and changes to methodologies have been documented and archived in paper and electronic form.

The same methodology and emission factors were used for the entire time series of emission estimates.

##### 6.5.1.7.5. Recalculations

The inclusion of cultivated histosols for perennial crop production and revisions of the IPCC default emission factors for annual crop production in the 2013 Wetland Supplement (IPCC, 2014) from the 2006 IPCC Guidelines (IPCC, 2006) resulted in recalculations. These recalculations increased emissions by 860 kt in 1990, 2005 and 2022.

##### 6.5.1.7.6. Planned Improvements

No improvements are currently planned for this category.

## 6.5.1.8. CO<sub>2</sub> Emissions from and Removals by Woody Biomass

### 6.5.1.8.1. Category Description

Estimated emissions from and removals by woody biomass in this category include those by trees and shrubs growing on agricultural land as well as by perennial woody crops such as vineyards, fruit orchards and Christmas trees. A portion of the tree biomass lost in cropland is transferred to the HWP pool to meet residential bioenergy requirements. Therefore, this C transfer is now reported as emissions in the Cropland Remaining Cropland category and transferred to the Harvested Wood Products category. For more details, see section 6.4 and section A3.5.4.1. Accordingly, the net emissions remained unchanged.

Under the definitional framework adopted in Canada for LULUCF reporting, abandoned cropland is still included in the Cropland category until there is evidence of a new land use. However, there is little information on the dynamics of cropland abandonment or re-cultivation. Owing to these data limitations, only vineyards, fruit orchards, Christmas trees, and trees and shrubs are considered in changes in woody biomass and abandoned and re-cultivated cropland are not included in this category.

Net CO<sub>2</sub> fluxes from woody biomass on agricultural land reported in the Cropland Remaining Cropland category including the transfers amounted to net removals of 0.2 Mt in 1990, and net emissions of 0.5 Mt in 2005 and 0.6 Mt in 2023. 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 0.4 Mt of the total firewood emissions reported under the Harvested Wood Products category in 1990, 2005 and 2023, respectively.

### 6.5.1.8.2. Methodological Issues

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yield. Vineyards and fruit trees are pruned annually, and old plants are replaced on a rotating basis for disease prevention or stock improvement purposes or to introduce new varieties. For all three of these crops, it is assumed that, because of rotational practices and sustained yield requirements, a uniform age-class distribution is generally found. Hence, there would be no net increase or decrease in biomass C in existing operations, since losses of C from harvest or replacement would be balanced by gains from new plant growth. Therefore, the approach used was limited to detecting changes in the areas occupied by vineyards, fruit orchards, and Christmas tree plantations and estimating the corresponding C stock changes in total biomass. More information on the assumptions and parameters involved can be found in section A3.5.4.1.

Woody biomass in the Cropland category also includes perennial trees and shrubs in farmyards, shelterbelts and hedgerows. The method employed tracks the woody volume lost as a result of clearing and gained as a result of planting and annual growth using earth observation-based monitoring and ecozone-specific growth parameters. More information on the assumptions and parameters involved can be found in section A3.5.4.1.

### 6.5.1.8.3. Uncertainty Assessment and Time-Series Consistency

When the loss of an area occupied by perennial woody crops occurs, all the C in the woody biomass is assumed to be immediately released. In addition, it is assumed that the uncertainty associated with the C losses equals the uncertainty associated with the mass of woody biomass C. The default uncertainty of  $\pm 75\%$  (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 fruit trees, vineyards or Christmas trees, the uncertainty associated with the annual C change was also assumed to be the default uncertainty of  $\pm 75\%$  (i.e. 95% confidence limits) (IPCC, 2006).

The overall means and uncertainties associated with emissions or removals of CO<sub>2</sub> from vineyards, fruit orchards and Christmas trees were estimated to be  $2 \pm 0.2$  kt for the level uncertainty and  $-29 \pm 42$  kt for the trend uncertainty (McConkey et al., 2007). The overall mean and uncertainty associated with removals of CO<sub>2</sub> from trees and shrubs is described in Huffman et al. (2015a) and is estimated to be  $-440 \pm 180$  kt for the annual estimate. Since removals resulting from the growth of trees and shrubs represent the biggest contribution to the overall removal/emission estimates, these two land cover types drive the uncertainty in the woody biomass subcategory, which is estimated to average 41% for the level uncertainty. More information on the method and factors considered in determining the uncertainty associated with C stock changes in trees and shrubs can be found in Huffman et al. (2015a).

The same methodology was used for the entire time series of emission estimates.

#### 6.5.1.8.4. QA/QC and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies have been documented and archived in paper and electronic form.

#### 6.5.1.8.5. Recalculations

Recalculations occurred due to transfers of carbon to the HWP pools reported in the source Land (Cropland Remaining Cropland) category and therefore this resulted in upwards recalculations to all the carbon in wood transferred to the HWP pools (see sections 6.3.1.5 and 6.9.5 for more details). These changes cause an upwards adjustment of emissions of 0.8 Mt in 1990, 0.5 Mt in 2005 and 0.4 in 2022.

#### 6.5.1.8.6. 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 (CRT Category 4.B.2)

This category includes the conversion of forest land and agricultural grassland to cropland. More than 99% of the total annual emissions estimated and reported in this category are in the Forest Land Converted to Cropland subcategory, with total annual emissions decreasing from 9.7 Mt in 1990 to 3.6 Mt in 2023. Emissions in the Grassland Converted to Cropland subcategory are relatively small.

#### 6.5.2.1. Forest Land Converted to Cropland (CRT Category 4.B.2.1)

##### 6.5.2.1.1. Category Description

The clearing of forest land for use as agricultural land is still an ongoing practice in Canada, accounting for 46% of forest area conversion in 2023. The cumulative area reported under the Forest Land Converted to Cropland subcategory in CRT Table 4.B amounted to 1300 kha during the 20 years prior to 1990 and 381 kha during the 20 years prior to 2023. 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 2023, immediate emissions from the conversion of forest to cropland totalled 1.5 Mt, while residual emissions from events that occurred in the last 20 years totalled 1.8 Mt.

##### 6.5.2.1.2. Methodological Issues

#### Dead Organic Matter and Biomass Pools

Approximately 90% of emissions originate from the biomass and DOM pools during and after conversion, with the remainder attributed to the soil pool. The same modelling environment is used for estimating these emissions as for the Forest Land Remaining Forest Land subcategory. A general description of this modelling environment is provided in section 6.3.1.2. For more information, see section A3.5.4.3.

#### Soils

Emissions from soils in this category include net C stock changes resulting from the actual conversion, a very small net source of CO<sub>2</sub> due to the change in management practices in the 20 years following conversion, and the N<sub>2</sub>O emissions from the decay of soil organic matter. Emissions/removals reported in the Forest Land Converted to Cropland subcategory also include those resulting from changes in land management practices, crop production, and manure application on this land. Soil emissions were calculated by multiplying the total area of conversion by the empirically derived emission factor which incorporates modelling-based SOC dynamics (see section A3.5.4.3). The pattern of SOC changes that occur after the conversion of forest land to cropland clearly differs in Eastern and Western Canada.

#### Eastern Canada

All agricultural land in the eastern part of the country was forested before its conversion to agriculture. Many comparisons of forest SOC with SOC in adjacent agricultural land in Eastern Canada—either in the scientific literature or the Canadian Soil Information System—show a mean C loss of 20% at depths to approximately 20–40 cm (see section A3.5.4.3). The average N change was -5.2%, equivalent to a loss of approximately 0.4 Mg N ha<sup>-1</sup>. For those comparisons in which both N and C losses were determined, the corresponding C loss was 19.9 Mg C ha<sup>-1</sup>. Therefore, it was assumed that N loss was a constant 2% of C loss.

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics involved in the conversion of forest land to cropland in Eastern Canada. More details on the methodologies used to determine the maximal C loss and associated rate constant involved in the conversion of forest land can be found in section A3.5.4.3. A Tier 2 methodology is used to estimate the removals from cropland biomass C stocks using historical data of crop yields, harvest index and root-shoot ratio in croplands. More details on the methodologies are available in section A3.5.4.2. As in the case of direct N<sub>2</sub>O emissions from agricultural soils (see Agriculture sector, [Chapter 5](#)), an IPCC Tier 2 method is used to estimate N<sub>2</sub>O emissions from the conversion of forest land to cropland, by multiplying the amount of C loss by the fraction of N loss per unit of C and by an emission factor (EF\_Base). EF\_Base was determined for each ecodistrict based on topographic and climate conditions (see Annex 3.4).

Western Canada

Much of the current agricultural land in Western Canada (the Prairies, as well as the Peace River region of British Columbia) was formerly native grassland. Therefore, in the West, forest land that has been converted to cropland consists primarily of forests on the fringe of former grassland areas.

The Canadian Soil Information System represents the best available source of SOC data for agricultural areas and areas managed for forest harvesting. On average, these data suggest that no loss of SOC occurs from forest conversion and that, in the long term, the balance between C input and SOC mineralization under agriculture remains similar to what it was under forest. It is important to recognize that, along the northern fringe of western Canadian agricultural lands, where most forest conversion occurs, the land is marginal for arable agriculture, and pasture and forage crops are the dominant management practices. As a result, in this region, the conversion of forest land to cropland managed exclusively for seeded pastures and hayfields was assumed to result in no long-term losses of SOC.

The C loss from forest conversion in Western Canada results from the loss of above- and below-ground tree biomass and the loss or decay of other above- and below-ground coarse woody DOM present at the time of forest conversion. The C gains occur in croplands after the conversion of forest to croplands from biomass using a Tier 2 methodology (see Annex 3, section 3.5.4). The average N change in Western Canada for sites at least 50 years after the breaking of the land for cultivation was +52% (see Annex 3.5), reflecting the substantial added N in agricultural systems compared with managed forests. However, when the uncertainty associated with the actual C-N dynamics of forest conversion is recognized, the conversion of forest land to cropland in Western Canada can be assumed not to be a source of N<sub>2</sub>O.

6.5.2.1.3. Uncertainty Assessment and Time-Series Consistency

Greenhouse gas fluxes in the Forest Land Converted to Cropland subcategory result from a combination of (i) logging and burning, producing immediate emissions from biomass and DOM; (ii) organic matter decay and subsequent CO<sub>2</sub> emissions in the DOM pool; and (iii) net C losses from SOC. Immediate CO<sub>2</sub> 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<sub>2</sub> emissions are produced exclusively by burning and occur during the conversion process.

Immediate and residual CO<sub>2</sub> emissions from the biomass and DOM pools represent the largest components in this category and contribute the most to the category uncertainty ([Table 6–10](#)). In all cases, uncertainty values are presented as the 95% confidence interval around the median (biomass and DOM pools) or mean (soil pool) value of the estimates.

Uncertainty estimates were derived independently for the biomass and DOM pools and soil organic matter using this estimation approach. The uncertainty associated with the activity data (see section [6.9.3](#) for more details) was incorporated in all analyses.

Table 6–10 Uncertainty Associated with the Components of CO <sub>2</sub> and Non-CO <sub>2</sub> Emissions from Forest Land Converted to Cropland for the 2023 Inventory Year		
Emission Components	Emissions (kt CO <sub>2</sub> eq)	Uncertainty (kt CO <sub>2</sub> eq)
Immediate CO <sub>2</sub> emissions	3 318	±972
Residual CO <sub>2</sub> emissions from the DOM pool <sup>a</sup>	1 790	±431
Residual CO <sub>2</sub> emissions from the soil pool	257	±159
CH <sub>4</sub> emissions	147	±69
N <sub>2</sub> O emissions	63	±20
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 used in the Forest Land category. Consequently, the corresponding uncertainty estimates were also developed under this framework, using the same Monte Carlo runs used to generate uncertainty estimates for the Forest Land category. For a description of the general approach, see section 6.3.1.3. More information can be found in section A3.5.4.3.

The uncertainty associated with the net CO<sub>2</sub> flux from the soil pool was estimated analytically (McConkey et al., 2007); for more information on the general approach used in this analysis, see section A3.5.4.3.

#### 6.5.2.1.4. QA/QC and Verification

This category underwent Tier 1 QC checks (see section 1.3, Chapter 1) in accordance with the 2006 IPCC Guidelines. AAFC, which derived the estimates of SOC changes, also performed external quality checks. The activity data, methodologies, and changes to methodologies have been documented and archived in paper and electronic form.

#### 6.5.2.1.5. Recalculations

Recalculations occurred due to transfers of carbon to the HWP. Carbon transfers to the HWP pool are now reported in the source land category which results in an apparent upward recalculation equivalent to the carbon transfer out of the source land ecosystem (see sections 6.3.1.5 and 6.9.5 for more details). The woody biomass transferred from croplands are now reported as gains in HWP (see section 6.5.1.3). Additionally, when deforestation occurs, the biomass C stocks gained in cropland after deforestation is reported in croplands. These changes cause an apparent upward adjustment of emissions of 4.9 Mt in 1990, 2.0 Mt in 2005 and of 2.4 Mt in 2022.

#### 6.5.2.1.6. Planned Improvements

The planned improvements described in section 6.9 will also affect this category. The modelled soil C change factors will be validated against a meta-analysis of published soil C change factors for forest land conversion to cropland. More details are provided in Chapter 8, Table 8–5.

### 6.5.2.2. Grassland Converted to Cropland (CRT Category 4.B.2.2)

#### 6.5.2.2.1. Category Description

The conversion of native grassland to cropland occurs in the Canadian Prairies and generally results in losses of SOC and soil organic N, and emissions of CO<sub>2</sub> and N<sub>2</sub>O to the atmosphere.

#### 6.5.2.2.2. Methodological Issues

Several studies on changes in SOC and soil organic N in grassland converted to cropland have been carried out in the Brown, Dark Brown and Black soil zones of the Canadian Prairies. The average SOC loss was 22%, and the corresponding average change in soil organic N was 0.06 kg N lost per kg C (see section A3.5.4.2).

Emissions from C stocks in biomass of grasslands are estimated using a Tier 1 methodology following the IPCC (2006) guidelines. A Tier 2 methodology is used to estimate the removals from cropland biomass C stocks using historical data of crop yields, harvest index and root-shoot ratio in croplands. More details on the methodologies are available in section A3.5.4.2. Emissions/removals reported in the Grassland Converted to Cropland subcategory include residual emissions from the loss of SOC due to the land-use change and are affected by changes in land management practices. The CENTURY model (Version 4.0) is used to estimate SOC dynamics in the conversion of grassland to cropland on Brown and Dark Brown Chernozemic soils. More details on the methodologies used to determine the maximal C loss and rate constant associated with the breaking of grassland can be found in section A3.5.4.2.

Emissions of N<sub>2</sub>O 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 section A3.4.3).

#### 6.5.2.2.3. Uncertainty Assessment and Time-Series Consistency

Although the conversion from agricultural grassland to cropland can and does take place, the opposite—the conversion from cropland to grassland—does not occur due to the definitional framework used for managed lands (see section 6.2). Therefore, the uncertainty surrounding the absolute value of the area of this conversion cannot be greater than the uncertainty surrounding the area of cropland or grassland. Consequently, the uncertainty associated with the area of conversion was considered equivalent to that associated with the area of either cropland or grassland in each ecodistrict, whichever is lower. The uncertainty associated with the SOC change was estimated in the same way as in the Forest Land

Converted to Cropland subcategory. The overall mean and uncertainty associated with emissions due to SOC losses in the Grassland Converted to Cropland subcategory were estimated to be  $27 \pm 13$  kt for the level uncertainty and  $-260 \pm 120$  kt for the trend uncertainty.

The same methodology and emission factors were used for the entire time series of emission estimates.

#### 6.5.2.2.4. QA/QC and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) following the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies have been documented and archived in paper and electronic form.

#### 6.5.2.2.5. Recalculations

Recalculations occurred due to the inclusion of biomass losses and gains from grassland to cropland for the whole time series. These modifications resulted in an upward recalculation of 0.92 kt in 1990, and a downward recalculation of 0.4 kt and 0.3 kt in 2005 and 2022, respectively.

#### 6.5.2.2.6. Planned Improvements

Canada plans to validate the modelled soil C change factors with measured and published soil C change factors for grassland conversion as these become available. More details are provided in Chapter 8, [Table 8–5](#).

### 6.6. Grassland (CRT Category 4.C)

Grassland used for agriculture is defined under the Canadian LULUCF framework as pasture or rangeland on which the only agricultural land management activity is the grazing of domestic livestock. It occurs only in geographical areas where the grassland would not naturally transition to forest if abandoned—the natural shortgrass prairie region in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. Agricultural grassland is found in three reporting zones: Semi-arid Prairies (7.0 Mha), Montane Cordillera (0.2 Mha) and Pacific Maritime (0.3 kha). As with the Cropland category, the change in management triggers a change in soil C stocks (IPCC, 2006). Very little information is available on management practices for Canadian agricultural grassland, and it is unknown whether the soil quality of grazed land is improving or degrading. Therefore, Canada reports emissions in the Grassland Remaining Grassland subcategory using an IPCC Tier 1 method, assuming that no changes in management practices have occurred since 1990. Under the current definitional framework, which is explained in section [6.2](#), the conversion of land to grassland in the Land Converted to Grassland subcategory is reported as “not occurring” ([Table 6–4](#)).

#### 6.6.1. Grassland Remaining Grassland (CRT Category 4.C.1)

##### 6.6.1.1. Category Description

In Canada, fires sometimes occur on managed grasslands in the form of prescribed burns to control invasive plants and stimulate the growth of native species, or are caused by lightning, accidental ignition, or military training exercises. The burning of managed grasslands is a net source of CH<sub>4</sub>, CO, NO<sub>x</sub> and N<sub>2</sub>O emissions (IPCC, 2006).

Emissions associated with the burning of managed grassland are reported in CRT Table 4(V), they have remained relatively small and stable at around 1 kt per year over the reported period.

##### 6.6.1.2. Methodological Issues

Emissions of CH<sub>4</sub> and N<sub>2</sub>O from the burning of managed agricultural grassland were estimated using an IPCC Tier 1 method, considering the area burned, fuel load and combustion efficiency for each burning event. Emission factors (2.7 g CH<sub>4</sub> kg<sup>-1</sup> dry matter burned, and 0.07 g N<sub>2</sub>O kg<sup>-1</sup> dry matter burned) were taken from the 2006 IPCC Guidelines (IPCC, 2006).

Activity data from 1990 to 2012 on the area, fuel load and combustion efficiency of each burning event on managed agricultural grassland were collected through consultations (Bailey and Liang, 2013). The activity data on the burning of managed agricultural grassland from 2013 to 2015 were updated in the 2018 submission.

### 6.6.1.3. Uncertainty Assessment and Time-Series Consistency

The uncertainties associated with emissions from this source are due to the uncertainties surrounding the area estimates, average fuel loads per hectare and combustion efficiency, along with the emission factors. The uncertainty associated with the 95% confidence intervals for burned materials is estimated at  $\pm 50\%$ , based on expert judgment. The uncertainty associated with the 95% confidence intervals for the default emission factors is  $\pm 40\%$  for  $\text{CH}_4$  and  $\pm 48\%$  for  $\text{N}_2\text{O}$  (IPCC, 2006). The overall uncertainties estimated for this source of emissions using error propagation were  $\pm 64\%$  for  $\text{CH}_4$  and  $\pm 69\%$  for  $\text{N}_2\text{O}$ , respectively.

The same methodology and emission factors were used for the entire time series of emission estimates.

### 6.6.1.4. QA/QC and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) following the 2006 IPCC Guidelines. The activity data and methodologies have been documented and archived in paper and electronic form.

### 6.6.1.5. Recalculations

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

### 6.6.1.6. Planned Improvements

No improvements are currently planned for this category.

## 6.7. Wetlands (CRT Category 4.D)

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 this report and following the land categories defined in the 2006 IPCC Guidelines (IPCC, 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.

