NATIONAL INVENTORY REPORT 1990–2020: GREENHOUSE GAS SOURCES AND SINKS IN CANADA

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

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Rapport d'inventaire national 1990–2020 : Sources et puits de gaz à effet de serre au Canada

FOREWORD

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

Canada's 2022 national GHG inventory complies with the requirements of the revised UNFCCC reporting guidelines for national GHG inventories (see Decision 24/CP.19). The Reporting Guidelines require Annex I Parties to develop their national inventories using the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. The reporting guidelines also require inventory reports to provide detailed and complete information on estimate 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 2021. Ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce their uncertainties as far as practicable.

April 2022

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Executive Summary

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Annexes

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Overall coordination of Canada's National Inventory Report was led by Raphaëlle Pelland St-Pierre. Centralized data compilation and the generation of comprehensive emission tables was led by Catherine Robert. Compilation of uncertainty estimates as well as key category analyses were led by Pegah Baratzadeh. Compilation and layout of the National Inventory Report for publication were led by Marida Waters with the support of Bruna Sunye. Editing and translation services were provided by the Translation Bureau of Public Services and Procurement Canada (PSPC). Special thanks to David Maher for the development of webpages related to this publication. The compilation and coordination of the CRF tables (companion to this document in Canada's United Nations Framework Convention on Climate Change submission) was managed by Catherine Robert. Policy context was drafted by Michael Copage.

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Readers' Comments

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LIST OF COMMON ABBREVIATIONS AND UNITS

Abbreviations

CAC .... criteria air contaminant
CANSIM .... Statistics Canada's key socioeconomic database
CEPA 1999 .... *Canadian Environmental Protection Act, 1999*
CESI .... Canadian Environmental Sustainability Indicators
CFC.................................. chlorofluorocarbon
CFS.................................. Canadian Forest Service
DOC .... dissolved organic carbon
ECCC .... Environment and Climate Change Canada
EF .... emission factor
FRD.................................. facility reported data
GDP .... gross domestic product
GHG .... greenhouse gas
GHGRP .... Greenhouse Gas Reporting Program
GWP .... global warming potential
HCFC .... hydrochlorofluorocarbon
HFC.................................. hydrofluorocarbon
HWP................................. harvested wood products
IPCC .... Intergovernmental Panel on Climate Change
IPPU .... Industrial Proccesses and Product Use
LTO .... landing and takeoff
LULUCF .... Land Use, Land-Use Change and Forestry
MSW .... municipal solid waste
N/A................................... not available
NDC .... nationally determined contribution
NIR................................... National Inventory Report
NMVOC .... non-methane volatile organic compound
NPRI .... National Pollutant Release Inventory
ODS .... ozone-depleting substance
OECD................................ Organisation for Economic Co-operation and Development
PFC.................................. perfluorocarbon
POP .... persistent organic pollutant
QA.................................... quality assurance
QC .... quality control

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

TAN .... total ammoniacal nitrogen

UOG .... upstream oil and gas

VKT .... vehicle kilometres traveled

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

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

Chemical Formulas

Al .... aluminium

$CaCO_3$ .... calcium carbonate; limestone

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

CaO .... lime; quicklime; calcined limestone

CF_4 .... carbon tetrafluoride

C_2F_6 .... carbon hexafluoride

CH_3OH .... methanol

CH_4 .... methane

C_2H_6 .... ethane

C_3H_8 .... propane

C_4H_{10} .... butane

C_2H_4 .... ethylene

C_6H_6 .... benzene

CO .... carbon monoxide

CO_2 .... carbon dioxide

CO_2 eq .... carbon dioxide equivalent

H_2 .... hydrogen

H_2O .... water

H_2S .... hydrogen sulphide

HNO_3 .... nitric acid

Mg .... magnesium

$MgCO_3$ .... magnesite; magnesium carbonate

MgO .... magnesia; dolomitic lime

N .... nitrogen

N_2 .... nitrogen gas

Na_2CO_3 .... sodium carbonate; soda ash

NF_3 .... nitrogen trifluoride

NH_3 .... ammonia

NH_4+ .... ammonium

NH_4NO_3 .... ammonium nitrate

N_2O .... nitrous oxide

N_2O-N .... nitrous oxide emissions represented in terms of nitrogen

NO .... nitric oxide

NO_2 .... nitrogen dioxide
NO_3- .... nitrate
NO_x .... nitrogen oxides
O_2 .... oxygen
SF_6 .... sulphur hexafluoride
SiC .... silicon carbide
SO_2 .... sulphur dioxide
SO_x .... sulphur oxides

Notation Keys

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

Units

g... gram
Gg .... gigagram
Gt .... gigatonne
ha .... hectare
kg .... kilogram
kha .... kilohectare
km .... kilometre
kt .... kilotonne
kWh .... kilowatt-hour
m .... metre
Mg .... megagram
Mha .... million hectares
mm .... millimetre
ML .... megalitre
Mt .... megatonne
MW .... megawatt
PJ .... petajoule
TJ .... terajoule
t.. tonne
TWh .... terrawatt-hour

EXECUTIVE SUMMARY

ES.1. Key Points

- After fluctuations in recent years, Canada's greenhouse gas (GHG) emissions decreased to 672 megatonnes of carbon dioxide equivalent (Mt CO_2 eq) in 2020 (the most recent year for which data are available for this report), net decreases of 66 Mt or 8.9% from 2019 and 69 Mt or 9.3% from 2005.
- The year 2020 was marked by the COVID-19 pandemic, coinciding with a decrease in emissions of 66 Mt or 8.9% across numerous sectors. Notable examples include Transport (-27 Mt or -12%) largely due to fewer kilometers driven and a decrease in air traffic; and Public Electricity and Heat Production (-7.4 Mt or -11%) due to decreased coal consumption partially offset by an increase in natural gas consumption.
- During the period covered by this report (1990–2020), Canada's economy grew more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (GHG per gross domestic product [GDP]) has declined by 39% since 1990 and by 26% since 2005. The decline in emissions intensity can be attributed to fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy. The drivers for these changes include continued implementation and strengthening of efforts to reduce emissions by all levels of government within Canada.
- Continuous improvement is a key principle underlying Canada's annual greenhouse gas inventory. Important methodological improvements are being implemented in this edition of the National Inventory Report (NIR) (e.g. fugitive methane emissions from upstream oil and gas and emissions from agricultural soils), and additional improvements are being considered for future editions (e.g. emissions and removals from managed forest land, and emissions from transport). The enhanced methods use Canadian-specific studies and knowledge, facilitate the adoption of new scientific data, and better capture the impact of improvements in technologies and industry practices on emissions.

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 December 1992, and the Convention came into force in March 1994.

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To achieve its objective and implement its provisions, the UNFCCC sets out several guiding principles and commitments. Specifically, Articles 4 and 12 commit all Parties to develop, periodically update, publish and make available to the Conference of the Parties their national inventories of anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol, with the exception of hydrofluorocarbons (HFCs).[1]

Canada's National Greenhouse Gas Inventory is prepared and submitted annually to the UNFCCC by April 15 of each year in accordance with the revised *Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention, Part I: UNFCCC Reporting Guidelines on Annual Inventories* (UNFCCC Reporting Guidelines), adopted through Decision 24/CP.19 in 2013. The annual inventory submission consists of the NIR and the Common Reporting Format (CRF) tables.

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

Significant improvements to NIR estimates are anticipated in future editions of this report, notably related to emissions and removals from managed forest land, and emissions from on-road and off-road transport. For more details on planned inventory improvements, please refer to Chapter 8.

In 2021, Canada formally submitted its enhanced Nationally Determined Contribution (NDC) to the United Nations, committing Canada to cut its GHG emissions to 40-45% below 2005 levels by 2030. This target represents a significant increase in ambition over its previous NDC, submitted in 2015, of reducing emissions to 30% below 2005 levels by 2030. Since 2005 was adopted as a base year for Canada's targets, many of the metrics in this report are presented in that context, in addition to the 1990 base year as required by the UNFCCC Reporting Guidelines.

Section ES.3 of this Executive Summary provides the latest information on Canada's net anthropogenic GHG emissions over the 2005–2020 period and links this information to relevant indicators of the Canadian economy. Section ES.4 outlines the major trends in emissions.

For the purposes of analyzing economic trends and policies, it is useful to allocate emissions to the economic sector from which they originate. Section ES.5 presents Canada's emissions broken down by the following economic sectors: Oil and Gas, Electricity, Transport, Heavy Industry, Buildings, Agriculture, and Waste and others.[2] Throughout this report, the word "sector" generally refers to activity sectors as defined by the IPCC for national GHG inventories; exceptions occur when the expression "economic sectors" is used in reference to the Canadian context.

Section ES.6 details GHG emissions for Canada's 13 sub-national jurisdictions. Finally, section ES.7 provides some detail on the components of this submission and outlines key elements of its preparation.

Canada's Action on Climate Change

Canada is on a path to significantly reduce greenhouse gas (GHG) emissions, through the raising of climate and economic ambition since 2015 supported by extensive national climate efforts—including the Pan-Canadian Framework on Clean Growth and Climate Change* (2016), the Strengthened Climate Plan (2020), Canada's enhanced 2030 target (2021), and the enactment of the *Canadian Net-Zero Emissions Accountability Act* (2021). Prior to these efforts, Canada's emissions were on a steady upwards climb and were projected to increase 12% above 2005 levels by 2030. The Government of Canada was required under the Act to establish the 2030 Emissions Reduction Plan (ERP) by the end of March 2022, to outline Canada's approach to reaching a reduction of 40-45% below 2005 levels by 2030, as committed to in Canada's NDC, and setting Canada on a path to reaching net-zero emissions by 2050.

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

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

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Pan-Canadian Framework on Clean Growth and Climate Change

Canada's first-ever national climate plan, the Pan-Canadian Framework on Clean Growth and Climate Change (PCF), was adopted in 2016. The PCF was developed in collaboration with Canada's provinces and territories, and in consultation with national Indigenous organizations, stakeholders, and Canadians.

In addition to the price on carbon pollution—among the most stringent in the world—the PCF included more than 50 measures to drive down Canada's emissions, help build resilience across the country, and support climate innovation for clean economic growth. Progress on implementation of these measures has been reported through annual Synthesis Reports.

A Healthy Environment and a Healthy Economy – Canada's Strengthened Climate Plan

In December 2020, the Government of Canada introduced its Strengthened Climate Plan – *A Healthy Environment and a Healthy Economy*.** This strengthened climate plan detailed a series of commitments, building on PCF measures, to reduce emissions to 31% below 2005 levels by 2030.

Significant investments have been made to support the implementation of measures in the PCF and the Strengthened Climate Plan. This includes $15 billion in additional funding for public and active transportation announced in February 2021, and an additional $17.6 billion committed to through Canada's federal Budget 2021 in support green economic recovery, while helping to address emissions from heavy industry and from buildings.

Canadian Net-Zero Emissions Accountability Act (CNZEAA)

While Canada has made significant progress in reducing emissions to 2030, it has also laid a strong foundation for the deeper reductions needed to achieve net-zero emissions by 2050.

With the enactment of the CNZEAA in June 2021, Canada has now put in place the legislative requirements that will underpin a transparent and accountable process to long-term emissions reduction planning, an approach that will incorporate consultation with Canadians, provinces and territories, and Indigenous Peoples, and be informed by expert advice.

Emissions Reduction Plan

Pursuant to the CNZEAA, the Emissions Reduction Plan (ERP) includes key measures the Government intends to take to achieve the 2030 target, an interim GHG emissions objective for 2026, an overview of relevant sectoral strategies, and a projected timetable for implementation of measures. The Government engaged with provinces, territories, Indigenous Peoples, the Net-Zero Advisory Body, and interested Canadians to identify what is needed to reach Canada's climate objectives. Full participation from Canadians and all sectors of the economy is essential for building an effective pathway to achieve Canada's 2030 and 2050 climate goals and a prosperous economy.

Net-Zero Advisory Body

On February 25, 2021, the Minister of Environment and Climate Change launched the Net-Zero Advisory Body (NZAB), an independent group of experts with a mandate to provide independent advice with respect to achieving Canada's target of net-zero emissions by 2050. Further information on the NZAB's current activities and forward-looking plans can be found on its website: nzab2050.ca.

Conclusion

Canada's National Inventory Report, along with other reports such as Canada's National Communications and Biennial Reports, the greenhouse gas and air pollutant emissions projections (also submitted to the UNFCCC), annual synthesis reports on the status of implementation of the PCF, and future legislated reports, all support Canada's assessment of its progress in reducing emissions and combatting climate change.

* https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework.html

** https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/healthy-environment-healthy-economy.html

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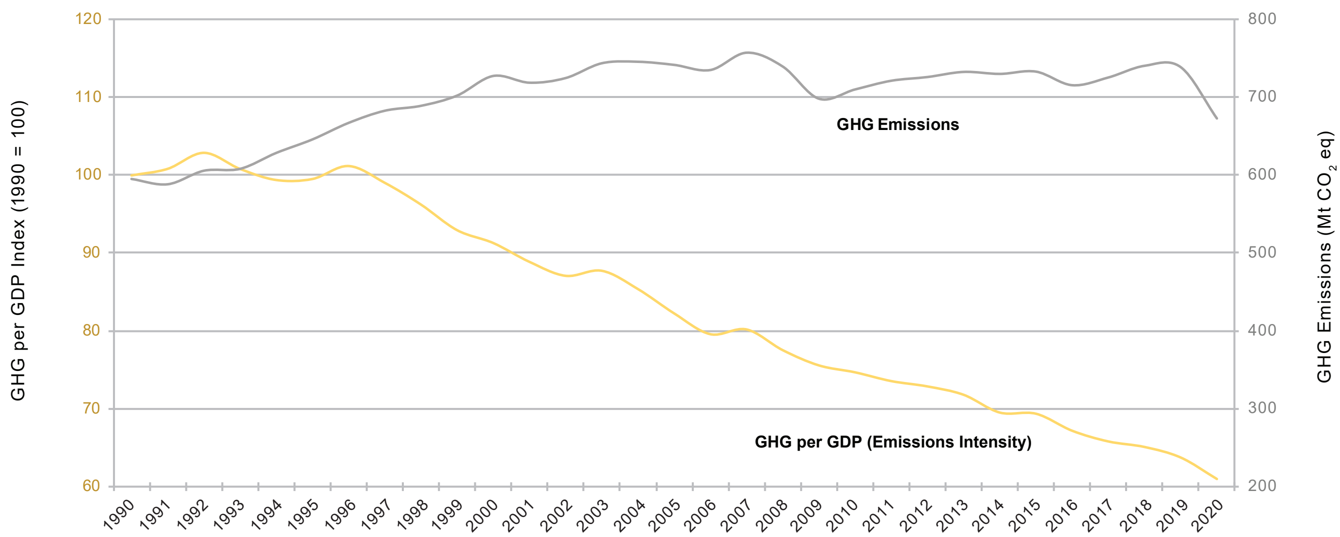
ES.3. Overview, National GHG Emissions

After fluctuations in recent years, Canada's GHG emissions were 672 Mt CO_2 eq[3] in 2020 (the most recent year for which data are available for this report), a net decrease of 69 Mt or 9.3% from 2005 emissions (Figure ES–1).[4] Emission trends since 2005 have remained consistent with previous editions of the NIR, with emission increases in the Oil and Gas and Transport sectors being offset by decreases in other sectors, notably Electricity and Heavy Industry.