Following 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.

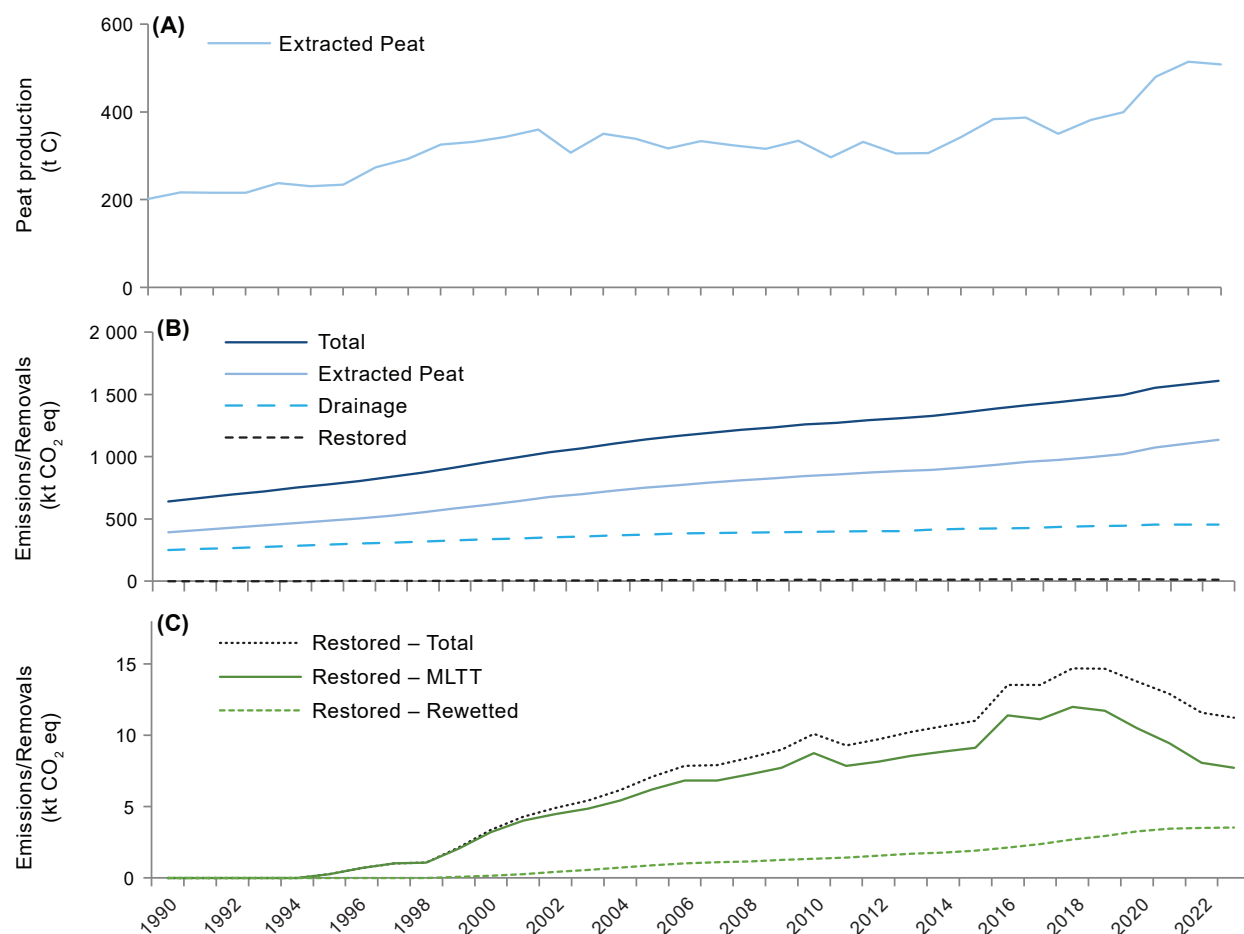
### 6.7.1. Peat Extraction (CRT Categories 4.D.1.1 and 4.D.2.1)

#### 6.7.1.1. Category Description

Approximately 38 kha of the estimated 114 Mha of peatlands in Canada (NRCan, 2011) have been drained for peat extraction. Roughly 21 kha of these are currently being actively managed, while 6 kha are currently unrestored, and 11 kha have undergone active restoration or have regenerated naturally. 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.

The annual amount of peat extracted from peatlands and transported off-site increased from 200 t C in 1990 to 510 t C in 2023 (see Figure 6–8A). Emissions from peat extraction increased from 0.6 Mt in 1990 to 1.6 Mt in 2023 (Figure 6–8B). The largest sources of emissions are peatland drainage and the decay of extracted off-site peat. Peat extraction trends were influenced by the expansion of active peat production areas, from 13 kha in 1990, to 18 kha in 2005 and 21 kha in 2023 with interannual weather variations impacting peat drying and harvesting. Restoration and reclamation efforts began in 1990 and reduced the impacted areas by 2.4 kha in 2005 to 8.4 kha in 2023. Emissions from peatland drainage continue to grow as more peatland areas are drained and subsequently decommissioned, with an increasing proportion of these sites undergoing restoration. Restored peatlands continue to act as a source, though net emissions have declined in recent years.

Figure 6–8 **Peat Extraction Production and Emissions/Removals from Land-use Conversion, Extracted Peat and Restoration**



### 6.7.1.2. Methodological Issues

Estimates were developed using a Tier 2 methodology, following 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 restored sites include on-site CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions and off-site CO<sub>2</sub> emissions from waterborne C losses and from the decay of extracted peat. Domestic emission factors were derived from flux measurements reported in multiple research studies (see section A3.5.6.1, Table A6.5-7). An earth-observation-based mapping approach was used to determine the extent of peatland areas converted for peat extraction in the 1990, 2007, 2013 and 2022 time periods and to identify the proportion of land-use types converted (forest land and other land). Converted areas were assigned to five land management subcategories: active extraction areas, unrestored areas, naturally regenerated areas, rewetted and actively restored areas using the Moss Layer Transfer Technique (MLTT; Rochefort et al., 2003). National peat production statistics (NRCan, 2024) were used to estimate the annual amount of peat extracted and shipped (see Figure 6–8A). The extent of peat extraction areas is reported in CRT 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 CRT Table 4(II) under the Peat Extraction Lands category. More information on the estimation methodology can be found in section A3.5.6.1.

### 6.7.1.3. Uncertainty Assessment 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., rewetted and restored) and variations in the moisture content of extracted peat.

### 6.7.1.4. QA/QC and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures implemented in Canada's GHG inventory, which also apply to this category. 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 activity data as well as an updated peat extraction emission model that incorporates new domestic emission factors from a compilation of Canadian research studies. See section A3.5.6.1 for details on method changes.

Activity data year was updated for a new 2022 year using aerial photography, satellite imagery, and ancillary data, and previous years from 1990, 2007, and 2013 were updated as well using geospatial data and expert information to update and classify restored and rewetted areas. These areas were refined using secondary sources, including industry statistics and surveys. Historical peat production statistics were used to determine pre-1990 data. These updates led to minor recalculations of total disturbed areas; however, they decreased active and unrestored areas by 2.3 kha in 2005 and 7.4 kha in 2022, and increased the reported restoration activity data by 0.4 kha in 2005 and 3.3 kha in 2022 as more areas were restored.

The most substantial change to the peat extraction emission model was a change from a Tier 1 approach, which assumed instant oxidation of off-site extracted peat products, to a Tier 2 model where emissions are released over time using an exponential decay model assuming an annual rate of decay of 5% obtained from the literature (Cleary et al., 2005, Hayne et al., 2014, Sharma et al., 2024). This change resulted in a downward revision of estimated total cumulative emission from peat products from 38 Mt CO<sub>2</sub> eq to 24 Mt CO<sub>2</sub> eq (-64%) within the reporting time period, where emissions from newly extracted peat are delayed as carbon is released over time. Additional changes to the peat extraction emission model were due to a greater availability of research on post-extraction restoration, such that different restoration techniques were disaggregated by accounting for rewetting and active MLTT restoration separately. Disaggregating emissions from different restoration strategies allows for more accurate temporal representation of emission and removal estimates, for example MLTT sites are a source of carbon for 12 years before flipping to a sink whereas rewetted sites are consistent sinks but emit higher rates of methane (see details in A3.5.6.1). The recalculation due to the separation of emission estimates for rewetting and MLTT restoration resulted in a small downward recalculation of 3 kt in 2005 and 10 kt in 2022 and result in an overall downward recalculation of 130 kt across the time series. The improvement in methodology allows Canada to better track the overall impact of restoration efforts over time, demonstrating that removals are beginning to outweigh emissions in restored areas in 2019 as seen in [Figure 6–8C](#).

These improvements resulted in a downward recalculation of emissions by 0.3 Mt CO<sub>2</sub> eq (32%) in 1990 and 0.4 Mt CO<sub>2</sub> eq (28%) in 2005, and 0.7 Mt CO<sub>2</sub> eq (31%) in 2022. The cumulative result of these methodological improvements resulted in a mean overall change of 13 Mt (26%) reductions in estimated emission from peat extraction.

### 6.7.1.6. Planned Improvements

Updates to activity data is planned as more newly active areas are converted as well as older abandon and active sites are restored or rehabilitated.

Eventually, improvements could be made by implementing a vegetation outcome method to better refine peatland recovery post extraction. This improvement is contingent upon the availability of monitoring data, which is critical for assessing the condition of naturally regenerating sites and evaluating the success rates of rewetting and restoration activities.

An uncertainty assessment is planned for future submissions.

More details are provided in Chapter 8, [Table 8–5](#).

## 6.7.2. Flooded Land (CRT Categories 4.D.1.2 and 4.D.2.2)

### 6.7.2.1. 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 2023, 46% of the 45 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 1.0 Mt in 2023.

### 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 section A3.5.2.10). Emissions from the burning of non-flooded DOM are reported in CRT Table 4(V) in the Land Converted to Wetlands subcategory. Emissions from the decay of the remaining on-site residues are reported in CRT 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 Toulouste, 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<sub>2</sub> 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 the decomposition of most submerged vegetation, when present, eventually no longer acts as a net source of CO<sub>2</sub> to the atmosphere. A country-specific approach was developed and used to estimate emissions from reservoirs based on measurements of CO<sub>2</sub> fluxes above reservoir surfaces from multiple research studies (see section A3.5.6.2), 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). Section A3.5.6.2 of this NIR contains more detail on this estimation methodology. The assessment includes CO<sub>2</sub> emissions only. Emissions from the surface of flooded lands are reported in CRT 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<sub>2</sub> emissions are calculated for hydroelectric reservoirs that were completely flooded between 1981 and 2023.

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 CRT 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. Uncertainty Assessment and Time-Series Consistency

For the Forest Land Converted to Flooded Land subcategory, see section 6.9, Forest Conversion. Section A3.5.6.2 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. QA/QC and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures implemented in Canada's GHG inventory, which also apply to this category. For the Forest Land Converted to Flooded Land subcategory, refer to the corresponding subheading in section 6.9, Forest Conversion.

Canada's approach to estimating emissions from forest flooding better reflects the land flooding processes over time than the default approach (IPCC, 2006), which assumes that all biomass C in flooded forests is immediately emitted. Canada's method is more refined in that it distinguishes forest clearing from flooding—emissions from the former are estimated in the same way as for all forest clearing activities associated with land-use changes. In addition, in Canada's approach, emissions from the surface of reservoirs are derived from measurements, rather than from an assumption (the immediate decay of all submerged biomass), which has not been verified.

#### 6.7.2.5. Recalculations

Recalculations occurred due to changes in the reporting of HWP. Carbon transfers to the HWP pool are now reported in the source land category which results in an apparent upward recalculation equivalent to the carbon transfer out of the source land ecosystem (see sections 6.3.1.5 and 6.9.5 for more details). This change caused an apparent upward adjustment of emissions of 11 kt in 1990, 22 kt in 2005, and no recalculations in 2022.

#### 6.7.2.6. Planned Improvements

Further refinements to estimate CO<sub>2</sub> 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 be ongoing.

Continuous improvements will focus on the development of knowledge, updated activity data, parameters, and emission factors to estimate CH<sub>4</sub> emissions from flooded lands.

More details are provided in Chapter 8, [Table 8–5](#).

### 6.8. Settlements (CRT 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 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 2023, the 0.59 Mha of land in the Land Converted to Settlements subcategory accounted for emissions of 9.2 Mt while the growth of urban trees removed 4.1 Mt.

#### 6.8.1. Settlements Remaining Settlements (CRT Category 4.E.1)

##### 6.8.1.1. Category Description

This category includes estimates of C sequestration by urban trees in Canada. Estimates of CO<sub>2</sub> 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 4.1 Mt, on average. Estimates are reported for nine of the southernmost reporting zones, where major urban centres are situated. The largest removals in 2023 were in the Mixedwood Plains (1.4 Mt) and Pacific Maritime (1.4 Mt) reporting zones, which together accounted for 70% of total removals.

Firewood attributed to urban tree biomass, transferred to the HWP pool, and used for residential bioenergy accounted for 0.3 Mt per year of the total firewood emissions reported under the Harvested Wood Products category.

### 6.8.1.2. Methodological Issues

Removals of CO<sub>2</sub> by urban trees were estimated using a Tier 2A crown cover area method from the 2006 IPCC Guidelines (IPCC, 2006). Urban tree crown (UTC) cover estimates for 1990 and 2012 were developed for a significant portion of the total urban area using a point-based sampling approach. Sample points were interpreted manually, from digital aerial photos or high-resolution satellite imagery, and classified in two broad categories: tree crown or non-tree crown. The total crown cover area was then estimated using the UTC and total urban area estimates for each time period. The estimated total crown cover area was then multiplied by a crown cover area-based growth rate (CRW, as defined in Chapter 8, Volume 4 of IPCC 2006) specific to each RU to yield an annual gross sequestration rate; net sequestration was estimated by applying a factor to the gross value. The values of C storage and sequestration in urban trees for 18 RUs (see Table A6.5–8) were derived as described in Steenberg et al. (2023). Growth and sequestration rates were applied to the 18 RUs confirming that estimates of UTC cover area and the sequestration rate are the main drivers of overall removal estimates. A more detailed description of this estimation methodology can be found in section A3.5.7.1.

### 6.8.1.3. Uncertainty Assessment 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<sub>2</sub> sequestration of urban trees is 38% for 1990 and 2012. Section A3.5.7.1 provides more information.

The same methodology and coefficients were used for the entire time series of emission estimates.

### 6.8.1.4. QA/QC and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures implemented in Canada's GHG inventory, which also apply to this category.

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 based on urban area, were within 2%.

### 6.8.1.5. Recalculations

Recalculations occurred due to changes in the reporting of HWP. Carbon transfers to the HWP pool are now reported in the source land category which results an apparent upward recalculation equivalent to the carbon transfer out of the source land ecosystem (see sections 6.3.1.5 and 6.9.5 for more details). These changes cause an apparent upward adjustment of emissions of 0.3 Mt in 1990, 2005 and 2022.

### 6.8.1.6. Planned Improvements

Further work will be done to update the methodology, activity data estimates, and the coefficients used to estimate gross and net removals. Updates 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 are planned around the 2005, 2015 and 2020 activity data.

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

## 6.8.2. Land Converted to Settlements (CRT Category 4.E.2)

In 2023, emissions in the Land Converted to Settlements subcategory totalled 9.2 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 1990–2023 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 section 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 (CRT Category 4.E.2.2)

#### 6.8.2.1.1. Category Description

Urban and industrial expansion for resource extraction purposes has been the main driver of the conversion of cropland to settlements in Canada. On average, 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. (2015b) using the methods described in section A3.5.7.2. Annual conversion rates were estimated by calculating the total areas of land converted between these three years and dividing them by the time range, assuming a constant conversion rate from year to year. Annual conversion rates were extrapolated using a constant conversion rate after 2010.

#### 6.8.2.1.3. Uncertainty Assessment and Time-Series Consistency

The uncertainty surrounding the area of land-use changes was quantified using 457 points in five main census metropolitan areas (CMAs) (i.e., Toronto, Hamilton, Oshawa, Montreal and Edmonton), which account for over 45% of the total conversion area. The overall accuracy in detecting areas of true change was above 80% and concurs with the values found by Huffman et al. (2015b) on the accuracy of each individual land-use map.

#### 6.8.2.1.4. QA/QC and Verification

Polygons from the 2011 census were used to define the boundary of each CMA, and Landsat imagery from the Global Land Survey data (provided with ArcGIS Online) was obtained for each area for 1990, 2000 and 2010.<sup>16</sup> Over 200 points were used to verify land cover / land-use change for each time period, using visual interpretation. The points were defined using stratified random sampling, with 50% of points in areas with a change from cropland to settlements and 50% in areas with no changes, separated by a minimum distance of 1 km, to avoid statistical bias.

#### 6.8.2.1.5. Recalculations

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

#### 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](#).

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

## 6.8.2.2. Grassland Converted to Settlements (CRT Category 4.E.2.3)

### 6.8.2.2.1. Category Description

Resource development is the dominant driver of land-use change in Canada's Arctic and subarctic regions. In 2023, the conversion of grassland to settlements in the Canadian North accounted for emissions of 140 kt, up from 125 kt in 1990. The major source of emissions in this category over the time series is the conversion of grassland to settlements in the Taiga Shield East, Taiga Plains and Boreal Cordillera zones (reporting zones 4, 13 and 16).

### 6.8.2.2.2. Methodological Issues

An accurate estimation of direct human impacts in Northern Canada requires that activities be geographically located and that the vegetation present prior to conversion is known—a significant challenge, considering that the area of interest extends over 560 Mha and intersects with 11 reporting zones (1, 2, 3, 4, 5, 8, 10, 13, 16, 17 and 18) (see [Figure 6–1](#)). Land-use change areas were estimated using mapping derived from image interpretation for the years 1990, 2000, 2010, and 2020, as described in section A3.5.7.3.

Biomass carbon stocks were obtained from an expert consultation held in 2020-21 and are based on primary literatures including field sampling and remote sensing, as well as expert understanding of the relationship between climate and plant productivity in northern environments, as described in A3.5.7.3. Emission estimates are limited to C stock changes in pre-conversion aboveground biomass and belowground biomass.

Due to the complex interactions between development practices and permafrost, it is not currently possible to accurately quantify emissions from soil disturbance in this region. Expert consultations (Lapointe, 2021) determined that additional research was required to provide measurements of emissions and removals associated with the diverse practices that occur when development occurs in Canada's north that can then inform methodological development.

### 6.8.2.2.3. Uncertainty Assessment and Time-Series Consistency

An error propagation approach described in section A3.5.7.3 was used to estimate uncertainty for this category. The uncertainty estimate for this category ranges between 15% to 66% for the different reporting zones, due to the variability of vegetation over this vast area and the allocation of widths assigned to human disturbances mapped as linear features in the activity data.

### 6.8.2.2.4. QA/QC and Verification

Section [1.3](#) 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

Recalculations in this category were the result of updated activity data, refined aboveground biomass factors, and the new inclusion of belowground biomass emission estimates. These changes resulted in upward recalculations to emissions of +77 kt for 1990, +54 kt for 2005, and +123 kt for 2022.

### 6.8.2.2.6. Planned Improvements

Future efforts to improve estimates in this category will focus on compiling Canadian science to estimate emissions from the soil pool, as well as improving estimates for biomass where regrowth might occur following the initial disturbance.

More details are provided in Chapter 8, [Table 8–5](#).

## 6.9. Forest Conversion

### 6.9.1. Category Description

Forest conversion is not a reporting category, since it overlaps with the Cropland Remaining Cropland, Land Converted to Cropland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Land Converted to Settlements and Harvested Wood Products categories. This section will briefly discuss the methodological issues specific to this type of land-use change and outline the general approach taken in estimating its extent, location and impact. A consistent approach was used for all types of forest conversion, minimizing omissions and overlaps, while maintaining spatial consistency as much as possible.