In general, year-to-year fluctuations are superimposed over actual trends observed over a longer time period. During the period covered in this report, Canada's economy grew more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (GHG per GDP) has declined by 39% since 1990 and by 26% since 2005 (Figure ES–1 and Table ES–1). The decline in emissions intensity can be attributed to fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.

Of note is a decrease of 66 Mt between the years 2019 and 2020, coinciding with the first year of the COVID-19 pandemic. This decrease occurred in numerous sectors, most notably Transport (-27 Mt or -12%), Stationary Combustion (-22 Mt or -6.8%), and Fugitive Sources (-17 Mt or -25%). The decrease in Transport emissions includes decreases in Light-Duty Gasoline Vehicles and Trucks (-15 Mt or -17%) and domestic Aviation (-3.8 Mt or -44%). These are linked to a decrease in the vehicle kilometres traveled (VKT) in the light-duty vehicles and trucks categories, and a decrease in air traffic in 2020 relative to 2019. Fugitive sources includes emissions decreases from venting (-11 Mt), and leaks from oil (-3 Mt) and natural gas production and processing facilities (-2 Mt). Within Stationary Combustion Sources, decreases in Public Electricity and Heat Production (-7.4 Mt or -11%) were due to decreased coal consumption partially offset by an increase in natural gas consumption; decreases in Manufacturing Industries (-4.5 Mt or -11%) can be partially attributed to plants that closed, temporarily and permanently, during the first year of the pandemic. Temporary shut-down of some plants can also only partially explain the decrease in the Industrial and Processes and Product Use sector (-3.1 Mt or -6.0%) between 2019 and 2020.

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



Notes:
Emissions do not yet reflect the impact of the most recent mitigation policies.
Total emissions fall within a 2% uncertainty range.
GDP data source: StatCan (n.d.[a])

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

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

The emissions trends and their drivers are summarized in the remainder of this Executive Summary and are described in greater detail in Chapter 2 of this report.

In 2020, the Energy sector (consisting of Stationary Combustion, Transport and Fugitive Sources) emitted 540 Mt, or 80% of Canada's total GHG emissions (Figure ES–2). The remaining emissions were largely generated by the Agriculture and IPPU sectors (8.2% and 7.5%, respectively), with contributions from the Waste sector (4.1%) and the LULUCF sector removed 6.8 Mt from the atmosphere.

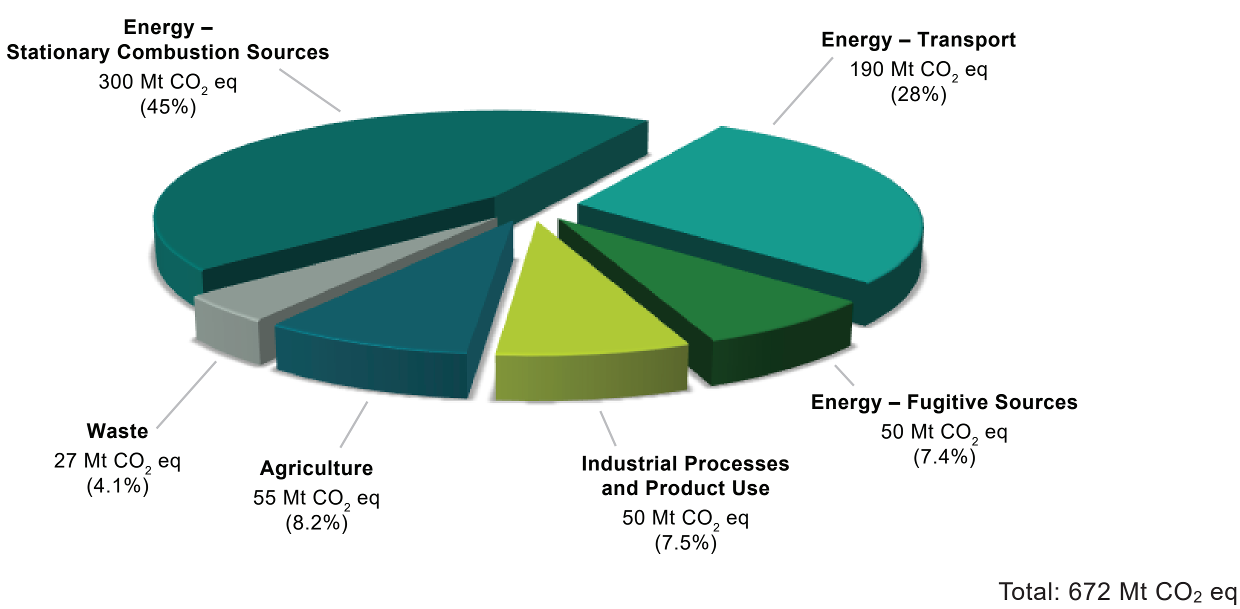
Canada's emissions profile is similar to that of most industrialized countries, in that CO_2 is the largest contributor to total emissions, accounting for 535 Mt or 80% of total emissions in 2020 (Figure ES–3). The majority of CO_2 emissions in Canada result from the combustion of fossil fuels. CH_4 emissions in 2020 amounted to 92 Mt or 14% of Canada's total. These emissions consist largely of fugitive emissions from oil and natural gas systems, agriculture and landfills. N_2O emissions mostly arise from agricultural soil management and accounted for 33 Mt or 4.9% of Canada's emissions in 2020. Emissions of synthetic gases (HFCs, PFCs, SF_6 and NF_3) accounted for slightly less than 2% of national emissions.

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

Year	2005	2015	2016	2017	2018	2019	2020
Total GHG (Mt)	**741**	**733**	**715**	**725**	**740**	**738**	**672**
Change since 2005 (%)	NA	-1.2%	-3.5%	-2.2%	-0.2%	-0.4%	-9.3%
GDP[a] (Billion 2012$)	**1 654**	**1 938**	**1 953**	**2 022**	**2 086**	**2 126**	**2 024**
Change since 2005 (%)	NA	17%	18%	22%	26%	29%	22%
GHG Intensity (Mt/$B GDP)	**0.45**	**0.38**	**0.37**	**0.36**	**0.35**	**0.35**	**0.33**
Change since 2005 (%)	NA	-16%	-18%	-20%	-21%	-23%	-26%

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

Figure ES–2 **Breakdown of Canada's Emissions by Intergovernmental Panel on Climate Change Sector (2020)**



Note: Totals may not add up due to rounding.

Canada accounted for approximately 1.6% of global GHG emissions in 2018 (Climate Watch, 2021), although it is one of the highest per capita emitters. Canada's per capita emissions have declined since 2005 from 23.0 t CO_2 eq/capita to a new low of 17.7 t CO_2 eq/capita in 2020 (Figure ES–4).