In 2023, 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 17 Mt, down from 25 Mt in 1990. This decline includes a 7.6-Mt decrease in immediate and residual emissions from forest conversion to cropland and a 2.2-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) that are reported under the “land remaining” categories (e.g., Cropland Remaining Cropland and Wetlands Remaining Wetlands categories). Additionally there are Carbon transfers associated with HWP originating from forest conversion activities since 1990. Total transfers are reported in the source category and the change in carbon storage as HWP are reported in the HWP category as a net storage of CO<sub>2</sub> in CRT Table 4.G. These transfers amounted to net increases in the carbon stored in HWP of -0.8 Mt in 2023, down from -4.0 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 2023) from the total area of forest land converted to other land uses, as reported in the CRT tables for each inventory year. The values in the CRT tables encompass all forest land conversion for 20 years, including the current inventory year (10 years for reservoirs), 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 2023, immediate emissions (7.0 Mt) represented 41% 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), after which they are reported as part of the C stock changes in the Cropland Remaining Cropland and Wetlands Remaining Wetlands categories.

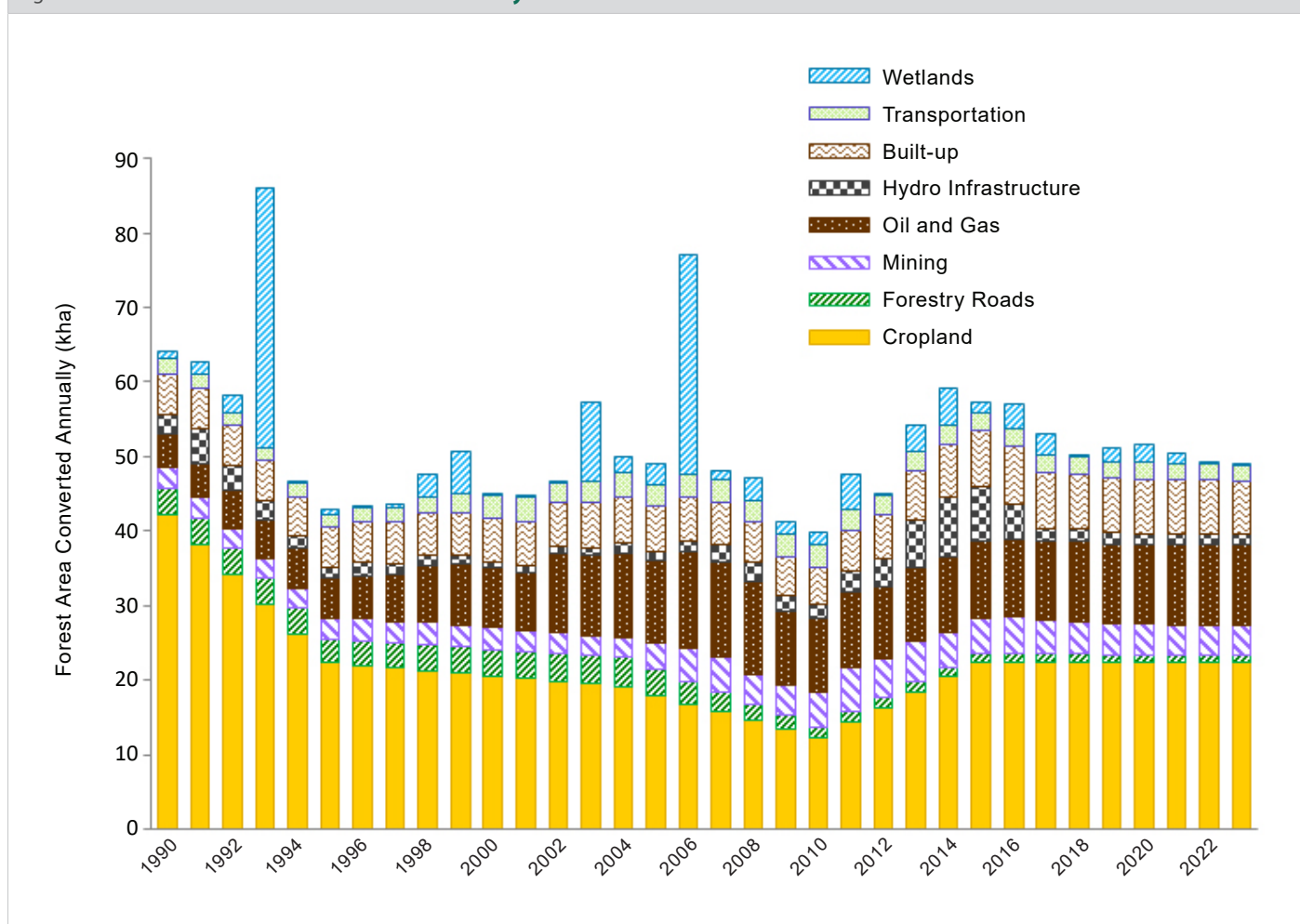
The primary drivers of forest conversion are agricultural expansion and resource extraction, accounting for 42% and 30%, respectively, of the cumulative area of forest conversion since 1990. Annual rates of forest conversion to cropland show a steady decrease over the 1990–2010 period. Since 2010, however, 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 6–9). 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 26 kha in 2023 (Figure 6–9). Since 2000, the conversion of land to settlements has become the main driver of forest conversion, accounting on average for 56% of the total area converted annually, except for the years 2003, 2006, and 2014 when large areas of forest were cleared for major hydroelectric development projects (Figure 6–9). 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 24% of the total forest area lost nationally in 2023.

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 6–9). 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 6–9 Annual Area of Forest Converted by End Land Use



### 6.9.2. Methodological Issues

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

The approach adopted for estimating forest areas converted to other uses is based on three main information sources: (i) systematic or representative sampling of remote sensing imagery; (ii) records; and (iii) expert judgment (Dyk et al., 2011, 2015). The core method involves mapping forest conversion by sampling remotely sensed Landsat images from circa 1975, 1990, 2000, 2008, 2013 and 2018, defining time periods as 1975–1990, 1990–2000, 2000–2008, 2008–2013, and 2013–2018. For implementation purposes, all permanent forest removal wider than 20 m from tree base to tree base and at least 1 ha in area was considered forest conversion. This convention was adopted as a guide to consistently label linear patterns in the landscape. The other main information sources consisted of databases or other documentation on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs. When the remote sensing sample was insufficient, expert opinion was called upon to resolve differences between records and remote sensing information and apparent discrepancies in area estimates. A more detailed description of the approach and data sources used is provided in section A3.5.2.10.

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 section A3.5.6). Emissions from the soil pool were estimated using different modelling frameworks, except for the Land Converted to Settlements subcategory, for which CBM-CFS3 decay rates were used. Consequently, methods are generally consistent with those used in the Forest Land Remaining Forest Land subcategory. Section A3.5.2.1 summarizes the estimation procedures.

### 6.9.3. Uncertainty Assessment and Time-Series Consistency

The estimate of the total forest area converted annually in Canada is associated with an overall uncertainty estimate of  $\pm 30\%$  (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 63 kha in 2023. Care should be taken not to apply the 30% range to the cumulative area reported in the CRT tables for forest land converted to another land category over the last 20 years (10 years for reservoirs). Section A3.5.2.10 describes the main sources of uncertainty associated with the area estimates derived from remote sensing.

### 6.9.4. QA/QC and Verification

General QA/QC procedures are implemented in this category as outlined in section 1.3 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 section A3.5.2.10.

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 CRT Reporter software.

### 6.9.5. Recalculations

Recalculations occurred in Forest Conversion due to implementing a Cropland biomass conversion see (see section 6.5.2.1 for additional details) and minor mapping activity data changes. The combined effect of these methodological and activity data changes resulted in small downward recalculations in estimates across the time series. Recalculations in key reporting years resulted in downward revisions in carbon storage in HWP of -0.6 Mt in 1990, -0.5 Mt in 2005 and 0.4 Mt in reporting year 2022 for immediate and residual emissions.

Recalculations occurred due to changes in the reporting of HWP. Carbon transfers to the HWP pool are now reported in the source land category which results in an apparent upward recalculation equivalent to the carbon transfer out of the source land ecosystem (see sections 6.3.1.5 for additional details). These changes cause an apparent upward adjustment of emissions of 7.2 Mt in 1990, 4.7 Mt in 2005 and 4.9 Mt in 2022.

More details can be found in section 6.3.1.5.

### 6.9.6. Planned Improvements

The development of new mapping data, parameters and processes for forest conversion is part of the continuous improvements to the LULUCF estimates. In the long-term, improvements include the revision of the 1970 to 2010 deforestation activity data, which will lead to improved estimates for earlier time periods.

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

# CHAPTER 7

## WASTE (CRT SECTOR 5)

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### 7.1. Overview

The Waste sector in Canada includes emissions from the treatment and disposal of wastes, including Landfills, Composting and Biological Treatment of Solid Waste, Incineration and Open Burning of Waste, and Wastewater Treatment and Discharge.

#### 7.1.1. Emissions Summary

Greenhouse gas (GHG) sources from the Waste sector include methane (CH<sub>4</sub>) from Landfills; CH<sub>4</sub> and nitrous oxide (N<sub>2</sub>O) from the Biological Treatment of Solid Waste; carbon dioxide (CO<sub>2</sub>), CH<sub>4</sub> and N<sub>2</sub>O from Incineration and Open Burning of Waste; and CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O from Wastewater Treatment and Discharge.

In 2023, greenhouse gas emissions from the Waste sector accounted for 23.0 Mt of total national emissions, compared with 23.6 Mt for 2005, a decrease of 0.57 Mt or 2.5% (Table 7–1). The emissions from this sector represented 3.5% of total Canadian GHG emissions in 1990, 3.1% in 2005 and 3.3% in 2023.

The primary contributor to the Waste sector emissions was Municipal Solid Waste Landfills, which in 2023 accounted for 19.0 Mt CO<sub>2</sub> eq or 82% of the Waste sector emissions (Table 7–1).

When the waste treated or disposed of is derived from biomass, CO<sub>2</sub> emissions attributable to such waste are reported in the inventory as a memo item. CO<sub>2</sub> emissions of biogenic origin are not reported if they are reported elsewhere in the inventory or if the corresponding CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions from wood and wood products are reported in the Land Use, Land-use Change and Forestry (LULUCF) sector. In contrast, CH<sub>4</sub> emissions from anaerobic decomposition of wastes are included in the inventory totals as part of the Waste sector.

Table 7–1 Overview of GHG Emissions from the Waste Sector, Selected Years								
GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2018	2019	2020	2021	2022	2023
<b>Waste</b>	<b>21 400</b>	<b>23 600</b>	<b>23 300</b>	<b>23 400</b>	<b>22 900</b>	<b>22 900</b>	<b>23 000</b>	<b>23 000</b>
<b>Landfills (5.A)</b>								
Municipal Solid Waste Landfills	18 100	19 700	19 200	19 400	18 900	18 800	19 000	19 000
Industrial Wood Waste Landfills	999	1 080	836	818	799	779	760	741
<b>Biological Treatment of Solid Waste (5.B)</b>	<b>81</b>	<b>243</b>	<b>376</b>	<b>379</b>	<b>384</b>	<b>504</b>	<b>504</b>	<b>503</b>
<b>Incineration and Open Burning of Waste (5.C)</b>	<b>262</b>	<b>345</b>	<b>171</b>	<b>169</b>	<b>154</b>	<b>145</b>	<b>166</b>	<b>156</b>
<b>Wastewater Treatment and Discharge (5.D)</b>								
Municipal Wastewater Treatment and Discharge	1 470	1 780	2 210	2 230	2 250	2 230	2 300	2 370
Industrial Wastewater Treatment and Discharge	429	436	481	429	387	375	300	258

Note: Totals may not add up due to rounding.

There were no methodological changes relative to the previous inventory submission. In this submission, all recalculations relative to the previous inventory submissions are from updates to activity data only (Table 7–2). Detailed descriptions of the activity data updates are provided in the recalculation section for each source category in this chapter and in Chapter 8.

Table 7–2 Summary of Recalculations for the Waste Sector, Selected Years								
Sector	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2005	2017	2018	2019	2020	2021	2022
<b>Landfills (5.A)</b>								
Previous Submission (2024 NIR)	19 100	21 400	20 500	20 300	20 400	19 900	20 000	20 200
Current Submission (2025 NIR)	19 100	20 800	20 200	20 100	20 200	19 700	19 600	19 700
Change in Emissions	71	-683	-683	-249	-241	-212	-337	-508
	0%	-3%	-3%	-1%	-1%	-1%	-2%	-3%
<b>Biological Treatment of Solid Waste (5.B)</b>								
Previous Submission (2024 NIR)	81	243	338	376	381	386	476	475
Current Submission (2025 NIR)	81	243	337	376	379	384	504	504
Change in Emissions	0.0	0.3	-1.2	0.4	-1.7	-1.6	28.0	29.1
	0%	0%	0%	0%	0%	0%	6%	6%
<b>Incineration and Open Burning of Waste (5.C)</b>								
Previous Submission (2024 NIR)	260	339	182	171	169	154	145	159
Current Submission (2025 NIR)	262	345	182	170	169	154	145	166
Change in Emissions	1.7	5.8	0.4	-0.4	-0.6	-0.4	0.5	7.3
	1%	2%	0%	0%	0%	0%	0%	5%
<b>Wastewater Treatment and Discharge (5.D)</b>								
Previous Submission (2024 NIR)	1 900	2 220	2 500	2 580	2 540	2 520	2 520	2 490
Current Submission (2025 NIR)	1 900	2 220	2 620	2 690	2 650	2 630	2 600	2 600
Change in Emissions	-1.3	3.0	113	117	114	109	80	116
	0%	0%	5%	5%	4%	4%	3%	5%

Note: Totals may not add up due to rounding.

## 7.2. Municipal Solid Waste Landfills (CRT Category 5.A.1)

### 7.2.1. Source Category Description

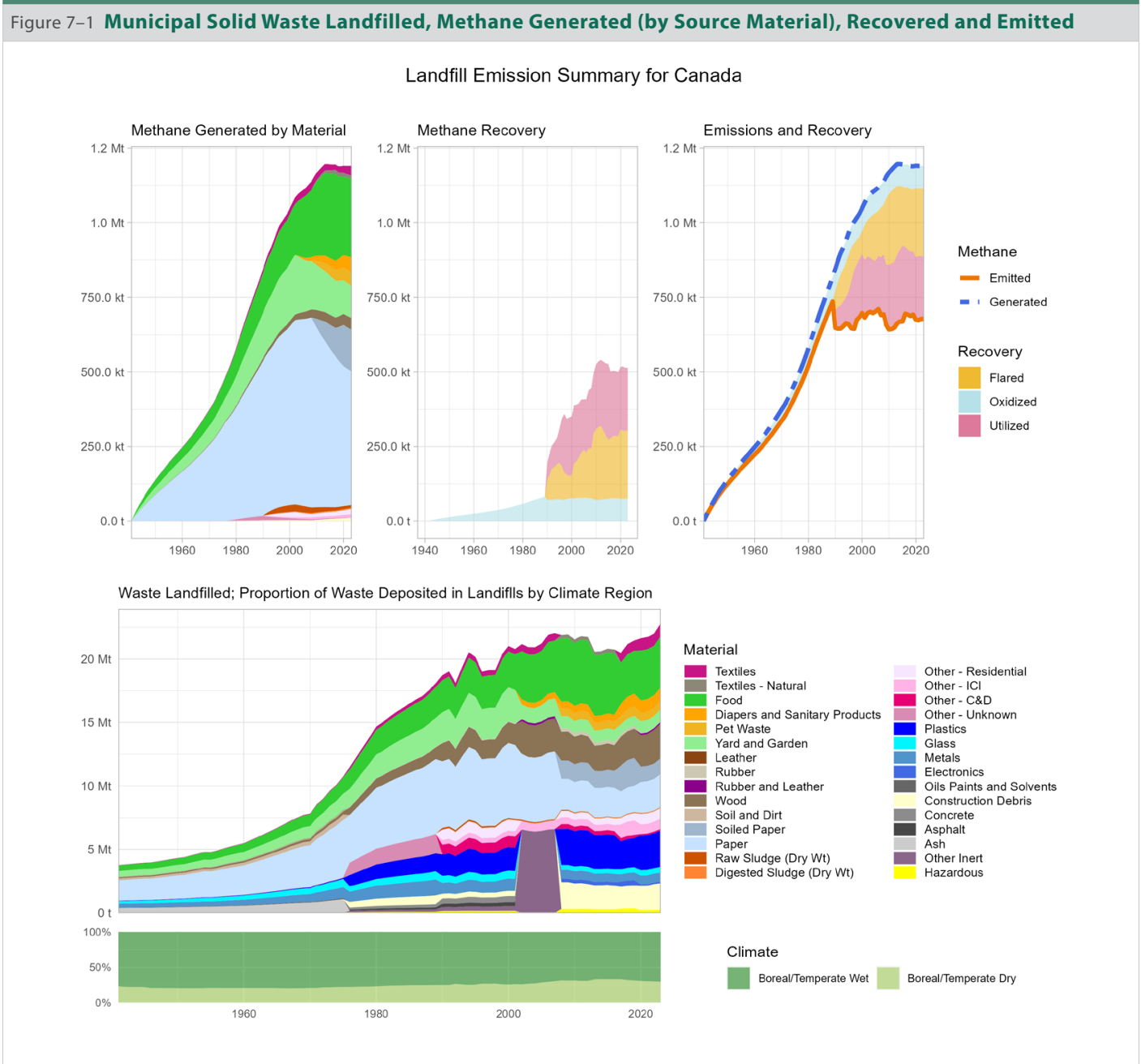
The Landfills emissions category is comprised of Municipal Solid Waste (MSW) landfills and industrial wood waste landfills. MSW encompasses waste from the Residential sector, the Industrial, Commercial and Institutional (ICI) sector and the Construction and Demolition (C&D) sector, as well as landfilled sewage sludge. Most waste landfilled in Canada is part of the MSW category. By contrast, industrial wood waste (i.e., waste from sawmill operations, pulp and paper production and other forest industry processes) is often deposited in small landfills at or near the originating facility. Because of the unique waste composition (i.e., wood and wood industry residuals) and distinct locations and practices of wood waste landfills, emissions from industrial wood waste are reported as a separate category from MSW Landfills (section 7.3).

In Canada, most MSW disposal occurs in managed municipal landfills. Few, if any, unmanaged waste disposal sites exist in Canada. The disposal of MSW is regulated by provinces and territories but is typically managed by municipal or regional authorities. While regulations vary across the country, common regulatory requirements include use landfill cover and installation of landfill gas capture at larger sites. Furthermore, many provinces are implementing, or already have in place, specific waste reduction targets, such as organic bans on landfilled waste, or per capita waste generation goals.

MSW landfills are the dominant contributor of emissions from the Waste sector. This category accounts for approximately 82% of the Waste sector emissions (Table 7–1). Emissions from waste disposal are generated by the anaerobic decomposition of buried organic waste in the landfill. While CO<sub>2</sub> is also produced, it is of biogenic origin and is therefore not reported as part of the total emissions of the Waste sector. Emissions of N<sub>2</sub>O are considered negligible.

The primary factors influencing emissions from MSW landfills include the amount of waste landfilled and methane recovery practices (Figure 7–1). Quantities of waste landfilled have steadily increased over time as a result of population growth and changes in per capita waste generation, from less than 5 Mt of waste landfilled per year before 1960 to approximately 20 Mt/year in 1990, and have remained relatively stable since the early 2000s at approximately 25 Mt/year. Methane recovery has increased since the early 1990s, from approximately 130 kt CH<sub>4</sub> recovered (flared and utilized)

in 1990 to approximately 330 kt CH<sub>4</sub> recovered in 2005, and has remained consistently around 450 kt CH<sub>4</sub>/year recovered from 2010 onward. Waste composition is another factor influencing emissions, with changes in the overall composition of waste influencing the overall methane generation potential and decay rates. For example, the changing waste composition and contribution of each material type to methane generated in landfills can be seen in [Figure 7-1](#).