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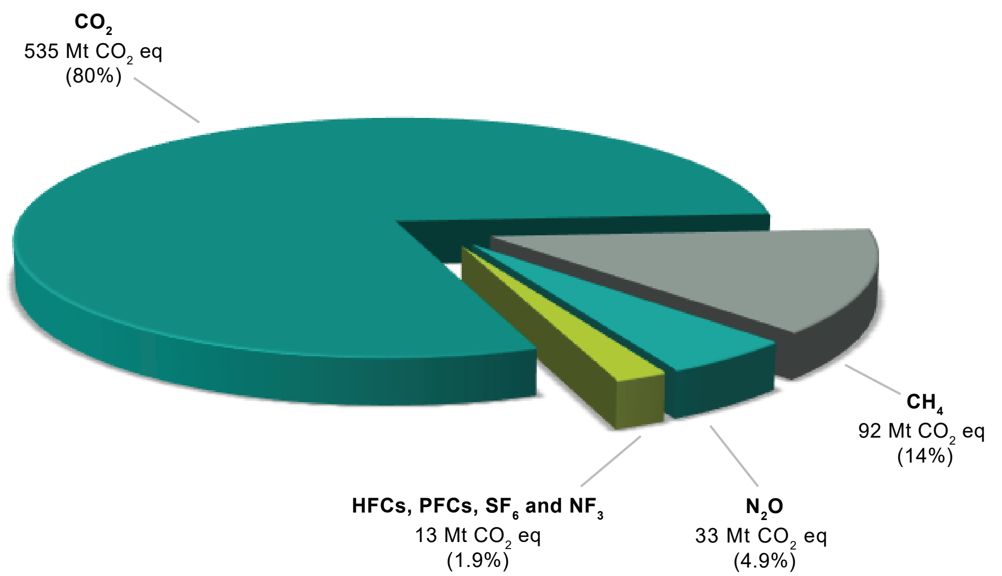
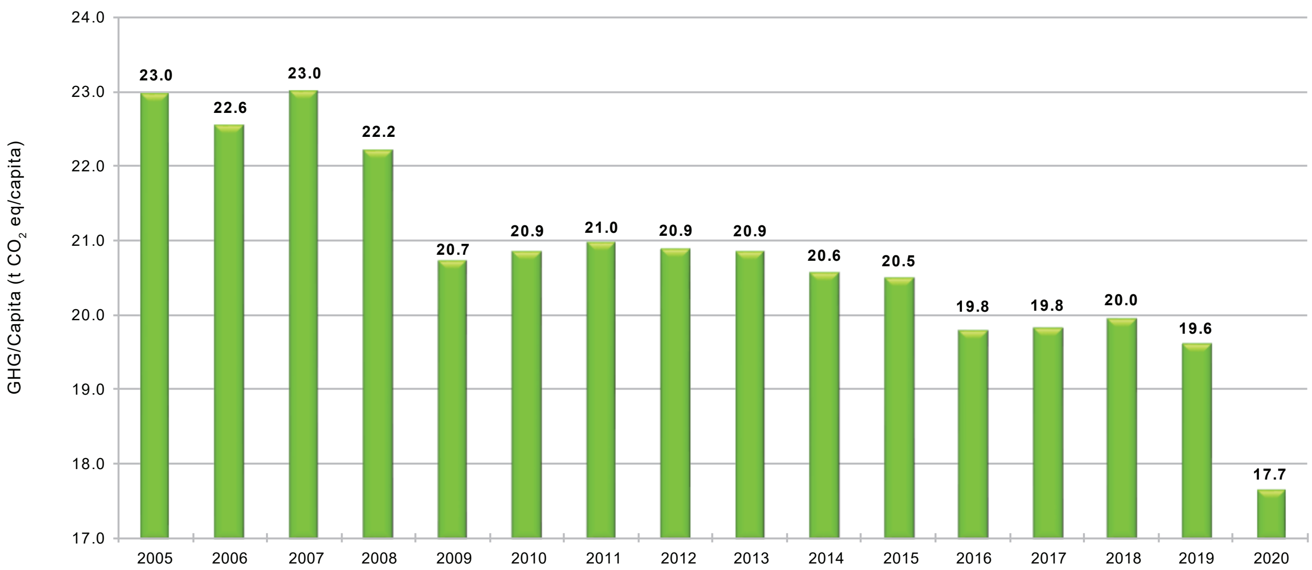
Figure ES–3 **Breakdown of Canada's Emissions by GHG (2020)**



Note: Totals may not add up due to rounding.

Figure ES–4 **Canadian per Capita GHG Emissions (2005–2020)**



Note: Population data source – StatCan (n.d.[b])

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

Trends in Emissions

Over the 2005–2020 period, total emissions have decreased by 69 Mt or 9.3% (Figure ES–5). Two sources of the Energy sector dominated this trend, with emission decreases of 23 Mt (32%) in Fugitive Sources and 39 Mt (12%) in Stationary Combustion Sources (Table ES–2). Over the same period, emissions have decreased by 6.3 Mt (11%) in the IPPU sector and 1.4 Mt (4.8%) in the Waste sector. Moreover, emissions from Transport (also in the Energy sector) have generally increased from 2005 to 2019 and decreased between 2019 and 2020, bringing the 2020 emissions to a level similar to 2005 (0.07 Mt or 0.0% increase). The Agriculture sector emissions have remained relatively stable with 0.98 Mt or 1.8% increase (Figure ES–6).

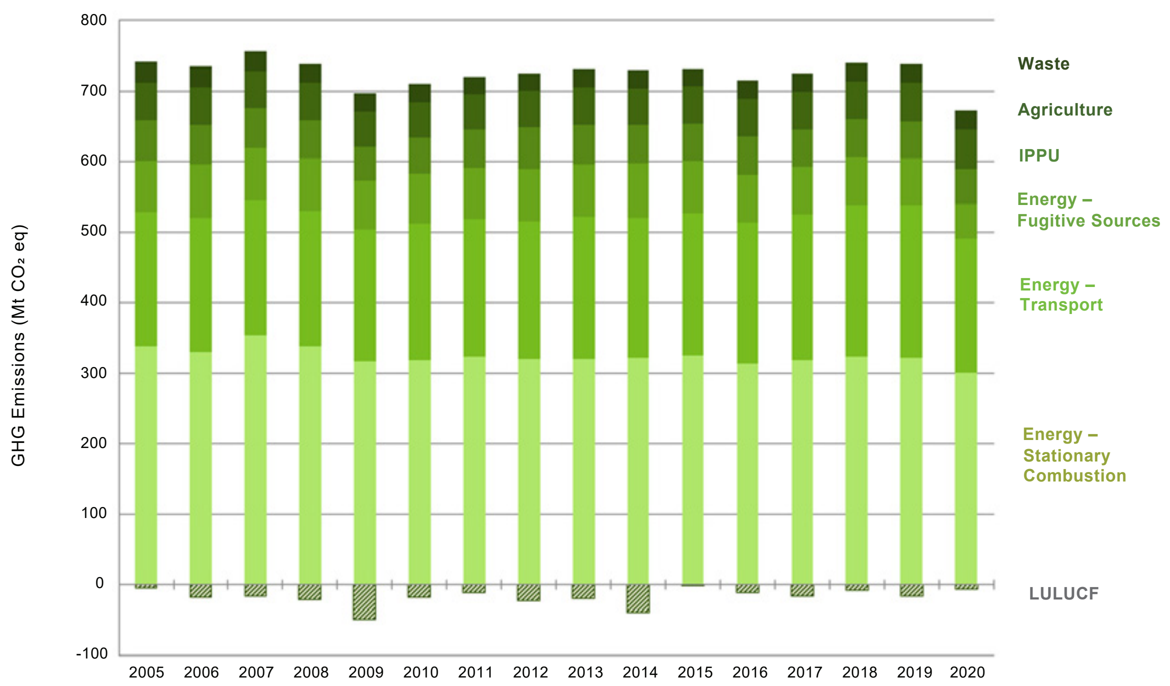
Chapter 2 provides more information on GHG emissions trends since 1990 and 2005 and their drivers.[5] Further breakdowns of emissions and a complete time series can be found at open.canada.ca.