### 7.2.2. Methodological Issues

Landfill emissions in Canada are estimated using the first-order decay methodology from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), with parameters from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019). The same methodology, but with different parameters, is used for MSW landfills and Industrial Wood Waste landfills (discussed in section 7.3.2). Emissions from landfills are modelled as one generic landfill for waste disposed in each climate zone (Boreal/Temperate Wet and Dry), for each Province and Territory.

Landfill gas, which is composed mainly of CH<sub>4</sub> and CO<sub>2</sub>, 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<sub>4</sub> and CO<sub>2</sub> gases are generated within 20 years of landfilling, emissions can continue for 100 years or more (Levelton, 1991).

A consistent source of data on the amount of waste landfilled over time is not currently available. Instead, the total amount of waste disposed (landfilled, exported and incinerated) in each province forms the basis of the emission calculations. Data are available on the amount of waste exported and incinerated and so are used to derive the amount of waste landfilled.

Several factors contribute to the generation of gases within a landfill. The key factors are the degree to which a landfill is anaerobic, the waste composition (specifically, the carbon content and degradability) and the moisture (which is the primary factor limiting decay rates). While there are several other factors affecting CH<sub>4</sub> generation in landfills, such as pH and nutrient availability, they are not considered to be as important as moisture and waste composition and are not represented in the IPCC first order decay model.

Not all CH<sub>4</sub> generated within a landfill will be released into the atmosphere. From the CH<sub>4</sub> generated in a landfill, some may be captured through landfill gas capture technology and some may be oxidized in landfill covers. Landfill gas capture on managed landfill sites is an increasingly popular activity in Canada. CH<sub>4</sub> from landfill gas can be used to generate electricity or heat or can be flared to reduce the GHG potential of emitted gases. Oxidation of CH<sub>4</sub> into CO<sub>2</sub> 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<sub>4</sub> emissions from MSW Landfills was estimated to be ±76% for CH<sub>4</sub> based on defaults available in the IPCC 2006 Guidelines (IPCC, 2006).

Time-series consistency is ensured through the use of consistent methods and activity data (type and sources) for all inventory years. Where necessary, time-series gaps in activity data are imputed with interpolated or extrapolated values, with consideration taken for details such as start of facility operations, collection system installation dates are considered. See Annex 3.6 for further details of activity data preparation.

### 7.2.4. QA/QC and Verification

The annual quality control process involves verifying that all activity data and methodological updates have been incorporated into the model. Expected changes in emission estimates from individual methodological updates and regular data updates were compared against the total actual changes in emissions to verify that all recalculations have been incorporated correctly. Time-series trends of activity data and emission estimates were reviewed to identify any unexpected changes in emissions at the regional and national level. Standard quality assurance checks were completed, such as confirming that records for all years and regions had been included in final estimates and that national totals matched the sum of regional totals.

### 7.2.5. Recalculations

Refinements were made to waste disposal tonnages (based on updated data from Statistics Canada (Statistics Canada, n.d. [a]) and export, incineration, and methane recovery data (based on Environment Canada and Climate Change (ECCC) internally compiled information). The updated data replaces previously extrapolated values. New landfill gas recovery data and landfill waste disposal data were acquired from a voluntary survey of landfill operators, conducted by ECCC. The survey included a full-time-series data validation with landfill operators. The survey and validation data have led to some revised landfill gas collection estimates and site-specific disposal data. The latest long-term climate data and site-specific disposal were used to update estimates of proportions of waste landfilled by climate zone (wet, dry), with changes for Ontario (from 7% dry climate to 3% dry climate) and Alberta (from 100% dry climate to 99% in dry climate). New waste characterization (composition) data and updated MSW disposal sources (Residential, ICI, C&D) have resulted in some to updates emissions in recent years (2021 and later). A correction to the proportion disposed that C&D from 1990 to 2002 for Quebec resulted in decreased emission estimates for that province from 1990 onward.

### 7.2.6. Planned Improvements

Opportunities for incorporating more refined data on amounts and types of waste landfilled in provinces and territories are being investigated. Increased collaboration with provincial and other regional authorities may result in higher quality data that can be integrated directly into the waste model or used to verify current estimates. Work is underway to incorporate site-level estimates and emissions modelling.

## 7.3. Industrial Wood Waste Landfills (Included in CRT Category 5.A.1)

### 7.3.1. Source Category Description

Industrial Wood Waste Landfills are privately owned and operated to manage waste from the forest industry produced at sawmills and pulp and paper mills. These landfills are used to dispose of surplus wood residue, including sawdust, wood shavings, bark, ash and wastewater treatment residuals. Wood waste disposed of in Canada originates from two primary sources; the solid wood industry (e.g., sawmills) and the pulp and paper industry (e.g., paper manufacturing). Increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes has limited the quantities of solid wood waste being disposed in industrial wood waste landfills, as residual wood is being processed as a value-added product (e.g., wood pellets for residential and commercial pellet stoves and furnaces, and hardboard, fibreboard and particleboard).

Wood waste landfills typically incorporate grading, cover use and water management, and as such are considered as managed waste sites. Industrial wood waste disposal accounts for 4.7% (1.0 Mt CO<sub>2</sub> eq) of the emissions from waste in 1990, 4.6% (1.1 Mt) in 2005, and 3.2% (0.74 Mt) in 2023.

### 7.3.2. Methodological Issues

As noted previously, the increasing demand for waste recovery and waste-to-energy applications in recent years has reduced the solid wood residuals to negligible amounts. Waste residuals are therefore specified as zero for the solid wood industry from 2010 onwards. In contrast, the available data indicates that landfilling of waste from pulp and paper facilities is continuing. There are limited data available on the amount of waste sent to industrial wood waste landfill sites, and, as such, interpolation between data points is necessary. Based on the available information, and given that methane production rates from decomposition of wood waste is typically less than methane generated at MSW landfills, it is assumed that no landfill gas recovery occurs at wood waste landfills. See Annex 3.6 for further details of activity data preparation and model methodology.

### 7.3.3. Recalculations

No recalculations occurred for this subcategory for the current year.

### 7.3.4. Uncertainties and Time Series Consistency

The level of uncertainty associated with CH<sub>4</sub> emissions from MSW landfills and wood waste landfills combined was estimated to be in the range of  $\pm 76\%$  for CH<sub>4</sub>. Time-series consistency is ensured through the use of consistent methods and activity data (type and sources) for all inventory years. Where necessary, time-series gaps in activity data are imputed with interpolated or extrapolated values.

### 7.3.5. 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 (CRT Category 5.B)

### 7.4.1. Source Category Description

This source category includes emissions from composting and anaerobic digestion at biogas facilities. Many municipalities in Canada utilize centralized composting facilities and some are establishing centralized anaerobic digestion facilities to reduce the quantity of organics sent to landfill. Additionally, several municipalities across Canada are considering, or have already established, organic waste bans on landfills in their jurisdiction to further divert organic waste to biological treatment. These practices have contributed to a large increase in the quantity of organic waste diverted in Canada since 1990.

GHG emissions from composting are affected by climate, moisture content and composition of the waste and the ability to maintain aerobic decomposition conditions among other factors. Anaerobic digestion of organic waste accelerates the natural decomposition of organic material without oxygen by maintaining optimal conditions for the process. Both biological treatment processes result in the production of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions. However, CO<sub>2</sub> emissions are not included in the national inventory total as the carbon is considered of biogenic origin and accounted for under the Agriculture, Forestry and Other Land Use (AFOLU) sector (IPCC, 2006).

In 2023, the Biological Treatment of Solid Waste category contributed 500 kt of CO<sub>2</sub> eq or 2.2% of total emissions to the Waste sector and 0.07% to Canada's total. Current year emissions from this category have increased 420 kt (520%) compared to 1990, and 260 kt (110%) compared to 2005.

#### 7.4.2. Methodological Issues

The estimation of CH<sub>4</sub> and N<sub>2</sub>O emissions from the biological treatment of waste in Canada is carried out by using a Tier 3 method. Facility-level data are available for both anaerobic digestion and composting facilities in Canada. These data have been collected with industry associations, online literature searches and annual reports as well as other contracts led by ECCC. Composting emissions are calculated based on the waste type accepted in wet tonnes at the facility-level in Canada. The emission factors by waste type have been developed through a literature review that compiled information from primary literature sources (ECCC, 2020a).

Under the Biological Treatment of Solid Waste category, anaerobic digestion emissions are calculated for industrial and municipal facilities. Emissions are calculated as the percent of CH<sub>4</sub> lost from the total biogas produced at the facility level. This percentage was developed based on primary literature and/or facility-based insight and compiled through a literature review (ECCC, 2020b). Some gaps exist in the activity data for both composting and anaerobic digestion, including a lack of data prior to the year 1992 for composting. To fill data gaps occurring at the beginning of the time series, the earliest available data point was carried back to 1990 for facilities that were known to be operating at that time. For gaps in subsequent parts of the time series, the last available data point was carried forward to the next available data point. For anaerobic digestion, there were no facilities in the industrial and municipal sectors that were in operation in 1990. Therefore, the earliest data point available for the facility was carried back to its opening year and carried forward until the next available data point for the facility. For verification of facility operational periods a review was completed of Statistics Canada's Waste Management Industry Survey: Business and Government Sectors (Statistics Canada, n.d.[b]), which includes waste diverted quantities to both composting and anaerobic digestion facilities. Further work will be conducted for future cycles to verify the operational status of these facilities.

#### 7.4.3. Uncertainties and Time Series Consistency

The combined uncertainties for emissions of CH<sub>4</sub> and N<sub>2</sub>O from composting and anaerobic digestion were calculated by waste type for composting and by the fugitive loss percentage for CH<sub>4</sub> for anaerobic digestion. Uncertainty ranges from ±176% to ±99% for CH<sub>4</sub> and ±136% to ±65% for N<sub>2</sub>O based on waste type for composting and ±79% for CH<sub>4</sub> for anaerobic digestion fugitive loss. This is based on emission factors collected and compiled through a literature review. Activity data uncertainty was not calculated given that it is based on facility data.

#### 7.4.4. QA/QC and Verification

The quality control process for the Biological Treatment of Solid Waste category consisted of visual inspection and comparison of activity data against previous values; following calculations in prescribed steps to ensure that equations, parameters and unit conversions were appropriately used, and that links were accurate; review of emission factors used; and inspection of emission estimate time series. Emissions were plotted to observe trends for any unusual patterns that were inconsistent with changes in activity data over time. When they occur, recalculated estimation values are compared to the previous submission, and a comparison was made of changes from one year to the next along the time series to identify unsupported significant changes that may point to a data processing error.

#### 7.4.5. Recalculations

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 (CRT Category 5.C)

### 7.5.1. Source Category Description

This category includes emissions from the incineration of waste. There are 28 incinerators currently in operation in Canada. Incinerators are classified by the source of their primary feed material: MSW, hazardous waste, sewage sludge or clinical waste. Some municipalities in Canada use incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application. Incineration can also be used for energy recovery from waste, and emissions from these facilities are reported in the Energy sector. GHG emissions from open burning of waste are assumed to be negligible, representing less than the reporting threshold of 500 kt CO<sub>2</sub> eq and 0.05% of national GHG total emissions.

Emissions from waste incineration include CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. In accordance with the 2006 IPCC Guidelines, CO<sub>2</sub> emissions from biomass waste combustion are not included in the inventory totals. The only CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O emissions are estimated from all incinerated waste.

GHG emissions from incinerators vary with the amount of waste incinerated, the composition of the waste, the carbon content of the non-biomass waste, and the facilities' operating conditions. Emissions are derived from the quantities of waste incinerated that were provided directly by facilities in a series of surveys conducted by ECCC, as well as additional reports which provide quantities of clinical waste incinerated for the early years in the time series (Chandler, 2006; Sawell, 1996; RWDI AIR Inc., 2014).

Incineration of MSW is not a common practice across most of Canada. In the 1990s, approximately 5% of Canada's total MSW is incinerated, mostly in energy-from-waste facilities. Since the 2000s, only about 3-4% of Canada's total MSW has been incinerated. The vast majority of Canada's incinerated MSW is processed in large, highly regulated facilities. However, there are still a small number of remote communities that rely on rudimentary incinerators to dispose of their MSW. There are currently four incinerators in operation in Canada that are classified as hazardous waste incinerators, all located in Ontario and Alberta. Two different types of sewage sludge incinerators exist in Canada: multiple hearth and fluidized bed. In both types of incinerators, the sewage sludge is partially dewatered prior to incineration. The dewatering is typically done using a centrifuge or a filter press. There is currently one major centralized clinical waste incinerator in Canada, the other clinical waste incinerators are small hospital-based incinerators and incinerators operated by the Government of Canada.

The Incineration and Open Burning of Waste category contributed 160 kt CO<sub>2</sub> eq (0.68%) of total emissions to the Waste sector or 0.02% of Canada's total emissions in 2023. Emissions from this category are 40% below the 1990 level of 260 kt CO<sub>2</sub> eq, and 55% below the 2005 level of 350 kt CO<sub>2</sub> 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<sub>2</sub> eq per year are required to report emissions to ECCC on an annual basis through the Greenhouse Gas Reporting Program (GHGRP). These publicly available data represent a significant portion of emissions from this sector.

Estimates for smaller facilities that are not required to report to the GHGRP are generated by ECCC using Tier 3 methodology and activity data from a biennial survey of incinerators across Canada. Estimates are further supported by historical emissions for those facilities operating before the GHGRP was put in place in 2004. This includes currently operating facilities that operated prior to 2004 and those that closed before the program began.

The ECCC emissions 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<sub>2</sub>O and CH<sub>4</sub> emissions are estimated based on the type of waste being incinerated as well as the facility specific incineration technology. IPCC default factors were used for all waste categories except for hazardous waste, for which emission factors were derived from site-specific data provided by a facility and are considered to be more representative than IPCC default values. As the IPCC 2006 Guidelines do not contain default emission factors for clinical waste incineration, the IPCC 2006 Guidelines default emission factors for MSW incineration were used in accordance with the IPCC 2000 Good Practice Guidance.

Facilities are distinguished as either energy-from-waste (EFW) facilities or non-EFW facilities, depending on whether they produce energy and/or heat from the incineration process. Emissions from EFW facilities are reported under the Energy sector, while emissions from non-EFW facilities are reported under the Waste sector.

### 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  $\pm 5\%$ , while the  $\text{CO}_2$ ,  $\text{CH}_4$  and  $\text{N}_2\text{O}$  emission factor uncertainties are  $\pm 35\%$ ,  $\pm 77\%$ , and  $\pm 92\%$ , respectively.

### 7.5.4. QA/QC and Verification

The quality control process consisted of verification in the model that all activity data updates were made, that all links were valid, and that the cells addressed by those links were populated. Recalculated estimation values were compared to the previous submission, and a comparison was made of changes from one year to the next along the time series to identify unsupported significant changes that may point to a data manipulation error. The emissions trend has been reviewed for the entire time series.

### 7.5.5. Recalculations

GHG emissions reported to the GHGRP were used where available. For facilities not reporting under the GHGRP, data from the ECCC surveys are used. The latest survey was conducted in 2024 which resulted in revised activity data for several facilities.

### 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 (CRT Category 5.D)

### 7.6.1. Source Category Description

The Wastewater Treatment and Discharge category is comprised of Municipal Wastewater Treatment systems and Industrial Wastewater treatment. In Canada, most wastewater from domestic and industrial sources is treated in centralized municipal wastewater treatment plants. Wastewater can also be treated by private, and occasionally communal septic systems, notably in rural areas; these are included in the municipal wastewater category. In some coastal areas, untreated wastewater is discharged directly to the sea, though this practice has been reduced in recent decades following the completion of large wastewater infrastructure projects. Most industrial facilities discharge their wastewater to municipal treatment systems where it is treated in common with domestic wastewater.

The Industrial Wastewater treatment and discharge category captures large industrial facilities that treat or pre-treat their wastewater on-site before discharging it to the environment or to municipal wastewater treatment systems for further treatment.

Wastewater treatment involves the removal of organics, measured as biological oxygen demand, or  $\text{BOD}_5$ , and nutrients such as nitrogen and phosphorus. The treatment process results in emissions of  $\text{CO}_2$ ,  $\text{CH}_4$  and  $\text{N}_2\text{O}$ .

Centralized treatment systems can encompass several technologies, often classified by the method of organic matter and nutrient removal: whether the removal mechanism is settling (primary treatment) or involves microbial activity to further breakdown organics and nutrients in the wastewater (secondary treatment). Tertiary treatment involves additional filtration and disinfection.

The most common types of treatment in Canada are primary treatment (settling of solids), and secondary treatment systems of conventional waste activated sludge aerobic and facultative lagoons, and septic systems. Other secondary treatment technology used in Canada include wetland treatment systems, sequence batch reactors, rotating biological contactors, trickling filters, and membrane filtration. Many of the largest systems in Canada use secondary waste activated sludge systems with tertiary level treatment.

Wastewater treatment produces varying amounts of  $\text{CH}_4$ , depending on the organic load ( $\text{BOD}_5$ )—determined by the population—and the treatment type.  $\text{CH}_4$  is produced from certain treatment processes, steps, or areas of the treatment systems that are anaerobic. For example, primary and secondary treatment and aerobic lagoons produce little or no  $\text{CH}_4$  emissions, whereas anaerobic steps in sequence batch reactors, anaerobic lagoons and septic systems produce relatively higher amounts of  $\text{CH}_4$ . Facultative lagoons have both naturally aerated and anaerobic layers and produce  $\text{CH}_4$ , but less than a fully anaerobic lagoon.

Centralized municipal wastewater treatment plants often have anaerobic sludge digestion, which produces CH<sub>4</sub> in the form of biogas or digester gas. The CH<sub>4</sub> generated in these systems is typically contained and combusted, with a growing portion used for energy (Figure 7–2). Industrial on-site wastewater treatment in Canada uses relatively more anaerobic treatment technology, where methane from the treatment process itself is collected and used as a source of energy (Figure 7–2).