The following describes the emissions and trends of each IPCC sector since 2005 in further detail.

Energy – 2020 GHG Emissions (540 Mt)

In 2020, GHG emissions from the IPCC Energy sector (540 Mt), or 80% of Canada's total GHG emissions, were 10% lower than in 2005 (602 Mt). Within the Energy sector, a 37 Mt increase in combustion emissions from Oil and Gas Extraction and a 1.5 Mt increase in Road Transportation emissions were largely offset by a 63 Mt decrease in emissions from Public Electricity and Heat Production, a 9.1 Mt decrease in emissions from stationary fuel consumption in Manufacturing Industries, a 5.6 Mt decrease in emissions from Petroleum Refining and a 5.3 Mt decrease in emissions in the Residential sector.

Figure ES–5 **Trends in Canadian GHG Emissions by Intergovernmental Panel on Climate Change Sector (2005–2020)**



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

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Stationary Combustion Sources (300 Mt)

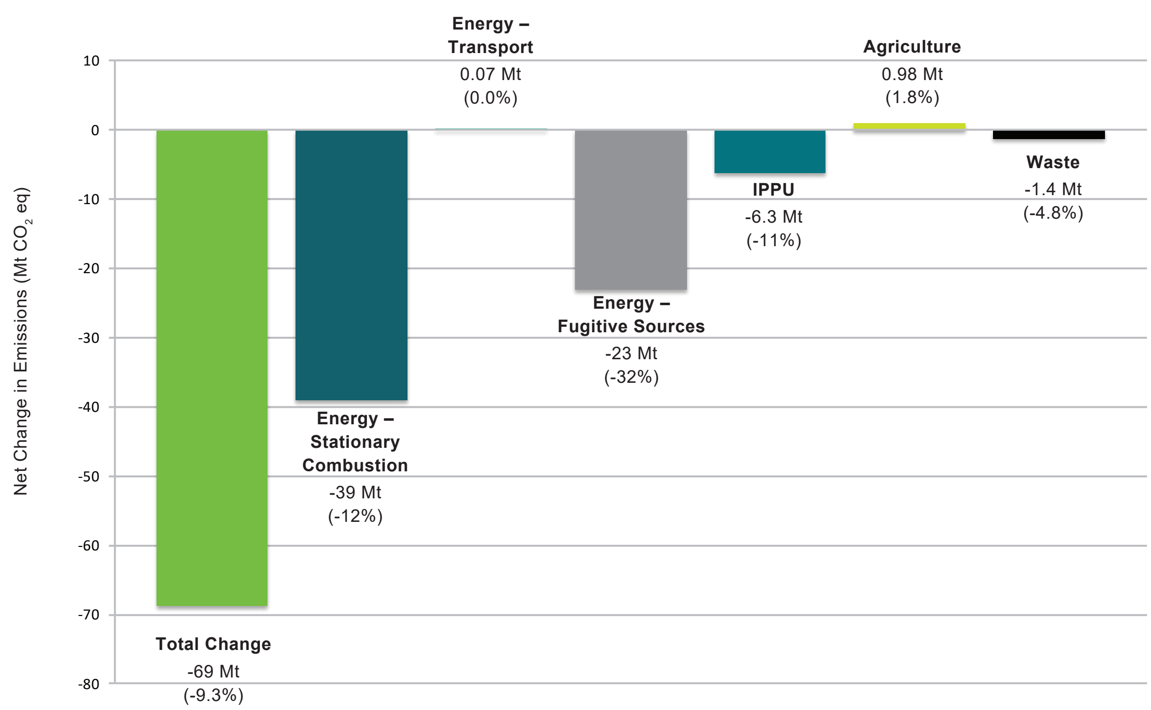
Decreasing electricity generation from coal and oil (decreases of 62% and 86%, respectively) was a large driver of the 63 Mt decrease in emissions associated with Public Electricity and Heat Production between 2005 and 2020. The permanent closure of all coal generating stations in Ontario by 2014 (Ontario Power Generation Inc. [OPG], 2015) accounted for 41% of the decreased coal consumption, and reduced coal consumption in Alberta and Saskatchewan accounted for an additional 45% and 9%, respectively. Reduced coal consumption also occurred in Nova Scotia (25%), New Brunswick (58%) and Manitoba (100%). Decreased oil consumption for electricity generation in New Brunswick (97%) and Nova Scotia (97%), offset by increased consumption in Newfoundland and Labrador (11%), accounted for 98% of the reduced oil consumption. Emission fluctuations over the period reflect variations in the mix of electricity generation sources; over the time period, the amount of low-emitting generation in the mix has increased.[6]

The 37 Mt increase in emissions from stationary fuel consumption in Oil and Gas Extraction is consistent with a 190% rise in the extraction of bitumen and synthetic crude oil from Canada's oil sands operations since 2005.

Since 2005, four petroleum refineries have permanently closed or converted to terminal facilities including one each in Ontario (2005), Quebec (2010), Nova Scotia (2013) and Newfoundland and Labrador (2020) contributing to the 5.6 Mt decrease in emissions from this sector.

GHG emissions from Manufacturing Industries decreased by 9.1 Mt between 2005 and 2020, consistent with a 19% decrease in energy use (StatCan, n.d.[c]). This includes a decrease of -5.0 Mt between 2005 and 2019, and an additional -4.5 Mt between 2019 and 2020. While the decrease between 2005 and 2019 is based on decreases in certain sectors (-3.4 Mt from Other Manufacturing, -1.4 Mt in both Cement, and Pulp, Paper and Print), offset by increases in others (1.4 Mt in Chemicals), the decrease between 2019 and 2020 occurred in all Manufacturing Industries. The largest decreases are from Iron and Steel (-1.4 Mt); Other Manufacturing (-1.0 Mt) and Cement (-0.9 Mt).