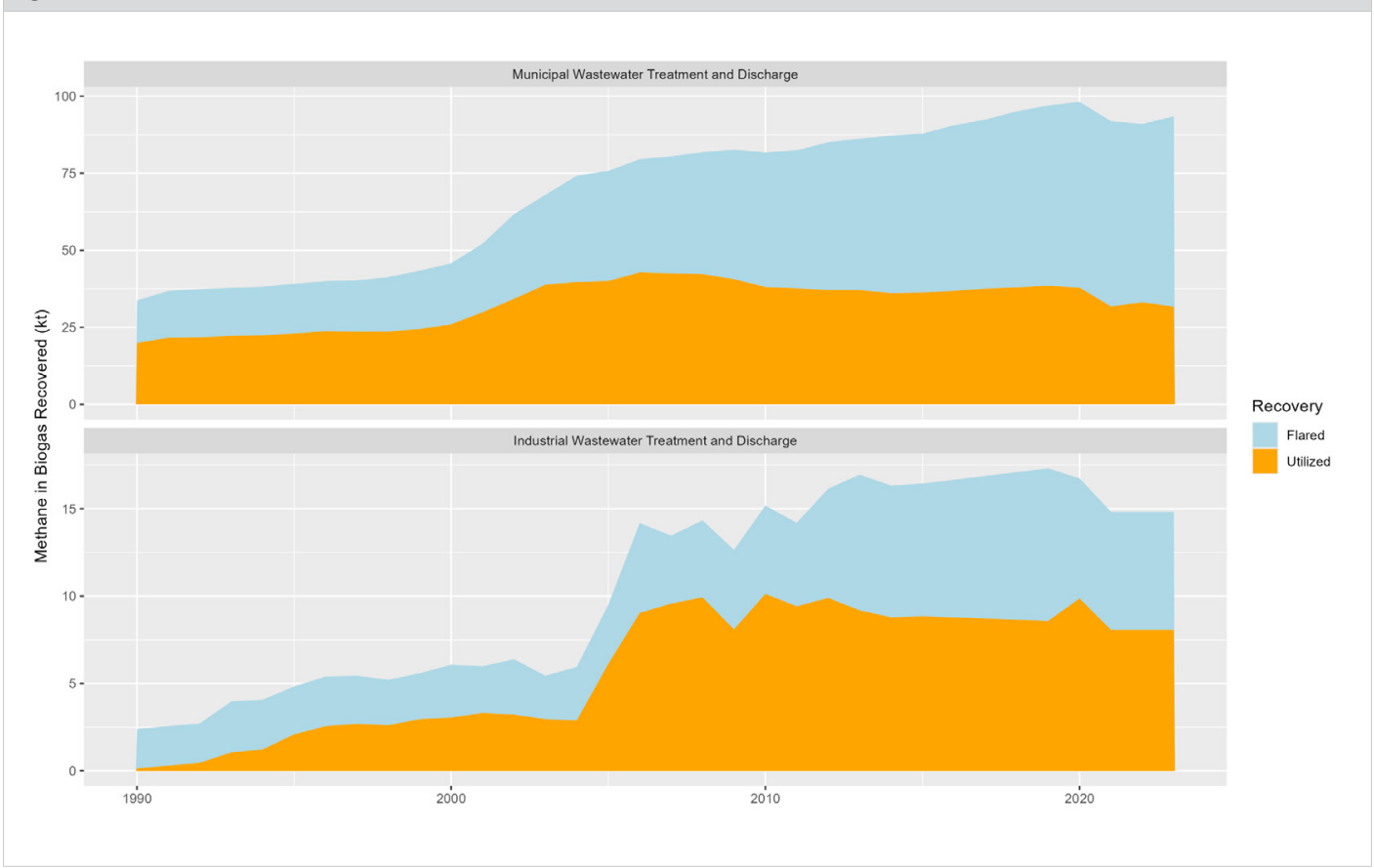
All methane recovery from municipal wastewater treatment came from recovery of biogas generated from anaerobic digestion of sludge; whereas, all methane recovery from industrial wastewater treatment came from the treatment process.

Wastewater treatment generates N<sub>2</sub>O through the nitrification and denitrification of sewage nitrogen at treatment facilities. N<sub>2</sub>O emissions are also considered to occur from the receiving body of discharged effluent, whether treated or untreated.

CO<sub>2</sub> is also a product of aerobic and anaerobic wastewater treatment. As detailed in section 7.1, CO<sub>2</sub> emissions originating from the decomposition of organic matter of biogenic origin are not included in the Waste sector total emissions. CO<sub>2</sub> emissions from organic matter of fossil origin, such as methanol or organic products of chemical manufacturing or oil refining, for example, are included in Waste sector totals.

The Wastewater Treatment and Discharge category accounted for 2600 kt CO<sub>2</sub> eq, or 11%, of the total emissions of the Waste sector in 2023. Wastewater Treatment and Discharge emissions in 2023 were 730 kt CO<sub>2</sub> eq (38%) above the 1990 level (1900 kt), and 410 kt CO<sub>2</sub> eq above the 2005 level (2200 kt).

Figure 7–2 Methane Recovered from Wastewater Treatment



Emissions from wastewater treatment show an increasing trend over time that roughly follows the trend in population growth. Changes in treatment technology have impacts on emission trends at the provincial level. For example, the growing percentage of the population using septic systems in several provinces results in increases in total emissions (septic systems have a relatively high emission factor). In contrast, recent upgrades of several major wastewater systems from untreated discharge to sea to primary and secondary treatment decreased total emissions in other provinces (reductions in emission from the receiving water body are greater than the added emissions from the new treatment). Overall, the increasing trend in emissions is consistent, with a slight acceleration in 2010 and 2011, largely due to an increase in the estimated population using septic systems in many provinces around that time. Overall, population growth is the most important factor in the emissions trend for Wastewater Treatment and Discharge. In part, this is because of assumed constant per capita organics loading ( $BOD_5$ ) and reasonably steady per capita protein consumption rates (increasing from 66.17 g per person per day in 1991 to 69.85 g per person per day in 2009, the earliest and latest data points available) (Statistics Canada, 2009).

## 7.6.2. Methodological Issues

Wastewater treatment emissions are estimated from three process steps: the treatment, the effluent discharged to receiving water bodies, and, where applicable, from anaerobic digestion of sewage sludges.

Although the emission generating processes are the same for both Municipal and Industrial wastewater treatment, the methods differ based on the type of data available. In both cases, estimates are calculated by facility and aggregated to quantify provincial/territorial totals. The methods follow the 2006 IPCC Guidelines and 2019 Refinement to the IPCC Guidelines, with model parameters based on additional information (AECOM [2011] and EnviroSim [2019]). Annex 3.6 provides additional information on the methodologies used for estimating emissions from Municipal Wastewater Treatment, and Industrial Wastewater Treatment.

### Municipal Wastewater Treatment

Municipal Wastewater Treatment emission estimates are based on the population served by each treatment technology and the per capita inputs of organic matter (measured as  $BOD_5$ ) and nitrogen (N). The population served, each year, by each of the more than 3000 wastewater treatment or discharge systems in Canada is estimated based a spatial analysis, which considers regional population and the relative regional volumes of wastewater treated by (or discharged through) each facility or system at the census division and census metropolitan area levels. The population connected to private septic systems are estimated from an analysis of Statistics Canada's Households and the Environment Survey (Statistics Canada, n.d.[c]).

Emissions of  $CH_4$  and  $N_2O$  from treatment are based on  $BOD_5$  and N inputs, respectively, and treatment technology-based emission factors. These are obtained from the 2006 IPCC Guidelines (IPCC, 2006) and 2019 Refinement (IPCC, 2019), with a few exceptions for treatment types not detailed in the Guidelines.

Treatment technology-specific parameters of treatment efficiency (removal rates) are used to estimate  $BOD_5$  and N discharged to receiving water bodies with the effluent. Emissions of  $CH_4$  and  $N_2O$  from the receiving water body are based on the  $BOD_5$  and N discharged with effluent and emission factors based on the waterbody type and eutrophic state.

Technology specific parameters are used to estimate the quantity of sludge generated and volatile suspended solids of the sludge. If the facility has on-site sludge digestion, emissions are estimated based on the sludge quantity and characteristics using the same approach and as biological treatment.

### Industrial Wastewater Treatment

Organic ( $BOD_5$ ) and N inputs to industrial wastewater treatment is highly variable between industry type, and between individual facilities based on production and practices. Emission estimates for industrial wastewater treatment are based on facility reported data. Three sources of data are used: Emissions reported through the GHGRP, quantities of N discharged with effluent reported through the National Pollutant Release Inventory (NPRI) (emission estimates calculated using emission factors), and emissions and methane recovery reported through ECCC voluntary surveys.

Emissions from the receiving water body are based on the  $BOD_5$  and N estimated in effluent and emission factors.

### 7.6.3. Uncertainties and Time Series Consistency

The uncertainty associated with the Municipal Wastewater Treatment and Discharge category was estimated to be in the range of  $\pm 55\%$  for  $\text{CH}_4$  and  $\pm 51\%$  for  $\text{N}_2\text{O}$ ; and is based on default IPCC 2006 values. Uncertainty for Industrial Wastewater Treatment and Discharge, which is based on facility-reported emissions, is estimated as the standard deviation about the mean at 95% confidence interval. This results in estimated uncertainty of 790% in 2005 and 345% in 2023 for  $\text{CH}_4$  emissions, 269% in 2005 and 360% in 2023 for  $\text{CO}_2$  emissions, and 265% and 279% for  $\text{N}_2\text{O}$  in 2005 and 2023, respectively.

Time series consistency is ensured through the use of consistent methods and activity data (type and sources) for all inventory years. Where necessary, time-series gaps in activity data are imputed with interpolated or extrapolated values, with consideration taken for details such as start of facility operations, collection system installation dates are considered.

### 7.6.4. QA/QC and Verification

The quality control process consisted of following calculations step by step to ensure that equations, parameters and unit conversions were appropriately used, and that links were accurate. Emissions were plotted to observe trends for any unusual jumps or patterns that were inconsistent with changes in activity data over time. Recalculated estimation values were compared to the previous submission, and a comparison was made of changes from one year to the next along the time series to identify unsupported significant changes that may point to a data processing error.

### 7.6.5. Recalculations

The recalculations in Municipal and Industrial Wastewater Treatment and Discharge are comprised of updated facility-level data and error corrections. Updated data includes volumes treated and treatment technology (Municipal); reported emissions via GHGRP and reported N in effluent via NPRI (Industrial). Error corrections for municipal wastewater treatment involved unit conversions at some facilities (methane recovery volumes were reported with relative pressures), updated inter-facility sludge transfers, and volumes treated for a few facilities (mostly in the early 1990s).

### 7.6.6. Planned Improvements

Planned improvements for Wastewater Treatment and Discharge include: characterization of the types of receiving waterbodies for all wastewater treatment systems in Canada to allow waterbody specific effluent emission factors, updated mapping of septic system use in Canada, and gathering of data to capture the influence of combined sewer overflows on emissions.

## RECALCULATIONS AND IMPROVEMENTS

8.1.	Impact of Recalculations on Emission Levels and Trends	234
8.2.	Inventory Improvements	240
8.3.	Planned Inventory Improvements	242

Canada's greenhouse gas (GHG) inventory undergoes a continuous process of updates, revisions, and improvements to maintain and to enhance its transparency, accuracy, completeness, consistency and comparability. Section 8.1 of this chapter provides an overview of the recalculations performed in this year's GHG inventory, including analyses by sector to facilitate an integrated view of changes in, and impacts on, emission levels and trends. A summary of the inventory improvements implemented this year can be found in section 8.2 and planned improvements for future inventories are described in section 8.3.

Further details on recalculations and improvements can be found in the individual chapters for each sector ([Chapter 3](#) to [Chapter 7](#)).

### 8.1. Impact of Recalculations on Emission Levels and Trends

Continuous improvement is a good inventory preparation practice. Environment and Climate Change Canada (ECCC) consults and works with key federal, provincial and territorial partners, along with industry stakeholders, research centres and consultants, on an ongoing basis to improve the quality of the underlying variables and scientific information used to compile the national inventory. As new information and data become available and more accurate methods are developed, previous estimates are updated to provide a consistent and comparable trend in emissions and removals.

Recalculations occur annually for a number of reasons, including the following:

- correction of errors detected by quality control procedures
- incorporation of updates to activity data, including changes in data sources
- reallocation of activities to different categories (this only affects subtotals)
- refinements of methodologies and emission factors (EF)
- inclusion of categories previously not estimated (which improves inventory completeness)
- recommendations from United Nations Framework Convention on Climate Change (UNFCCC) reviews
- implementation of [modalities, procedures and guidelines for the transparency framework for action and support](#) referred to in Article 13 of the Paris Agreement (MPGs)<sup>1</sup>

#### 8.1.1. Estimated Impacts on Emission Levels and Trends

In this GHG inventory, total emissions were revised downward for most years, as shown in [Figure 8–1](#). Overall, as shown in [Table 8–1](#), recalculations of previously reported 1990–2022 estimates have resulted in a change in emissions between a minimum of -0.1% (-0.5 Mt) in 2010 and a maximum of -1.1% (-7.9 Mt) in 2022. The trend between 1990 and 2022 is now reported as a 15.4% increase in total GHG emissions since 1990, compared with a 16.5% increase reported in last year's NIR. The trend between 2022 and the base year (2005) corresponds to a decrease of -7.8% (-59 Mt) in total GHG emissions. There is a net downward recalculation of -0.4% (-2.8 Mt) for the base year.

<sup>1</sup> [https://unfccc.int/sites/default/files/resource/cp24\\_auv\\_transparency.pdf](https://unfccc.int/sites/default/files/resource/cp24_auv_transparency.pdf)

Figure 8–1 **Comparison of Emission Trends (2024 NIR vs 2025 NIR)**

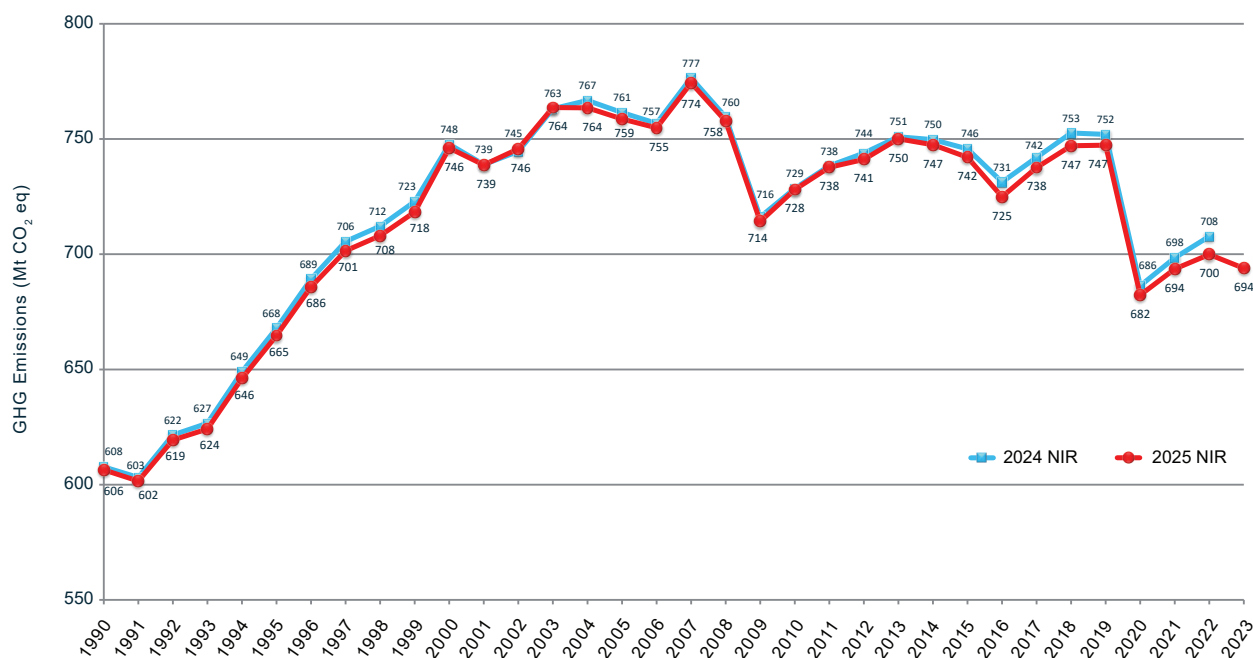


Table 8–1 **Summary of Recalculations in the 2025 National Inventory (Excluding Land Use, Land-Use Change and Forestry)**

National Total	Annual Emissions (kt CO <sub>2</sub> eq)								Trend	
	1990	2005	2017	2018	2019	2020	2021	2022	1990–2022	2005–2022
Previous Submission (2024 NIR)	607 749	761 492	742 010	752 631	752 025	686 362	698 441	707 767	16.5%	-7.1%
Current Submission (2025 NIR)	606 392	758 718	737 607	747 051	747 308	682 283	693 574	699 899	15.4%	-7.8%
Change in Total Emissions	-1 357	-2 774	-4 404	-5 579	-4 717	-4 079	-4 868	-7 868	-	-
	-0.22%	-0.36%	-0.59%	-0.74%	-0.63%	-0.59%	-0.70%	-1.11%	-	-

Note: " - " = Not applicable

### 8.1.2. Recalculations by Sector

As previously noted, good inventory preparation practice requires that methodological improvements and updates be applied across the time series (i.e., from 1990 to the most recent year reported). Methodological consistency across the time series avoids confounding a methodological change with an actual change in GHG emissions or removals.

Recalculations conducted this year have resulted in changes to previously reported emissions/removals for the majority of the IPCC sectors (Energy; Industrial Processes and Product Use [IPPU]; Agriculture; Land Use, Land-Use Change and Forestry [LULUCF]; and Waste), Energy subsectors (Stationary Combustion, Transport and Fugitive Sources), and for all applicable years in the time series (1990–2022).

As reflected in Table 8–2, for 2022, the revisions made resulted in the most significant changes in Fugitive Sources (-5.0 Mt) and Stationary Combustion (-2.5 Mt). These revisions are largely due to improved estimation methodologies and allocation as well as updated energy data. The national total went from 708 Mt for the year 2022 (as presented in the previous inventory) to 700 Mt for 2022 (as presented in the current inventory) because of the sum of recalculations of -7.9 Mt for all sectors. And then, the 2022 national total updated to 700 Mt, decreased by 6 Mt to reach 694 Mt in 2023. Change and recalculations contribution for each source are presented in Table 8–2. Emission and recalculations values of those sources, for current and previous inventory, are presented in Table 8–3.

Table 8–2 **Change in Canada's GHG Emissions: from 708 Mt (for 2022, Previous Submission) to 694 Mt (for 2023, Current Submission)**

Sector	2022 to 2023 Change (Mt CO <sub>2</sub> eq)	2022 Change Due to Recalculations (Mt CO <sub>2</sub> eq)
Energy (Stationary Combustion)	-5.2	-2.5
Energy (Transport)	0.8	-1.2
Energy (Fugitive Sources)	-1.7	-5.0
Industrial Processes and Product Use	1.0	1.2
Agriculture	-0.8	0.0
Waste	0.0	-0.4
<b>Total Change</b>	<b>-6.0</b>	<b>-7.9</b>

Note: Totals may not add up due to rounding.

Table 8–3 **Summary of Recalculations by Sector**

	Annual Emissions (kt CO <sub>2</sub> eq)								Trend	
	1990	2005	2017	2018	2019	2020	2021	2022	1990–2022	2005–2022
<b>ENERGY (STATIONARY COMBUSTION)</b>										
Previous Submission (2024 NIR)	277 861	338 488	321 486	323 866	325 933	302 467	303 587	306 085	10.2%	-9.6%
Current Submission (2025 NIR)	276 753	334 956	317 939	318 694	322 372	299 257	300 632	303 574	9.7%	-9.4%
<b>Change in Emissions</b>	<b>-1 108</b>	<b>-3 532</b>	<b>-3 547</b>	<b>-5 172</b>	<b>-3 561</b>	<b>-3 209</b>	<b>-2 955</b>	<b>-2 512</b>	-	-
	<b>-0.4%</b>	<b>-1.0%</b>	<b>-1.1%</b>	<b>-1.6%</b>	<b>-1.1%</b>	<b>-1.1%</b>	<b>-1.0%</b>	<b>-0.8%</b>	-	-
<b>ENERGY (TRANSPORT)</b>										
Previous Submission (2024 NIR)	145 049	190 245	202 322	208 516	209 890	178 600	188 052	195 887	35.0%	3.0%
Current Submission (2025 NIR)	145 073	190 308	202 281	208 613	209 151	177 962	186 792	194 641	34.2%	2.3%
<b>Change in Emissions</b>	<b>24</b>	<b>63</b>	<b>- 42</b>	<b>98</b>	<b>- 739</b>	<b>- 638</b>	<b>-1 260</b>	<b>-1 246</b>	-	-
	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>-0.4%</b>	<b>-0.4%</b>	<b>-0.7%</b>	<b>-0.6%</b>	-	-
<b>ENERGY (FUGITIVE SOURCES)</b>										
Previous Submission (2024 NIR)	66 148	96 880	89 382	89 138	86 063	76 630	77 139	75 175	13.6%	-22.4%
Current Submission (2025 NIR)	65 542	97 569	88 031	87 560	84 312	74 692	74 918	70 214	7.1%	-28.0%
<b>Change in Emissions</b>	<b>- 606</b>	<b>689</b>	<b>-1 350</b>	<b>-1 578</b>	<b>-1 752</b>	<b>-1 938</b>	<b>-2 220</b>	<b>-4 961</b>	-	-
	<b>-0.9%</b>	<b>0.7%</b>	<b>-1.5%</b>	<b>-1.8%</b>	<b>-2.0%</b>	<b>-2.5%</b>	<b>-2.9%</b>	<b>-6.6%</b>	-	-
<b>IPPU</b>										
Previous Submission (2024 NIR)	54 891	55 396	52 300	53 503	52 318	49 681	51 499	51 315	-6.5%	-7.4%
Current Submission (2025 NIR)	55 096	56 032	52 982	54 719	53 737	51 414	53 217	52 522	-4.7%	-6.3%
<b>Change in Emissions</b>	<b>205</b>	<b>637</b>	<b>682</b>	<b>1 215</b>	<b>1 419</b>	<b>1 733</b>	<b>1 718</b>	<b>1 207</b>	-	-
	<b>0.4%</b>	<b>1.1%</b>	<b>1.3%</b>	<b>2.3%</b>	<b>2.7%</b>	<b>3.5%</b>	<b>3.3%</b>	<b>2.4%</b>	-	-
<b>AGRICULTURE</b>										
Previous Submission (2024 NIR)	42 485	56 242	53 008	54 157	54 299	56 016	55 061	55 947	31.7%	-0.5%
Current Submission (2025 NIR)	42 541	56 286	53 006	54 146	54 287	55 986	55 109	55 912	31.4%	-0.7%
<b>Change in Emissions</b>	<b>57</b>	<b>43</b>	<b>- 2</b>	<b>- 11</b>	<b>- 12</b>	<b>- 30</b>	<b>48</b>	<b>- 35</b>	-	-
	<b>0.1%</b>	<b>0.1%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>-0.1%</b>	<b>0.1%</b>	<b>-0.1%</b>	-	-
<b>WASTE</b>										
Previous Submission (2024 NIR)	21 314	24 241	23 511	23 450	23 521	22 968	23 103	23 357	9.6%	-3.6%
Current Submission (2025 NIR)	21 386	23 567	23 367	23 319	23 391	22 863	22 875	23 001	7.6%	-2.4%
<b>Change in Emissions</b>	<b>71</b>	<b>- 674</b>	<b>- 144</b>	<b>- 131</b>	<b>- 130</b>	<b>- 105</b>	<b>- 228</b>	<b>- 356</b>	-	-
	<b>0.3%</b>	<b>-2.8%</b>	<b>-0.6%</b>	<b>-0.6%</b>	<b>-0.6%</b>	<b>-0.5%</b>	<b>-1.0%</b>	<b>-1.5%</b>	-	-
<b>LULUCF</b>										
Previous Submission (2024 NIR)	49 184	65 994	19 100	22 987	13 631	25 642	13 537	51 459	4.6%	-22.0%
Current Submission (2025 NIR)	49 847	65 973	21 205	24 024	14 629	25 006	14 770	50 797	1.9%	-23.0%
<b>Change in Emissions</b>	<b>663</b>	<b>- 21</b>	<b>2 106</b>	<b>1 036</b>	<b>998</b>	<b>- 636</b>	<b>1 233</b>	<b>- 662</b>	-	-
	<b>1.3%</b>	<b>-0.03%</b>	<b>11.0%</b>	<b>4.5%</b>	<b>7.3%</b>	<b>-2.5%</b>	<b>9.1%</b>	<b>-1.3%</b>	-	-

Note:  
\* - " = Not applicable

## Energy (Stationary Combustion)

With respect to Stationary Combustion emissions, most of the recalculations for 2022 occurred in Public Electricity and Heat Production (+1.7 Mt [2.9%]), Petroleum Refining Industries (+0.4 Mt [2.8%]), Oil and Gas Extraction (-2.9 Mt [-2.7%]), Manufacturing Industries (-0.8 Mt [-1.9%]), Residential (-0.6 Mt [-1.4%]), and Mining (-0.3 Mt [-6.7%]). Recalculations also occurred throughout the time series, with the major source being updates to petroleum coke and residential firewood EFs, reallocation of natural gas from stationary combustion to IPPU, and fuel consumption data in the Report on Energy Supply and Demand (RESO).

Recalculations in the Public Electricity and Heat Production category occurred from 2004 to 2022. These recalculations were a result of revised petroleum coke EFs with the impact ranging from -0.7 Mt (-17%) to -0.1 Mt (-8.8%). Revisions to natural gas and petroleum coke volumes from 2010 to 2022 caused changes in emissions ranging from +0.1 Mt (0.1%) to +1.8 Mt (3.3%).

Recalculations to Petroleum Refining Industries were a result of revisions to the RESD, specifically volumes for natural gas, petroleum coke, still gas, propane, and butane, and revisions to petroleum coke EFs. The updates resulted in revisions from 1990 to 2022 ranging from -1.9 Mt (-12%) in 2016 to +0.4 Mt (2.8%) in 2022.

Recalculations to the Oil and Gas Extraction category occurred from 1990 to 2022. Revisions to producer-consumed natural gas CO<sub>2</sub> EFs in Alberta and CH<sub>4</sub> EFs in Alberta and Saskatchewan, and petroleum coke EFs caused downward revisions from 1990 to 2022 ranging from -0.6 Mt (-1.9%) in 1990 to -0.9 Mt (-0.8%) in 2021. Revisions to natural gas, petroleum coke, propane, and still gas volumes from 1990 to 2022 caused changes in emissions ranging from -2.5 Mt (-2.6%) in 2016 to +1.1 Mt (1.3%) in 2013.

Recalculations for Manufacturing Industries occurred for the entire time series. Revisions to the RESD occurred from 2010 to 2022, with impacts ranging from -0.1 Mt (-0.3%) to +0.4 Mt (1.1%). The reallocation of natural gas from iron and steel stationary combustion to iron and steel production in IPPU resulted in downward revisions ranging from -0.01 Mt (-0.2%) in 1990 to -1.2 Mt (-26%) in 2018. Revisions to petroleum coke and mixed waste fuel EFs along with revised quantities of mixed waste fuel and sludge gas caused recalculations ranging from -0.5 Mt (-16%) to +1.0 kt (0.04%).

Recalculations in the Residential category occurred between 1990 and 2022. These revisions were due to changes to residential firewood EFs and propane volumes, causing recalculations ranging from -0.3 Mt (-0.8%) in 2017 to -0.8 Mt (-1.9%) in 1990. See Chapter 3, section 3.1 for further recalculation details.

**Energy (Transport)**

Recalculations for Transport were made to all reporting years but were insignificant overall, ranging from a +0.1 Mt (+0.1%) in 2015 to -1.3 Mt (-0.7%) in 2021. Changes at this level are primarily due to revised activity data from the Marine Emission Inventory Tool (MEIT) for all reporting years and revised RESD fuel volumes for reporting years 2010 and later.

Recalculations for Domestic Aviation and Military Aviation were insignificant and solely a result of revised RESD fuel volumes. These recalculations were only applicable to the 2022 reporting year, resulting in a combined revision of -27 kt (-0.3%).

Recalculations for Road Transportation were primarily due to improvements to the Railway emissions methodology and revised RESD fuel volumes for reporting years 2020 and later. The improvements to the Railway emissions methodology resulted in small increases to proportions of RESD diesel fuel being attributed to Road Transportation whereas the revised RESD fuel volumes collectively resulted in small increases to amounts of fuel used for Road Transportation. Revisions to modelled off-road vehicle/engine populations also impacted Road Transportation estimates but to a lesser degree. While these changes had minimal impact on Road Transportation totals, revisions to modelled road vehicle populations for reporting years 2017 and later significantly changed the distribution of these totals amongst its subcategories. Cumulatively, these recalculations resulted in Road Transportation revisions ranging from -5.0 t (-0.0%) in 1996 to +1.1 Mt (+1.0%) in 2022.

Recalculations for Railways were significant and were applied to most reporting years because of improvements to the Railway emissions methodology. Activity data from the Railway Association of Canada was used to determine volumes of fuel being used in locomotives, which resulted in excess amounts of fuel associated with Railways in the RESD to be attributed to select road vehicles and off-road engines within Road Transportation and Other Transportation (Off-Road), respectively. This improvement was most significant for the 2008 reporting year, where the Railways total was revised by -1.2 Mt (-16%).

Recalculations for Domestic Navigation, Fishing, and Military Water-Borne Navigation were made to all reporting years and are significant for reporting years 2019 and later because of revised activity data from the MEIT and revised RESD fuel volumes. The revisions associated with the MEIT resulted in more fuel being used for vessel trips that are domestic in nature whereas the revisions associated with the RESD reduced the amount of heavy fuel oil used for navigation. Cumulatively, these recalculations resulted in revisions ranging from -1.4 Mt (-28%) in 2022 to +0.2 Mt (+5.4%) in 2018, for Domestic Navigation, Fishing, and Military Water-Borne Navigation combined.

Recalculations for Other Transportation (Off-Road) were made to all reporting years but were insignificant overall. These recalculations are primarily due to recalculations associated with Road Transportation and Railways which impact the proportions of RESD fuel attributed to Off-Road. Revisions to Road Transportation decreased proportions of RESD motor gasoline attributed to Off-Road whereas revisions to Railways increased proportions of RESD diesel fuel oil attributed to Off-Road. Revisions to modelled off-road vehicle/engine populations and RESD fuel volumes also impact Off-Road estimates for all reporting years but to a lesser degree. Cumulatively, these recalculations resulted in revisions ranging from -62 kt (-0.1%) in 2022 to +0.1 Mt (+0.2%) in 2019.

## Energy (Fugitives)

Significant recalculations occurred in the Oil and Natural Gas category of the Fugitives subsector for the entire time series. Updates to methodologies and activity data resulted in significant downward revisions from 1990 to 2000 and from 2015 to 2022, with overall decreases ranging from -0.6 Mt (-0.9%) in 1990 to -5.0 Mt (-6.6%) in 2022. Recalculations led to upward revisions from 2001 to 2014, ranging from +84 kt (+0.1%) in 2014 to a maximum increase of +1.5 Mt (+1.6%) in 2002. These revisions resulted from several recalculations with varying impacts:

1. Atmospheric measurements of CH<sub>4</sub>: atmospheric measurements of CH<sub>4</sub> emissions from storage tanks, unlit flares, compressor buildings, engine sheds, and wellheads (Saskatchewan only) at Upstream Oil and Gas (UOG) facilities conducted in 2023 were included in the inventory following the existing methodology. For a full description of the methodology and how atmospheric measurements from 2020, 2021, and 2023 have been incorporated for UOG in British Columbia, Alberta, and Saskatchewan, see Annex 3.2, section A3.2.2.1.5.

The addition of 2023 measurement-based CH<sub>4</sub> emissions for these sources resulted in recalculated emissions for 2022 in British Columbia, Alberta, and Saskatchewan. Overall, this resulted in a downward revision of -2.2 Mt (-8.3%).

2. Flaring and reported venting: updates to fugitive emissions from unlit flares resulted in recalculated flaring estimates in the UOG sector. See Annex 3.2, section A3.2.2.1.5 for a full description of how vented emissions from unlit flares are reconciled with flaring estimates to prevent double counting. Along with activity data updates, this led to an upward revision to flaring emissions of +74 kt (+1.4%) in 2022.

Reported venting emissions are also interdependent with atmospheric measurement-based estimates. Adjustments to the related procedure for reconciling estimates from fugitive and combustion emissions associated with compressor buildings in the UOG sector for Saskatchewan led to recalculations from 2020 to 2022. This resulted in upward revisions each of these years by +0.2 Mt (+3.3% in 2020, +4.7% in 2022). A detailed explanation of the recalculations related to this procedure can be found in Chapter 3, section 3.3.

3. British Columbia pneumatics: certain model parameters were updated to better reflect the number of emitting pneumatic devices in the British Columbia UOG sector. The updated parameters were derived using device populations extracted by the British Columbia government and provided directly to ECCC, which have been incorporated as described in Annex 3.2, section A3.2.2.1.3. This model update resulted in upward revisions from 1990 to 2020, ranging from +0.1 Mt (+104%) in 1990 to +0.7 Mt (+156%) in 2014.
4. British Columbia Formation CO<sub>2</sub>: the methodology used to extrapolate formation CO<sub>2</sub> emissions from British Columbia's natural gas processing sector was updated to account for changes to the average content of CO<sub>2</sub> in produced gas since 2012. The resulting recalculations included an upward revision of +0.2 Mt (+12%) in 2013 and downward revisions from 2014 to 2022, ranging from -28 kt (-1.6%) in 2014 to -1.3 Mt (-79%) in 2022.
5. Natural gas transmission and storage, distribution: fugitive estimates for each of the gas transmission, gas storage, and gas distribution sectors have been updated to directly incorporate aggregated operator reported emissions data from 2015 onwards. This update replaced the extrapolation of 2014 emissions for each subsequent year using activity data. Historical estimates were also updated to utilize more accurate EFs for equipment leaks in the gas transmission sector and to account for the gradual phase out of cast-iron piping in the Canadian gas distribution network. For a full description of the new methodology, see Annex 3.2, section A3.2.2.2.

These methodological changes led to upward revisions from 2001 to 2009 and downward revisions from 1990 to 2000 and from 2012 to 2022, while 2010 and 2011 estimates were unchanged. Overall, the revisions ranged from -3.8 Mt (-46%) in 1999 to +1.2 Mt (+50%) in 2002.

6. Fugitive equipment leaks: the reported compliance rate for UOG facilities under leak detection and repair requirements in Alberta was updated for 2022 in modelled equipment leak estimates. Combined with other minor updates to estimated facility counts, this resulted in a downward revision of -0.1 Mt (-1.6%) in 2022 and upward revisions of +10 kt (0.1%) in 2020 and 2021. The impacts of recalculations in earlier years due to updated facility counts were not significant.

Further recalculations to fugitive Oil and Natural Gas emissions occurred due to activity data updates, with minor impacts. The most significant changes involved petroleum refining fugitives and surface casing vent flow. Estimates for petroleum refining were revised in all years with changes ranging from -29 kt (-1.8%) in 2004 to +19 kt (+1.4%) in 2010. Surface casing vent flow emissions were revised upwards for the entire time series by a maximum of +26 kt (+1.7%) in 2016.

Recalculations also occurred for fugitive emissions from Solid Fuels due mainly to corrections of gross coal production values for Alberta and Nova Scotia. Refer to Chapter 3, section 3.3.1.5 for specific details. These updates to activity data for the Coal Mining and Handling sector resulted in revisions from 2000 to 2022, with a maximum downward revision of -136 kt (-8.9%) in 2022 and an upward revision of +81 kt (+5.4%) in 2018.

Note that more detailed recalculation explanations for Fugitive Emissions from Fuels can be found in Chapter 3, section 3.3.

## CO<sub>2</sub> Transport and Storage

Recalculations occurred for the CO<sub>2</sub> transport and storage category due to updates to facility reported emissions data, resulting in upward revisions from 2019 to 2022 with a maximum change of +0.1 Mt in 2020. Further details on these recalculations can be found in Chapter 3, section 3.4.

## Industrial Processes and Product Use

There were recalculations for the IPPU sector for the whole time series (1990–2022), ranging from +0.21 Mt to -1.73 Mt. Explanations on the category- and subsector-specific recalculations are provided below.

1990 to 2022 emissions for the Non-Energy Products from Fuels and Solvent Use subsector have undergone recalculations due to revisions to Statistics Canada's RESD data, updates to the use of lubricating oils and greases for off-road two-stroke engines and updates to the Methanol Production model that impacted the amount of natural gas assumed to be used as feedstock. The changes ranged from -0.05 kt in 2006 to +0.92 Mt in 2020.

For the Iron and Steel Production category, the entire time series (1990–2022) were also recalculated due to a methodological change that reallocated emissions from Energy to IPPU for the use of natural gas as a reductant in the production of pig iron. The magnitude of recalculations ranged from +0.007 Mt in 1990 to +1.27 Mt in 2021.

Recalculations also occurred for the Lime Production category for the period of 1990 to 2020. These were due to revisions to facility-reported data, and a methodological change which incorporated emissions from lime by-products and waste and revised the split between dolomitic lime and high-calcium lime production in Canada. The magnitude of these recalculations ranged from -0.030 Mt in 2018 to +0.095 Mt in 2000.

For the Magnesium Production category, 1990 to 2008 emissions were recalculated to include the reporting of CO<sub>2</sub> emissions. A portion of these CO<sub>2</sub> emissions were previously reported in the Non-Metallurgical Magnesia Production (Magnesite Use) category and have been recalculated using methodologies provided in the 2006 IPCC Guidelines. The magnitude of recalculations ranged from +0.014 Mt to +0.096 Mt.

## Agriculture

New activity data on drained organic soils under perennial production combined with a change to Tier 1 emission factors from the 2013 Wetland Supplement were included in the Agricultural estimates. Also, a minor correction was made to the non-growing season ratio-factor to assure consistency with the final value published in Pelster et al. (2024) that had a minor impact on soil N<sub>2</sub>O EFs.

## Land Use, Land-Use Change and Forestry

Recalculations occurred in the estimates of emissions and removals from the LULUCF sector, notably in the Forest Land, Cropland, Harvested Wood Products (HWP), Wetland and Settlement categories. The most important recalculations were:

1. Forest Land estimates have had activity data updates, specifically: updates of 2015–2022 clearcut harvesting and commercial thinning forest management data and updates in early and late time series of firewood harvest from Forest Land to Forest Land (FLFL) related to residential bioenergy.
2. New activity data on drained organic soils under perennial crop production combined with a change to Tier 1 emission factors of soil organic carbon losses from the 2013 Wetland Supplement were included in the Cropland Remaining Cropland estimates.
3. To address UNFCCC review recommendations on reporting completeness, biomass C gains and losses from Grassland to Cropland conversions using Tier 1 default values for grasslands and country-specific historical crop production values are included in Cropland estimates. Likewise, biomass C gains that occur in Cropland after deforestation as well as biomass C losses that occur from afforestation reported in Forestland were included in land use change estimates based on country-specific crop production data.
4. Peat extraction has been updated with revised country-specific emission factors and methodologies. Rewetted and restored areas have been differentiated, and new activity data has been included for the period between 2015 and 2022.
5. Estimates of emissions that result from Grassland to Settlement conversions that occur above the northern treeline have been updated with new activity data for the year 2020. Aboveground and below-ground biomass estimates were revised based on expert consultations and literature review.

The combined impact of these and other minor recalculations in the LULUCF sector increased the emission estimates by 0.7 Mt (1.3%) for 1990, and decreased by -0.7 Mt (-1.3%) in 2022.

Though, not visible in [Table 8–3](#), at the sectoral level, a very important revision to reporting occurred internally within the LULUCF reporting framework. Based on UNFCCC review recommendations, transfers of carbon to the HWP pool that result from harvest and Forest Land conversion are reported in the contributing Land categories. The HWP pool is now reported as the change in carbon stocks resulting from net difference between the carbon transfers into the HWP pool and the annual fluxes of carbon out of the HWP pool to the atmosphere or to the Waste stream, due to disposals. This change in reporting is most notable in the Forest Land and HWP reporting categories as Forest Land now reports a positive carbon flux and HWP is reported as a negative carbon flux throughout the time series. This change better captures the immediate impact of harvest on Forest carbon stocks and the important role of HWP as a significant global carbon store.

Refer to [Table 8–4](#) and [Chapter 6](#) for more details on recalculations.