Figure ES–6 **Changes in GHG Emissions by Intergovernmental Panel on Climate Change Sector (2005–2020)**



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

Table ES–2 **Canada's GHG Emissions by Intergovernmental Panel on Climate Change Sector, Selected Years**

GHG Categories		2005	2015	2016	2017	2018	2019	2020
		Mt CO_2 Equivalent						
TOTAL[a, b]		**741**	**733**	**715**	**725**	**740**	**738**	**672**
ENERGY		**602**	**600**	**581**	**594**	**606**	**604**	**540**
a.	Stationary Combustion Sources	339	325	313	318	323	322	300
	Public Electricity and Heat Production	125	88	81	79	71	70	62
	Petroleum Refining Industries	20	16	16	15	15	16	14
	Oil and Gas Extraction	63	98	94	98	104	104	100
	Mining	4.4	4.6	4.4	5.0	6.5	6.4	6.0
	Manufacturing Industries	48	44	42	43	43	43	39
	Construction	1.4	1.3	1.3	1.3	1.4	1.4	1.4
	Commercial and Institutional	32	30	32	34	36	38	36
	Residential	43	41	38	40	44	41	38
	Agriculture and Forestry	2.2	3.0	3.2	3.1	3.2	3.5	3.1
b.	Transport	190	201	200	208	215	216	190
	Aviation	7.7	7.6	7.5	7.9	8.7	8.6	4.8
	Road Transportation	130	142	145	148	152	153	131
	Railways	6.6	7.1	6.5	7.5	7.6	7.7	7.2
	Marine	4.0	3.4	3.5	3.6	3.8	4.4	4.2
	Other Transportation	42	41	38	41	43	43	43
c.	Fugitive Sources	73	74	68	68	68	66	50
	Coal Mining	1.4	1.1	1.3	1.2	1.3	1.4	1.1
	Oil and Natural Gas	71	73	67	67	67	65	49
d.	CO_2 Transport and Storage	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
INDUSTRIAL PROCESSES AND PRODUCT USE		**57**	**54**	**55**	**53**	**54**	**53**	**50**
a.	Mineral Products	10	8.0	7.9	8.6	8.6	8.8	8.1
b.	Chemical Industry	10	6.8	7.0	6.4	6.8	6.7	6.6
c.	Metal Production	20	14	15	15	15	14	13
d.	Production and Consumption of Halocarbons, SF_6 and NF_3	5.1	11	11	11	12	12	12
e.	Non-Energy Products from Fuels and Solvent Use	10	13	12	11	11	11	10
f.	Other Product Manufacture and Use	0.54	0.54	0.60	0.63	0.70	0.66	0.73
AGRICULTURE		**54**	**52**	**53**	**52**	**53**	**53**	**55**
a.	Enteric Fermentation	31	24	24	24	24	24	24
b.	Manure Management	8.7	7.7	7.8	7.9	7.8	7.8	7.8
c.	Agricultural Soils	13	18	18	17	19	19	21
d.	Field Burning of Agricultural Residues	<0.05	0.06	0.05	0.05	0.05	0.05	0.05
e.	Liming, Urea Application and Other Carbon-Containing Fertilizers	1.4	2.6	2.5	2.4	2.6	2.7	3.0
WASTE		**29**	**26**	**26**	**27**	**27**	**27**	**27**
a.	Solid Waste Disposal (Landfills)	23	21	21	21	22	22	22
b.	Biological Treatment of Solid Waste	0.24	0.31	0.32	0.33	0.36	0.36	0.36
c.	Wastewater Treatment and Discharge	1.9	2.6	2.4	2.5	2.5	2.5	2.5
d.	Incineration and Open Burning of Waste	0.35	0.20	0.20	0.19	0.18	0.18	0.16
e.	Industrial Wood Waste Landfills	3.3	2.5	2.4	2.4	2.3	2.2	2.2
LAND USE, LAND-USE CHANGE AND FORESTRY		**- 4.2**	**- 0.08**	**- 11**	**- 17**	**- 8.5**	**- 16**	**- 6.8**
a.	Forest Land	-135	-135	-136	-137	-134	-138	-130
b.	Cropland	-22	-10	-17	-23	-19	-14	-9.6
c.	Grassland	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
d.	Wetlands	3.1	3.0	3.1	3.1	2.8	2.9	2.9
e.	Settlements	1.7	2.5	2.5	2.4	2.2	2.2	2.2
f.	Harvested Wood Products	148	140	137	137	140	131	128

Notes:

Totals may not add up due to rounding.

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

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

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In the Residential category, decreasing consumption of light fuel oil in all provinces and territories, except Newfoundland and Labrador (4% increase) between 2005 and 2020 is the largest driver of the 5.3 Mt decrease in emissions. Quebec and Ontario account for 88% of the decrease in emissions from light fuel oil, with the remaining provinces and territories making up the remaining 12%.

Transport (190 Mt)

The majority of transport emissions in Canada are related to Road Transportation, which includes personal transportation (light-duty vehicles and trucks) and heavy-duty vehicles. The growth in road transportation emissions is largely due to more driving, exemplified by increases in the supply of diesel, in gasoline retail pump sales, and in the number of on-road vehicles. Despite a reduction in kilometres driven per vehicle, the total vehicle fleet has increased by 42% since 2005, most notably for trucks (both light- and heavy-duty), leading to more kilometres driven overall.

From 2005 to 2019, emissions from Transport have generally increased. From 2019 to 2020, Transport emissions decreased 27 Mt, bringing 2020 Transport emissions back to 2005 levels.

Fugitive Sources (50 Mt)

Since 2005, fugitive GHG emissions from fossil fuel production (coal, oil and natural gas) have decreased by 23 Mt. This includes a 6.5 Mt decrease between 2005 and 2019 that is largely the result of provincial regulations to increase conservation of natural gas (comprised mainly of CH_4) as well as a 16.6 Mt decrease between 2019 and 2020 that coincides with federal regulations to reduce methane emissions from the upstream oil and gas industry and equivalent provincial regulations in Saskatchewan, Alberta and British Columbia.

Industrial Processes and Product Use – 2020 GHG Emissions (50 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 50 Mt (7.5%) to Canada's 2020 emissions.

Between 2005 and 2020, process emissions from most IPPU categories decreased. A notable exception is the 6.8 Mt (134%) increase in emissions from the use of HFCs to replace CFCs and HCFCs before the gradual phase down of HFCs mandated under the Kigali Amendment to the Montreal Protocol, which came into force in 2019.

Temporary shut downs of some industrial facilities in 2020 caused process emission decreases of 0.50 Mt (-7.0%) for Cement Production and of 0.15 Mt (-11%) for Lime Production, when compared to the 2019 emission values.

Since 2005, process emissions for the iron and steel industry have reduced by 3.3 Mt (-32%) primarily due to decline in use of metallurgical coke as reductant during the pig iron production process and drop in pig iron production in 2020. The aluminium industry has also decreased its process emissions by 2.8 Mt (32%) since 2005, largely due to the implementation of technological improvements to mitigate PFC emissions and the shutdown of older smelters using Søderberg technology, the last of which was closed in 2015. Closure of primary magnesium plants in 2007 and 2008 also accounted for 1.1 Mt (92%) of the overall process emission drop (-7.2 Mt or -36%) seen in Metal Production between 2005 and 2020.

The overall decrease of 3.8 Mt (37%) of GHG emissions from chemical industries since 2005 is primarily the result of the 2009 closure of the sole Canadian adipic acid plant located in Ontario. N_2O emissions abatement installations at a nitric acid production facility are responsible for a smaller proportion (1.0 Mt) of the decrease. Variations throughout the time series in petrochemical industry-related emissions can be attributed to facility closures and changes in production capacities at existing facilities, such as the closure of two methanol facilities in 2005 and 2006, and an increase in ethylene production in 2016.

Agriculture – 2020 GHG Emissions (55 Mt)

The Agriculture sector covers non-energy GHG emissions related to the production of crops and livestock. Emissions from Agriculture accounted for 55 Mt, or 8.2% of total GHG emissions for Canada in 2020.

In 2020, Agriculture accounted for 30% of national CH_4 emissions and 75% of national N_2O emissions.

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 in the Prairie provinces. Since 2005, fertilizer use has increased by 89%, while major livestock populations peaked in 2005, then decreased sharply until 2011. In 2020, emissions from livestock digestion (enteric fermentation) accounted for 43% of total agricultural emissions, and the application of inorganic nitrogen fertilizers accounted for 21% of total agricultural emissions.

Waste – 2020 GHG Emissions (27 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from Waste contributed 27 Mt (4.1%) to Canada's total emissions in 2020 and 29 Mt (3.9%) in 2005.

The primary sources of emissions in 2020 for the Waste sector are disposal in landfills including municipal solid waste (MSW) (22 Mt) and industrial wood waste landfills (2.2 Mt). In 2020, these landfills combined accounted for 89% of Waste emissions, while Biological Treatment of Solid Waste (composting), Wastewater Treatment and Discharge, and Incineration and Open Burning of Waste together accounted for the remaining 11%.

In 2020, CH_4 emissions from MSW landfills made up 81% of all waste emissions; these emissions decreased by 3.6% between 2005 and 2020. Of the 35 Mt CO_2 eq of CH_4 generated by MSW landfills in 2020, 22 Mt CO_2 eq (62%) were actually emitted to the atmosphere, with a large proportion (30% or 10 Mt CO_2 eq) being captured by landfill gas collection facilities and flared or used for energy, as compared to 25% in 2005.

Land Use, Land-Use Change and Forestry – 2020 (Net GHG Removals of 6.8 Mt)

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

In this sector, the net flux is calculated as the sum of CO_2 and non-CO_2 emissions to the atmosphere and CO_2 removals from the atmosphere. In 2020, this net flux amounted to net removals of 6.8 Mt that, when included with emissions from other sectors, decreases Canada's total GHG emissions by 1.0%.

Net removals from the LULUCF sector have varied over recent years fluctuating between removals of 0.1 Mt in 2015 to 49 Mt and 39 Mt in 2009 and 2014, respectively. Fluctuations are driven by the variability in crop yields and by variations in emissions from HWP and removals from Forest Land, which are closely tied to harvest rates.

Estimates from the Forest sector are split between emissions from HWP, emissions and removals resulting from significant natural disturbances on managed forests (wildfires and insects) and anthropogenic emissions and removals associated with forest management activities. The combined net flux from Forest Land and Harvested Wood Products—from forest harvest—fluctuated from a net source of 9.4 Mt in 2005 to a net sink of 22 Mt in 2009 (lowest harvest year), and was observed to be a net sink of 6.5 Mt in 2020. Approximately 33% of HWP emissions result from long-lived wood products reaching the end of their economic life decades after the wood was harvested. Emission and removal patterns in both HWP and Forest Land have therefore been influenced by recent forest management trends and by the long-term impact of forest management practices in past decades.

Cropland has contributed to net removals in the land sector over the reporting period, with the exception of drought years on the prairies in early 2000s that result in a peak in net emissions in 2003 (7.6 Mt). Interannual variability is high throughout the time series, reflecting weather-related impacts to crop production. Net removals have increased, on average, as a result of improved soil management practices including conservation tillage and an overall gradual increase in crop productivity resulting from increased fertilization and reduced use of summerfallow. 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 peak yields and subsequently peak removals in 2009 (-36 Mt) and 2014 (-44 Mt).

The conversion of forests[7] 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 2020 have fluctuated around 16 Mt.

ES.5. Canadian Economic Sectors

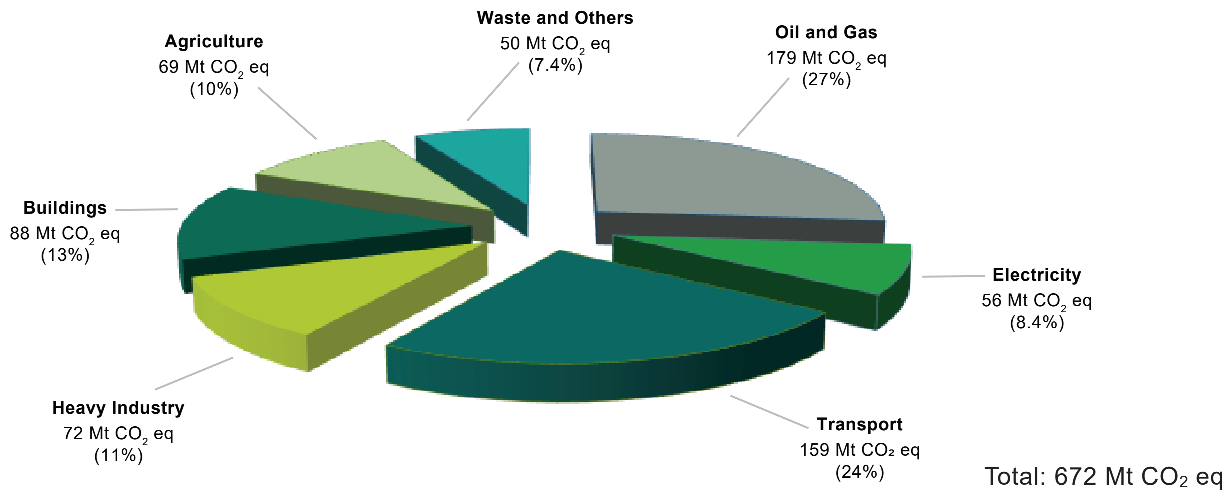
For the purposes of analyzing economic trends and policies, it is useful to allocate emissions to the economic sector from which they originate. In general, a comprehensive emission profile for a specific economic sector is developed by reallocating the relevant proportion of emissions from various IPCC subcategories. This reallocation simply re-categorizes emissions under different headings and does not change the overall magnitude of Canadian emissions estimates.

7 Forest conversion emissions are incorporated within sums of emissions of other LULUCF categories; therefore, the values reported here are included in the sums associated with the other category totals.

GHG emissions trends in Canada's economic sectors are consistent with those described for IPCC sectors, with the Oil and Gas and Buildings economic sectors showing emission increases of 7.5 Mt or 4.4% and 4.1 Mt or 4.9%, respectively, since 2005 (Figure ES–7 and Table ES–3). These increases have been more than offset by emission decreases in Electricity (-61 Mt or -52%), Heavy Industry (-15 Mt or -18%), and Waste and others (-5.0 Mt or -9.0%). Since 2005, Transport emissions have generally increased; emissions in 2020 dropped and are comparable to 2005 levels (-0.93 Mt or -0.6% since 2005). Between the years 2019 and 2020, Oil and Gas emissions have decreased significantly (-25 Mt or -12%), coinciding with federal regulations to reduce methane emissions from the upstream oil and gas industry and equivalent provincial regulations in Saskatchewan, Alberta and British Columbia.

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

Figure ES–7 **Breakdown of Canada's GHG Emissions by Economic Sector (2020)**



Note: Totals may not add up due to rounding.

Table ES–3 **Canada's GHG Emissions by Economic Sector, Selected Years**

	2005	2015	2016	2017	2018	2019	2020
	Mt CO_2 equivalent						
NATIONAL GHG TOTAL	**741**	**733**	**715**	**725**	**740**	**738**	**672**
Oil and Gas	171	205	194	196	205	203	179
Electricity	118	80	74	73	63	62	56
Transport	160	172	173	179	184	185	159
Heavy Industry[a]	87	78	76	76	77	77	72
Buildings	84	84	82	87	93	92	88
Agriculture[b]	66	65	65	64	66	67	69
Waste and Others[c]	55	50	50	50	51	52	50

Notes:

Totals may not add up due to rounding.