## Waste

Recalculations in the Waste sector resulted in changes to emission estimates of +0.07 Mt (+0.34%) in 1990, -0.67 Mt (-2.8%) in 2005 and -0.36 Mt (-1.5%) in 2022 compared to the previous submission. These changes are the result of updated activity data, detailed as follows:

1. Recalculations for municipal solid waste landfills include updated waste disposal (facility-level and provincial/territorial totals), export and incineration data; updated and corrected waste source fractions; updated regional climate data; and updated methane recovery data. Updated waste characterization, representing the waste composition for 2020 forward, has been added. Recent voluntary surveys and data validation with facility operators have resulted in updates to facility-level disposal, methane recovery, and incineration data throughout the time series. Updated regional disposal, incineration and export data inform the estimates of total waste landfilled by province. The updated climate data combined with the updated facility-level disposal data yielded changes to the proportion of provincial/territorial waste landfilled by climate zone, impacting the entire time series for some provinces and territories, notably Ontario and Alberta. Some of the updated data replaced previously extrapolated values (between biennial survey years).
2. Recalculations in municipal wastewater treatment and discharge include updates and revisions to facility-level data, such as volumes treated, treatment technology and methane recovered. The majority of these updates were derived from the latest data reported through the Effluent Reporting Information System, as part of the *Wastewater Systems Effluent Regulation* (Canada, 2012) and recent voluntary surveys. Updated protein supply (FAOSTAT, n.d.) impacts N<sub>2</sub>O emissions estimates from 2010 forward, resulting in a 9% to 10% increase across all years.
3. Industrial wastewater recalculations include updated data from the latest Greenhouse Gas Reporting Program (GHGRP) and National Pollutant Release Inventory (NPRI; releases to water) data, which includes new data and revisions throughout the time series. Updated methane recovery data has become available through recent voluntary surveys.
4. Recalculations for incineration of waste include updates and revisions to facility-level quantities of waste incinerated for the entire time series from survey data and updates from the latest GHGRP inventory.
5. Recalculations for biological treatment of waste include updates to activity data in 2021 and 2022. For facilities not captured in the latest survey, it was assumed that the facility has remained active until confirmation of its closure (permanent or temporary) is obtained. A review of the activity data for biogas production was completed and updates were made across the time series.

## 8.2. Inventory Improvements

Inventory improvements aim to improve the accuracy of GHG estimates or enhance components of the inventory preparation process, including the supporting institutional, legal and procedural arrangements. Improvements that involve a methodological change or refinement are documented and reviewed prior to implementation. Where applicable, improvements that lead to recalculations of estimates for multiple years are applied to maintain time series consistency.

Improvements to Canada's inventory result from recommendations from the UNFCCC reviews completed in previous years, continued implementation of the reporting requirements and *2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories* (2006 IPCC Guidelines), and internal continuous improvement activities, for example, with the integration of the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019).

[Table 8–4](#) provides additional information about the improvements implemented this year presented by IPCC sectors and UNFCCC Common Reporting Table (CRT) categories.

### 8.2.1. UNFCCC Review Recommendations

Up to 2023, Canada's inventory submission was typically reviewed annually by an Expert Review Team (ERT) following agreed-upon UNFCCC review guidelines<sup>2</sup> as adopted in Decision 13/CP.20 in 2014. Starting in 2025, in accordance with Decision 18/CMA.1 (2018) and under Article 13 of the Paris Agreement, information submitted by each Party will undergo a technical expert review (TER) consistent with the MPGs. Every 2 years, these reviews will examine the information presented in the NIR and Biennial Transparency Report (BTR).<sup>3</sup> The BTR summarizes some of the information presented in the NIR, but also include information on progress towards Nationally Determined Contributions (NDCs), policies and measures, climate change impacts and adaptation, levels of financial, technology development and transfer and capacity-building support, and areas of improvement. Parties to the Paris Agreement are required to submit BTRs every two years, with the first submission that was due by the end of the year 2024.

Reviews are coordinated by the UNFCCC Secretariat, and the ERT (or now referred to as technical expert review team [TERT] under the Paris Agreement) is composed of inventory experts from developed and developing countries. The purpose of the review is to provide a thorough and comprehensive technical assessment of the implementation of the Convention and adherence to the reporting requirements. At the end of the review, the TERT provides technical feedback on any methodological and procedural issues encountered. The TERT focuses on instances where the guiding principles of transparency, consistency, comparability, completeness, and accuracy of the inventory could be improved. The outcome of the review is presented in a review report (referred to as technical expert review report [TERR] under the Paris Agreement) that is provided to the country under review and made public by the UNFCCC.

On the years that a BTR isn't due to the UNFCCC, Canada's NIR will undergo a simplified review instead of a TER. A simplified review consists of an initial assessment of completeness and consistency with the MPGs of predetermined aspects, mostly quantitative from the Common Reporting Tables (CRTs). This type of review is conducted by the UNFCCC Secretariat and in line with procedures developed by the lead reviewers. The findings of this initial assessment, to be published on the UNFCCC website, will form part of the subsequent TER of the NIR.

The recommendations from ERTs, from 2023 and prior, were taken into consideration when identifying potential improvements for this year. The latest review report completed by the ERT can be found on the [UNFCCC website](#).<sup>4</sup>

Methodological changes made this year that addressed the ERTs recommendations include:

- updates to the activity data and emission factors for waste fuels in the cement industry
- the integration of facility-level activity data from Canada's GHGRP for Lime Production for 2017 onwards
- the reallocation of emissions from the use of natural gas as a reductant in pig iron production from category 1.A.2.a to 2.C.1.b Iron and Steel
- the implementation of Tier 1 and 2 methods to refine the biomass change estimates associated with afforestation, deforestation and grassland conversions

Furthermore, an important revision to the way that emissions and removals are reported for Harvested Wood Products (HWP) in the LULUCF section was implemented based on the 2023 ERT recommendations. The change does not result in a recalculation for the section as a whole, but results in significant transfers of emissions and removals among Land Use categories.

### 8.2.2. Continuous Improvements

The GHG inventory team also identifies improvements based on evolving science, quality assurance / quality control (QA/QC) and verification activities (in accordance with the QA/QC Plan), and new and innovative modelling approaches or new sources of activity data. Implementation of the improvements is prioritized by taking into consideration the outcomes of the key category and uncertainty analysis, the level of effort and the significance of the improvements. Examples of continuous improvement activities implemented in this year's inventory include:

- updated model parameters for fugitive emissions from pneumatic devices in the British Columbia upstream oil and gas sector
- revisions to fugitive emission estimates from activities in the natural gas transmission, storage and distribution industries
- updated activity data and emission factors for waste fuel combustion in the cement industry

<sup>2</sup> 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>.

<sup>3</sup> Further details about the scope of technical expert reviews, including on exclusions from its scope, are available in the MPGs.

<sup>4</sup> <https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports-2023>.

- revision of emission factors (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) used for methanol production
- incorporation of locomotive fuel consumption data from the Railway Association of Canada to reallocate the quantity of fuel used for non-locomotive consumption from the volumes reported under railways in the RESD to the off-road sector
- new activity data on drained organic soils under perennial production combined with a switch to Tier 1 emission factors from the 2013 Wetland Supplement were included in the Agricultural estimates
- updated activity data on drained organic soils under perennial crop production were integrated into Cropland Agricultural Soils estimates and emission factors were updated to 2013 Wetland Supplement defaults
- refinements occurred in the LULUCF sector, with improved emission and removal factors for peat extraction under the Wetlands land use category, and revisions to Forest Land and HWP, in particular, harvest rates in the past two inventory years
- continued refinement of waste models with waste-specific parameters for municipal solid waste (MSW) and industrial wood waste landfills

### 8.3. Planned Inventory Improvements

Canada's official GHG inventory identifies and tracks potential planned improvements to emission estimates (including underlying activity data, EFs and methodologies). The planned improvements are based on recommendations from a variety of sources, including external review processes, collaborative work between inventory sector experts and industry, and other government departments and academia.

In addition, planned improvement activities ([Table 8–5](#)) are prioritized by taking into consideration key category analysis, QA/QC activities, uncertainty assessments, the level of effort and the significance of the improvements. Although the quantification of uncertainty for the emission estimates (Annex 2) helps prioritize improvement activities for future inventories, uncertainty itself is not an indicator of potential future changes resulting from continuous improvement activities. [Table 8–4](#) and [Table 8–5](#) are updated annually to track progress in implementing improvements to the inventory.

A detailed interdepartmental improvement plan has been developed specific to estimates related to the Forest Land and Harvested Wood Products categories reported in the LULUCF sector as described in section [8.3.1](#).

#### 8.3.1. Improvement Plan for Forest Land and Harvested Wood Products Greenhouse Gas Estimates

The improvement plan for Forest Land and Harvested Wood Products GHG estimates (NRCan and ECCC, 2024) was developed jointly and is updated annually by the Carbon Accounting Team of the Canadian Forest Service in Natural Resources Canada (NRCan-CFS-CAT) and the Pollutant Inventory and Reporting Division of the Science and Technology Branch in ECCC (S&T-PIRD) and approved by a Director Oversight Committee from both departments. Implementation schedules are re-evaluated annually in light of scientific and technical progress, changing priorities and resource availability.

The improvement plan provides a summary of recent consultation that the federal government has undertaken related to the quantification of carbon from the land sector. The government has engaged with experts and stakeholders through multiple fora to identify knowledge and information gaps and prioritise input to the scientific process that underlies carbon reporting in order to develop and continually improve the LULUCF inventory. Early in the development of the Forest Land reporting methodology, NRCan-CFS undertook the development of [A Blueprint for Forest Carbon Science in Canada](#). Prior to the implementation of the methodology used to focus reporting on the anthropogenic component of forest management, in 2016, an international review was commissioned and organized by NRCan-CFS and ECCC. Over the past four years, ECCC has led or commissioned consultations such as [Climate Science 2050](#), [The 2019 Carbon Workshop](#) or the recent Canadian Council of Academies report on [Nature-Based Climate Solutions](#). In addition, department officials have also engaged in dialogues with environmental groups who have published reports on the topic of forest carbon reporting and accounting. The most recent consultation focused directly on forest carbon science and including representatives from government, academia, industry and environmental organisations, the [2023 Blueprint for Forest Carbon Science](#), was completed in 2023 and published in 2024. The projects developed in the improvement planning process reflect these dialogues as well as recommendations from the ERT of the UNFCCC.

The improvement plan consists of projects that (1) can be operationalized<sup>5</sup> 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

<sup>5</sup> “Operationalized” means being incorporated into the annual inventory production process.

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 2025 GHG inventory submission represents the sixth edition of the 3-year rolling (2024 to 2026) GHG emissions and removals from forests, land-use change events involving forests, and HWP that are reported in the NIR. The current three-year window includes improvements being implemented in this inventory submission, as noted in [Table 8–4](#).

Several improvements are planned for the Forest Land category in future inventory submission, some details on the most significant changes are provided in section 6.3.1.6. In [Table 8–5](#), a summary of improvement projects is provided, and the complete [improvement plan](#) is published annually on the Government of Canada's [Open Data webpage](#).

IPCC Sector	CRT Category	Improvement	Description and Basis of Improvement	Section in NIR for more details
Energy (Stationary combustion Emissions)	Non-Metallic Minerals (1.A.2.f)	Updated activity data and emission factors for waste fuels in cement industry.	Following an ERT recommendation, activity data and emission factors from fossil fuel and biomass sources were separately developed to more accurately allocate emissions from waste fuels into the appropriate fuel category. From 2017 onward, facility-level activity data and emissions reported to Canada's GHGRP were integrated into the inventory in place of facility-level activity data and emission factors reported through the Cement Association of Canada.	section <a href="#">3.2.5.5</a>
	Residential (1.A.4.b)	Incorporating emission factors from wood stove study.	This update improves the accuracy of GHG estimates through incorporating updated emission factors for residential wood burning appliances into the inventory. ECCC commissioned a study of GHGs and air pollutant emissions from seven residential wood burning appliances, including an open fireplace, different types of wood stoves with varying types of emission controls, a fireplace heater, and a pellet stove. Study parameters emulated what are considered typical Canadian operating conditions of ambient temperature, wood type and wood moisture content. Average emission factors for CO <sub>2</sub> , CH <sub>4</sub> , and N <sub>2</sub> O were developed based on the results of the emission testing.	section <a href="#">3.2.7.5</a>
	Commercial/Institutional (1.A.4.a)	Energy use for industrial and municipal biogas facilities.	This update incorporates GHG emissions from the energy use of biogas in Canada. Facility-level survey data is used to identify biogas production and use for all known industrial and municipal Anaerobic Digesters covered under "Biological Treatment of Waste" in Canada. Biogas can be used on- or off-site for electricity or heat generation with the associated emissions integrated into the Energy section.	section <a href="#">3.2.7.5</a>
Energy (Fugitive Emissions)	Coal Mining and Handling (1.B.1.a)	Updates to Alberta coal production data.	Statistics Canada corrected Alberta's gross production volumes back to 2020, due to programing errors. Information from Alberta Energy Regulator (AER) Statistical Series 26 was used for quality control purposes of the historical dataset. This update improves the accuracy of fugitive coal mining emissions in Alberta.	section <a href="#">3.3.1.5</a>
	Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Revisions to natural gas transmission, storage and distribution emissions.	This update improves the accuracy of GHG estimates by integrating fugitive emissions data for the period from 2015 to 2022 provided by the Canadian Energy Partnership for Environmental Innovation (CEPEI). The CEPEI data are compiled using updated emission factors for key sources, replacing estimates that were previously extrapolated from 2014 onwards. The new approach minimizes historical time-series inconsistencies that arose from a patchwork of data sources used in the previous method, as well as potential inconsistencies associated with integrating the more recent CEPEI emissions data.	section <a href="#">3.3.2.5</a>
	Venting and Flaring – Venting (1.B.2.c.i)	Improvements to British Columbia formation CO <sub>2</sub> emissions.	The updated methodology improves the accuracy of formation CO <sub>2</sub> venting at natural gas processing facilities in British Columbia. Gas composition data from the British Columbia Energy Regulator is incorporated into the existing method to account for annual changes in CO <sub>2</sub> content of produced natural gas in B.C. since 2012.	section <a href="#">3.3.2.5</a>
	Venting and Flaring – Venting (1.B.2.c.i)	Revisions to British Columbia Upstream Oil and Gas (UOG) emissions from pneumatic devices.	In collaboration with representatives from the provincial government of British Columbia, model parameters used to estimate historical emissions from pneumatic devices have been updated to better reflect the number of emitting pneumatics present in the B.C. Upstream Oil and Gas sector. This update uses detailed device count data from the B.C. Industrial GHG Reporting Program to modify the relevant model parameters.	section <a href="#">3.3.2.5</a>
Energy (Transport Emissions)	Road Transportation (1.A.3.b)	Updates to road vehicle populations.	This update improves the comparability of modelled road vehicle populations to Statistics Canada's latest road vehicle registration data, which were recently updated for reporting years 2017 and later.	section <a href="#">A3.1.4.2</a>
	Railways (1.A.3.c)	Isolating locomotive fuel use from the Report on Energy Supply and Demand.	Locomotive fuel consumption data from the Railway Association of Canada was incorporated into the railway methodology as part of the continual effort to improve the accuracy of sectoral emissions.  The railway fuel volumes reported in the RESD are collected from suppliers who sell to industries with NAICS codes 482 (Rail Transport) and 4882 (Support Activities for Rail Transportation). Therefore, the RESD potentially contains fuel used for rail support activities, so the fuel consumption reported to the Railway Association of Canada is used to isolate the volume of fuel consumed by locomotives versus off-road rail support equipment. In the event that the RESD reports more fuel than what is reported to the Railway Association of Canada the fuel difference is reallocated to the off-road sector.	sections <a href="#">A3.1.4.2.4</a> and <a href="#">3.2.6.5</a> Recalculation section <a href="#">8.1.2</a>

Table 8–4 Improvements to Canada's 2025 NIR (cont'd)

IPCC Sector	CRT Category	Improvement	Description and Basis of Improvement	Section in NIR for more details
IPPU	Lime Production (2.A.2)	Activity data update for 2017 onwards.	Following an ERT recommendation, for 2017 onwards, facility-level activity data reported to Canada's GHGRP has been integrated into the inventory in place of national activity data. National activity data was previously sourced from Statistics Canada's Annual Mineral Production Survey (2019 onwards) and Natural Resources Canada (2017-2018).	section <a href="#">4.3.2</a>
	Lime Production (2.A.2)	Update to Tier 3 methodology used to calculate CO <sub>2</sub> emissions for 2017 onwards.	The Tier 3 methodology, used to estimate CO <sub>2</sub> emissions for 2017 onwards, has been updated to incorporate chemical compositions of products reported by facilities to Canada's GHGRP. Previously, facility-reported CO <sub>2</sub> emissions were directly integrated into the inventory.	section <a href="#">4.3.2</a>
	Lime Production (2.A.2)	Update to LKD correction factor.	The correction factor for lime kiln dust (LKD) applied to activity data of 1990-2016 has been revised to account for emissions from other by-products and waste from lime production, to ensure time-series consistency. Data reported by facilities to Canada's GHGRP was used to calculate the revised correction factor.	section <a href="#">4.3.2</a>
	Lime Production (2.A.2)	Update to the disaggregation of activity data for 1990-2016.	National lime production data was previously divided into two types: high-calcium and dolomitic, based on facility capacities, information on types of lime produced at each facility, and a default split factor for facilities where both types were produced. Facility-specific data on lime type(s) produced, reported to Canada's GHGRP, has been integrated to increase the accuracy of the disaggregation of national activity data for 1990-2016.	section <a href="#">4.3.2</a>
	Methanol Production (2.B.8)	Updated emission factors for post 2011 production.	Emissions of CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O for methanol production were previously calculated based on emission factors derived from data of facilities that ceased operations in 2006. In 2011, a new facility began production and updated emission factors were developed based on the data reported to Canada's GHGRP by this facility.	section <a href="#">4.9.2</a>
	Iron and Steel Production (2.C.1)	Reallocation of emissions from the use of natural gas from 1.A.2.a to 2.C.1.b.	Emissions of CO <sub>2</sub> and CH <sub>4</sub> resulting from the use of natural gas as a reductant in pig iron production were reallocated from CRT category 1.A.2.a to 2.C.1.b. Volumes of natural gas consumed, for the years 1990 to 2017, were obtained through a survey sent to existing operating facilities and beginning in 2018, the volumes were reported to Canada's GHGRP.	section <a href="#">4.10.2</a>
	Non-Metallurgical Magnesia Production (2.A.4.c) Magnesium Production (2.C.4)	Reallocation of CO <sub>2</sub> emissions associated with magnesium production from Non-Metallurgical Magnesia Production to Magnesium Production.	A portion of CO <sub>2</sub> emissions from magnesium production facilities that use magnesite as a raw material were previously reported under Non-Metallurgical Magnesia Production. These emissions have been recalculated using the 2006 IPCC Tier 1 methodology (volume 3, section 4.5) and reallocated to Magnesium Production. The CO <sub>2</sub> emissions to be reported under Magnesium Production further accounts for facilities that use dolomite as a raw material.	sections <a href="#">4.4.2</a> and <a href="#">4.13</a>
Agriculture	Agricultural Soils (3.D)	Emissions from drained Organic Soils.	Updated activity data including drained organic soils under perennial agricultural production and emission factors were updated to 2013 Wetland Supplement Tier 1 defaults.	sections <a href="#">5.4</a> and <a href="#">A3.4.5.1</a>
LULUCF	Forest Land Remaining Forest Land, Cropland, Settlement, Wetland and Harvested Wood Products (4.A, 4B, 4D.1, 4E and 4G)	Changes to Harvested Wood Product Reporting.	Based on an ERT recommendation, Harvested Wood Products will be reported as -44/12 × (annual carbon domestic harvest – annual flux of carbon associated with disposal of HWP that came from wood harvested in the reporting country). This reporting change makes Canada's reporting more comparable to other countries and resolves completeness issues raised by the ERT for each of the land-use categories. Transfers of carbon to HWP will be reported as a flux of carbon to HWP from each land use (Forest Land, Cropland, Settlement and Wetland) that contribute to HWP. As a result, HWP will be reported as an increase in carbon stocks (a negative flux) and the contributing land categories will be reported as the net flux resulting from the difference between removals of CO <sub>2</sub> from the atmosphere, emissions from decomposition and fluxes of C to the HWP pool. It does not result in a recalculation at the level of LULUCF but affects HWP and each of the land use categories indicated.	sections <a href="#">6.3</a> , <a href="#">6.4</a> , <a href="#">6.5</a> , <a href="#">6.7</a> , <a href="#">6.8</a> and <a href="#">6.9</a>
	Cropland Converted to Forest Land (4.A.2)	Implementation of Tier 2 method to include the biomass losses associated with afforestation.	Based on an ERT recommendation, a Tier 2 methodology has been implemented to account for the biomass C stocks lost from cropland when converted to Forest Land. Historical activity data on crop yields, crop residue biomass were used to estimate the emissions from Cropland biomass losses.	sections <a href="#">6.3.2</a> and <a href="#">A3.5.2.8</a>
	Forest Land Converted to Cropland (4.A.2)	Implementation of Tier 2 method to include the biomass losses associated with afforestation.	Based on an ERT recommendation, a Tier 2 methodology has been implemented to account for the biomass C stock gains on Cropland when converted from Forest Land. Historical activity data on crop yields, crop residue biomass were used to estimate the stock change from Cropland biomass gains.	sections <a href="#">6.5.2.1</a> and <a href="#">A3.5.4.3</a>
	Land Converted to Forest Land (4.A.2)	Refinements to recent afforestation land use conversion types.	As a result of a review of activity data used for afforestation: i) New 2019 afforestation activity in Ontario was added; ii) 2004, 2005 and 2022 data was revised.	section <a href="#">6.3.2</a> section <a href="#">A3.5.2.6</a>
	Cropland Remaining Cropland (4.B.)	Emissions from drained Organic Soils.	Updated activity data including drained organic soils under perennial agricultural production were integrated into Cropland estimates and emission factors were updated to 2013 Wetland Supplement defaults.	sections <a href="#">6.5</a> and <a href="#">A3.5.4</a>
	Wetland Remaining Wetland (4.D.1)	Updated Peat Extraction Model and Activity Data.	Updated Canadian science was integrated into the peat extraction model. Emission factors and activity data quantifying wetland extraction, restoration and abandonment were updated and high-resolution satellite imagery was used for a new sampling point for 2022 estimating extent of peatland areas disturbed by peat extraction.	sections <a href="#">6.7.1</a> and <a href="#">A3.5.6.1</a>
	Grassland to Settlements (4.E.2.3)	Updated emission factors and activity data.	New emission factors based on improved science and a new 2020 sampling point for activity data were integrated.	sections <a href="#">6.8.2.2</a> and <a href="#">A3.5.7.3</a>

Table 8–5 **Summary of Canada's Inventory Improvement Plan**

IPCC Sector	CRT Category	Improvement	Description
Energy	General	Conversion of volumes of natural gas to energy units.	An assessment of energy conversion factors is underway across three federal departments to allow volumes of natural gas to be converted to energy units by the province in which they are consumed.
	Fuel Combustion (1.A)	Improved tracking of low-carbon fuels.	Work is underway to improve tracking and allocation of emissions associated with low-carbon fuel (e.g., bio-ethanol, biodiesel, renewable natural gas, etc.) production and combustion.
	Fuel Combustion (1.A)	Update EFs for fuels with variable carbon content.	Work is underway to analyze data reported to ECCC's GHG Reporting Program to improve emission factors for fuels with carbon contents that vary such as still gas, natural gas and petroleum coke.
	Fuel Combustion - Other Sectors (1.A.4)	Analyze and incorporate digester gas into emission estimates.	Work is underway to incorporate emissions from on-farm digester gas used for energy purposes into the stationary combustion model.
	Fugitive Emissions from Fuels – Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Analyze and incorporate gas composition data for the province of British Columbia into emission estimates.	Work is underway to incorporate raw gas composition data collected and published by the British Columbia Energy Regulator (BCER) into oil and gas fugitive emission estimates. The data is also being analyzed to improve CO <sub>2</sub> EFs used to estimate emissions from raw gas combustion at oil and gas facilities.
	Fugitive Emissions from Fuels – Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Analyze and incorporate updated EFs for abandoned oil and gas wells in Alberta and Saskatchewan.	New CH <sub>4</sub> emission factors derived from recent province-specific measurement studies of abandoned (plugged) and inactive/suspended (unplugged) oil and gas wells are being evaluated for incorporation into emission estimates.
	Fugitive Emissions from Fuels – Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Analyze reported data to improve fugitive emission estimates from equipment leaks.	Work is underway to review and analyze data reported to British Columbia's industrial GHG reporting program and Alberta's OneStop reporting system in order to improve emission estimates from equipment leaks and better track the impact of Leak Detection and Repair (LDAR) programs on Upstream Oil and Gas emissions.
	Fugitive Emissions from Fuels – Oil and Natural Gas and Other Emissions from Energy Production (1.B.2)	Petroleum refining fugitive emissions.	Work is underway to evaluate data collected under ECCC's expanded GHG Reporting Program for the purpose of improving the quality of petroleum refining fugitive emissions (flaring, venting, and other unintentional leaks).
	Transport (General)	Evaluate and update renewable fuel content for transportation fuels.	Work is underway to evaluate and update average renewable fuel content values used as input in several transportation emissions methodologies, for the entire time series.
	Road Transportation (1.A.3.b)	Adoption of MOVES4.	Work is underway to adopt the latest version of the United States Environmental Protection Agency's Motor Vehicle Emissions Simulator (MOVES4). Notable changes compared to MOVES3 include updates to energy consumption rates and N <sub>2</sub> O emission rates associated with heavy-duty vehicles. In addition, MOVES4 will be executed to better respect Canadian road vehicle population input for all reporting years.
	Road Transportation (1.A.3.b)	Updates to road vehicle populations.	Work is underway to update the road vehicle fleet data used to allocate Statistics Canada's vehicle registration data amongst the appropriate IPCC categories. It is possible that the road vehicle fleet data will serve as direct input to MOVES, pending a thorough review of those data.
	Off-Road Transportation (General)	Port of NONROAD model.	Work is underway to port the Fortran-based version of NONROAD to an SQL environment. The port will facilitate various updates which may include updates to engine technology distributions, updates to geographical distributions, and updates to annual usage rates.
Oil and Gas (economic sector)	Natural Gas Production and Processing Conventional Light Oil Production Conventional Heavy Oil Production Oil Sands (Mining, In-Situ, Upgrading) Mining Coal Production	Refine allocation of combustion emissions to the Oil and Gas, Mining, and Coal Production economic sectors.	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 and data sources used to allocate fuel consumption and the subsequent emissions from the aggregated category to more discrete categories and subcategories.
IPPU	Cement Production (2.A.1)	Investigate 2018 activity data discrepancy.	An activity data outlier in 2018 was identified, impacting the Implied Emission Factor (IEF) for Cement Production for this year. Following an ERT recommendation, the activity data in question is under review to determine if corrections are required.
	Titanium Dioxide Production (2.B.6)	Collect activity data and report as a category in the inventory.	Process emissions are currently included elsewhere in CRT categories 1.A.2.b, 1.A.2.c and 2.C.3. Efforts are being made to collect activity data that would allow for reallocation of emissions from other categories to this category.
	Ethylene Oxide Production (2.B.8.d)	Collect activity data to apply a Tier 2 method and account for permanent carbon capture and storage.	Currently, Tier 1 emission estimates are developed using production data, and a mix of IPCC default emission factors and consultant-informed emission factors from 2010. Work is underway to obtain activity data, including carbon capture and storage information, from facilities to increase the emission estimate accuracy.
	Iron and Steel Production (2.C.1.e)	Estimate emissions from the production of iron ore pellets.	Emissions from the production of iron ore pellets is currently not estimated. Efforts are being made to identify suitable activity data for the entire time series.
	Rare Earths Production (2.C.7.a)	Include as a new category in the NIR	Historically, rare earths have not been produced in Canada and the category has not been included in the NIR. A facility began producing rare earth metals commercially in 2024. This category will be introduced into the inventory using methods presented in the 2019 Refinement to the 2006 IPCC Guidelines.
	Non-Energy Products from Fuels and Solvent Use (2.D)	Update EFs for various non-energy petroleum products and natural gas.	EFs for various non-energy petroleum products and natural gas were developed based on studies conducted in 1992 and 2005, respectively. To address an ERT recommendation, there is a plan to evaluate whether these emissions factors are still valid and to update if necessary.

Table 8–5 **Summary of Canada's Inventory Improvement Plan (cont'd)**

IPCC Sector	CRT Category	Improvement	Description
IPPU (cont'd)	Product Uses as Substitutes for ODS (HFCs, 2.F)	Update imports and exports of manufactured items containing HFCs.	To update data on imports and exports of HFC-containing items and to address an ERT recommendation, alternative data sources are being explored.
	Product Uses as Substitutes for ODS (HFCs, 2.F.1 & 2.F.2)	Update end-of-life EFs for HFCs in refrigeration, air-conditioning and foam blowing applications.	To address an ERT recommendation and examine the possibility of EF updates, sources of quantitative information on recent end-of-life practices are being explored.
	Electrical Equipment (2.G.1)	Reporting of CF <sub>4</sub> emissions.	Currently, only SF <sub>6</sub> is reported for this source category. It is planned to report CF <sub>4</sub> emissions as well, as it can be used with SF <sub>6</sub> in certain electrical equipment.
	Hydrogen Production (2.B.10.a)	Include CO <sub>2</sub> emissions resulting from stand-alone hydrogen production facilities in Canada.	Work is underway to estimate CO <sub>2</sub> emissions from hydrogen production using methods presented in the 2019 Refinement to the 2006 IPCC Guidelines.
	SF <sub>6</sub> and PFCs from other product use (2.G.2)	Data collection and significance assessment.	This category is currently reported as "not estimated". Based on an ERT recommendation, an evaluation of the significance of emissions from this category will be conducted. An activity data collection is planned and analysis of existing historical data is underway.
	PFC Emissions from Other Contained Product Uses (2.G.4)	Reallocation of all activity data to other CRT categories, such as applications in CRT 2.E.1, 2.F, or 2.G.2.	Following an ERT recommendation, activity data contributing to CRT 2.G.4 are under review and legacy data sources are being investigated to reallocate activity data to the correct categories.
Agriculture	Enteric Fermentation/Manure Management (3.A/3.B)/ Agricultural Soils (3.D)	Integrate new information on animal nutrition.	Based on an ERT recommendation noting that production data has not been reviewed recently, continued improvements to animal nutrition time series are being considered 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 new machine learning techniques are being considered and model development is not complete. Approval and alignment with Agriculture and Agri-Food Canada (AAFC) methodologies, specifically methodologies used in the estimation of ammonia volatilization, are required, to be followed by database implementation.
	Enteric Fermentation/Manure Management (3.A/3.B)/ Agricultural Soils (3.D)	Update dairy nutrition parameters.	Based on an ERT recommendation noting that production data has not been reviewed recently, the dairy nutrition time series that is currently used to track changes in animal feed and characteristics for dairy cattle is being extended. Updates to the nutrition data for dairy cattle are being derived for years after 2010. Data have been acquired and are undergoing analysis. Approval and alignment with AAFC methodologies will be followed by database implementation.
	Manure Management (3.B)	Integrate new information on manure management systems.	Based on the need to integrate new data into models efforts are ongoing to integrate information from multiple surveys to 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 new machine learning techniques are being considered and require approval and alignment with AAFC methodologies, specifically methodologies used in the estimation of ammonia volatilization, followed by database implementation.
	Manure Management (3.B)	Revise methane conversion factors (MCFs).	New science is being considered to replace methane conversion factors (MCFs) obtained from the 2006 IPCC Guidelines 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.
	Agricultural Soils (3.D)	Integrate estimates of N <sub>2</sub> O emissions from land application of compost.	The availability of new data may allow the reporting of N <sub>2</sub> O emissions from the application of compost to agricultural soils. A contract was carried out to collect information on land application of compost in Canada, and the resulting data is under analysis, for future alignment and integration with the existing organic nitrogen fertilizer methodology.
	Field Burning of Agricultural Residues (3.F)	Improve estimates of crop residue burning.	More recent data on crop residue burning are available from recent versions of the Farm Environmental Management Survey and Farm Management Survey, 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.
LULUCF	Cross-cutting	Address completeness of LULUCF subcategories with estimates reported as not estimated (NE).	An ERT recommendation notes that Canada needs to improve the completeness of reporting of pools in mandatory categories currently reported as NE. Continual progress is aimed to be made in each version subsequent of the NIR
	Cross-cutting	Development of a plan and time frame for estimating and reporting uncertainties for all LULUCF subcategories.	The UNFCCC ERT has noted that Canada provides detailed uncertainty analysis for most LULUCF subcategories. However, uncertainty analysis for all subcategories has not yet been prioritized. Uncertainty estimates for new and updated categories have been included in recent submissions. Canada aims to develop a plan for estimating, updating and reporting uncertainties for all LULUCF subcategories.
	Forest Conversion and other land-use change categories (it may impact Cropland, Wetlands, Settlements land categories and Harvested Wood Products, i.e., 4.B.2, 4.D.2, 4.E.2 and 4.G respectively)	Land-use change improvements.	As a part of efforts to address completeness of LULUCF subcategories with estimates reported as not estimated (NE) as indicated by the UNFCCC ERT, 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-CF53 and v) update deforestation impact assumptions.
	Forest Land (4.A) Harvested Wood Products (4.G)	Baseline data/processes/ parameters improvements.	Improvements include: i) improved spatial distribution of harvest and volume to C; ii) update climate normal data; iii) continue integration activity data associated to recent afforestation; and iv) provincial inventory updates.

Table 8–5 **Summary of Canada's Inventory Improvement Plan (cont'd)**

IPCC Sector	CRT Category	Improvement	Description
LULUCF (cont'd)	Forest Land (4.A) Biomass burning (4(V))	Science improvements.	Improvements include: i) refinements to wildfire emissions estimates through variable burn intensity; ii) refinements to British Columbia slashburning activity; iii) new calibrated soil and dead organic matter C modelling parameters, updated uncertainty analysis confidence intervals; and iv) integrating nationwide estimates of controlled biomass burning in the NIR, Air Pollutant and Black Carbon Emissions Inventories.
	Forest Land (4.A)	Methodological Validation.	Based on an ERT recommendation, Canada will undertake analyses to validate aspects of its Forest Land methodology, specifically: i) Revisiting Canada's natural/anthropogenic partitioning methodology in relation with human impacts on wildfire activity in the managed forest through a Delphi consultation that will engage a broad group of Canadian wildfire experts; ii) Exploration of long-term historic fluctuations in carbon emissions from fire activity and its interaction with Canada's natural/anthropogenic partitioning methodology using multi-century dendroecological fire history reconstructions; iii) Validation of CBM estimates using a provincial network of permanent sampling plots.
	Cropland (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).
	Cropland (4.B.1)	Woody Biomass improvements.	To better capture changes associated with woody biomass on croplands resulting from agricultural intensification and concurrent efforts to plant additional trees on Croplands, efforts are underway to improve estimation of woody biomass changes in C stocks in croplands through use of empirical data collection, earth observation data and deep learning methods.
	Wetland Converted to Cropland (4.B.2)	Land-use change improvements.	Improve the completeness of reporting of pools in mandatory categories currently reported as NE. Carbon loss resulting from agricultural drainage of inland mineral wetlands in the Prairie Potholes Region.
	Wetland Remaining Wetland (4.D.1.2) Land Converted to Wetland (Flooded Land) (4.D.2.2)	Development of activity data, parameters and EFs for CH <sub>4</sub> and CO <sub>2</sub> in flooded lands.	Improve knowledge of CH <sub>4</sub> and CO <sub>2</sub> emissions in flooded lands with updated activity data and EFs.
	Settlements Remaining Settlements (4.E.1.1)	Development of a new time series for 2005, 2015, and 2020 for urban trees and urban area boundaries. Revise model and urban boundaries.	Updates for 2005, 2015 and 2020 activity data by sampling of digital air photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas. Updates to urban area boundaries that better represent settlements. Refine model to improve estimates of carbon stock change.
	Harvested Wood Products (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.
Waste	Municipal Landfills (5.A.1)	Inclusion of Tier 3, facility-reported emissions.	Work is underway to incorporate facility-level emissions modelling, and facility reported emissions.
	Wood Waste Landfills (5.A.2)	Improved wood waste emissions modelling	Improvements underway include updating the landfill first-order-decay modelling parameters for industrial solid wood waste landfills. Efforts also include improving the characterization of harvested wood products in the waste stream.
	Wastewater Treatment and Discharge (5.D)	Update to receiving waterbody type (effluent emissions).	Efforts are underway to map effluent discharge to water body type (such as lake, river, estuary, etc.) to apply specific receiving water body type emission factors.
	Municipal Wastewater Treatment and Discharge (5.D.1)	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 also influence estimates of population using centralized treatment systems.
	Municipal Wastewater Treatment and Discharge (5.D.1)	Inclusion of combined sewer overflow.	Efforts are underway to compile (and model) occurrences of combined sewer overflow, to account for this contribution to untreated discharge to receiving waterbodies.

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# PART 2 AND PART 3

The 2025 edition of Canada's National Inventory Report (NIR) has been published simultaneously in both official languages, English and French. The NIR Part 1 ([Executive Summary](#) and chapters [1](#) to [8](#)) has been submitted in PDF format to the United Nations Framework Convention on Climate Change (UNFCCC) in both official languages. All content from NIR Parts 2 and 3 (annexes [1](#) to [13](#)) is also available in both official languages, in various formats at [open.canada.ca](https://open.canada.ca)<sup>1</sup> as outlined below.

NIR	Annex	Content
Part 2	<a href="#">1</a>	<a href="#">Key categories</a>
	<a href="#">2</a>	<a href="#">Uncertainty</a>
	<a href="#">3</a>	<a href="#">Methodologies</a>
	<a href="#">3.1</a>	<a href="#">Fossil fuel combustion</a>
	<a href="#">3.2</a>	<a href="#">Fossil fuel production, processing, transmission and distribution</a>
	<a href="#">3.3</a>	<a href="#">Industrial Processes and Product Use sector</a>
	<a href="#">3.4</a>	<a href="#">Agriculture sector</a>
	<a href="#">3.5</a>	<a href="#">Land Use, Land-Use Change and Forestry sector</a>
	<a href="#">3.6</a>	<a href="#">Waste sector</a>
	<a href="#">4</a>	<a href="#">Comparison of sectoral and reference approaches, and the national energy balance</a>
	<a href="#">5</a>	<a href="#">Assessment of completeness</a>
	<a href="#">6</a>	<a href="#">Emission factors</a>
	<a href="#">7</a>	<a href="#">Ozone and aerosol precursors</a>
Part 3	<a href="#">8</a>	<a href="#">IPCC sector rounding protocol</a>
	<a href="#">9</a>	<a href="#">Canada GHG emission tables by IPCC sector, 1990–2023</a>
	<a href="#">10</a>	<a href="#">Canada GHG emission tables by economic sector, 1990–2023</a>
	<a href="#">11</a>	<a href="#">Provincial and territorial GHG emission tables by IPCC sector, 1990–2023</a>
	<a href="#">12</a>	<a href="#">Provincial and territorial GHG emission tables by economic sector, 1990–2023</a>
	<a href="#">13</a>	<a href="#">Electricity in Canada: Summary and intensity tables</a>

<sup>1</sup> Environment and Climate Change Canada. 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>.