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

a. Heavy Industry represents emissions arising from non-coal, -oil and -gas mining activities, smelting and refining, and the production and processing of industrial goods such as fertilizer, paper or cement.
b. Emissions associated with the production of fertilizer are reported in the Heavy Industry sector.
c. "Others" includes Coal Production, Light Manufacturing, Construction and Forest Resources.

ES.6. Provincial and Territorial GHG Emissions

Emissions vary significantly by province and territory as a result of such factors 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 that rely more on hydroelectricity.

Historically, Alberta and Ontario have been the highest-emitting provinces. Since 2005, emission patterns in these two provinces have diverged. Emissions in Alberta have increased by 19 Mt (8.2%) since 2005, primarily as a result of the expansion of oil and gas operations (Figure ES–8 and Table ES–4). In contrast, Ontario's emissions have decreased by 55 Mt (27%) since 2005, owing primarily to the closure of the last coal-fired electricity generation plants in 2014.

Quebec's emissions decreased by 10 Mt (12%) between 2005 and 2020 and those in Saskatchewan and British Columbia also decreased by 5.4 Mt (7.6%) and 1.8 Mt (2.9%), respectively, over the same time period. Emissions in Manitoba have increased since 2005, (1.1 Mt or 5.6%). Other provinces that have seen significant decreases in emissions include New Brunswick (7.3 Mt or a 37% reduction), Nova Scotia (8.4 Mt or a 36% reduction), Newfoundland and Labrador (1.0 Mt or a 9.1% reduction) and Prince Edward Island (0.29 Mt or a 15% reduction). Furthermore, emissions in the Northwest Territories have also decreased (0.32 Mt or 19%), and Yukon and Nunavut have seen increases in emissions (0.03 Mt or 5.6%, and 0.02 Mt or 3.2%, respectively).

ES.7. National Inventory Arrangements

Environment and Climate Change Canada is the single national entity with responsibility for preparing and submitting the national GHG inventory to the UNFCCC and for managing the supporting processes and procedures.

The institutional arrangements for the preparation of the inventory include formal agreements on data collection and estimate development; a quality management plan, including an improvement plan; identifying key categories and generating quantitative uncertainty analysis; a process for performing recalculations due to improvements; procedures for official approval; and a working archive system to facilitate third-party review.

Submission of information regarding the national inventory arrangements, including details on institutional arrangements for inventory preparation, is also an annual requirement under the UNFCCC Reporting Guidelines (see Chapter 1, section 1.2).

Structure of Submission

The UNFCCC requirements include the annual compilation and submission of both the NIR and the CRF tables. The CRF tables are a series of standardized data tables containing mainly numerical information that are submitted electronically. The NIR contains the information to support the CRF tables, including a comprehensive description of the methodologies used in compiling the inventory, the data sources, the institutional structures, and the quality assurance and quality control procedures.

Part 1 of the NIR includes Chapters 1 to 8. Chapter 1 (Introduction) provides an overview of Canada's legal, institutional and procedural arrangements for producing the inventory (i.e., the national inventory arrangements), quality assurance and quality control procedures, and a description of Canada's facility emission-reporting system. Chapter 2 provides an analysis of Canada's GHG emission trends in accordance with the UNFCCC reporting structure and a breakdown of emission trends by Canadian economic sectors. Chapters 3 to 7 provide descriptions and additional analysis for each sector, according to UNFCCC reporting requirements. Chapter 8 presents a summary of recalculations and planned improvements.

Part 2 of the NIR consists of Annexes 1 to 7, which provide a key category analysis, an inventory uncertainty assessment, detailed explanations of estimation methodologies, Canada's energy balance, completeness assessments, emission factors and information on ozone and aerosol precursors.

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

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Figure ES–8 **GHG Emissions by Province and Territory in 2005, 2010 and 2020**

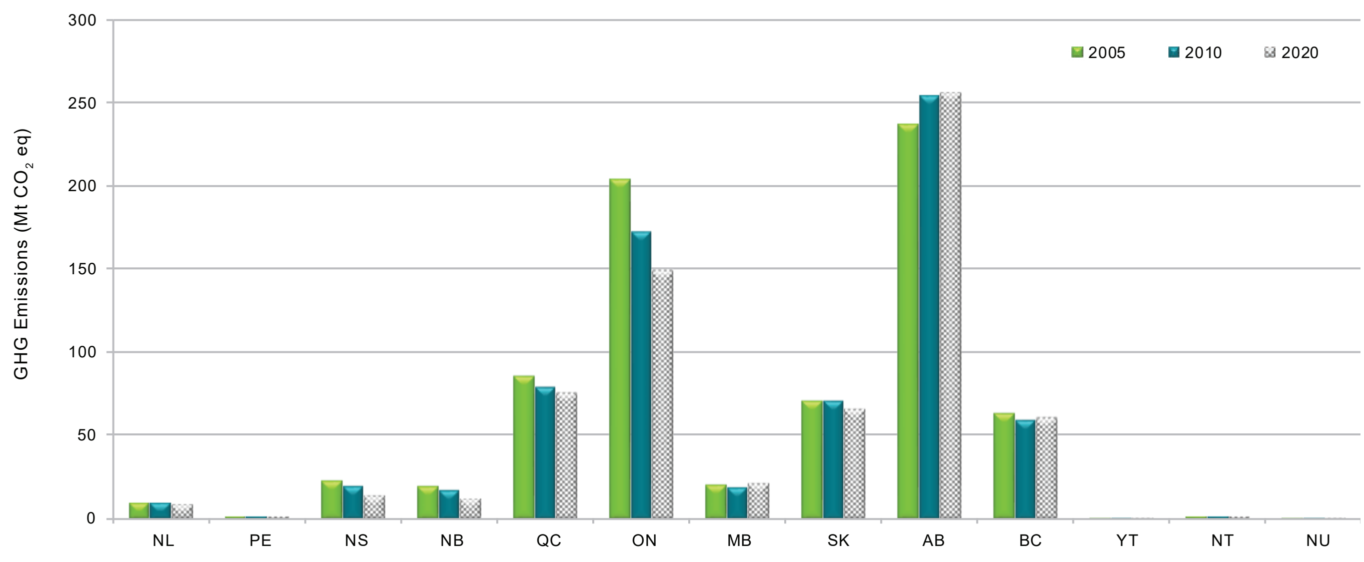

Table ES–4 **GHG Emissions by Province and Territory, Selected Years**

	GHG Emissions (Mt CO_2 eq)							Change (%)
Year	2005	2015	2016	2017	2018	2019	2020	2005–2020
GHG Total (Canada)	**741**	**733**	**715**	**725**	**740**	**738**	**672**	**-9.3%**
NL	10	11	11	11	11	11	9.5	-9.1%
PE	1.9	1.6	1.6	1.6	1.6	1.7	1.6	-15%
NS	23	17	15	16	17	16	15	-36%
NB	20	14	15	14	14	13	12	-37%
QC	86	79	78	80	82	84	76	-12%
ON	204	164	162	159	167	166	150	-27%
MB	21	21	21	22	23	22	22	5.6%
SK	71	79	77	79	80	78	66	-7.6%
AB	237	284	268	276	277	279	256	8.2%
BC	64	60	62	63	66	65	62	-2.9%
YT	0.57	0.53	0.53	0.56	0.65	0.69	0.60	5.6%
NT	1.7	1.6	1.5	1.6	1.6	1.6	1.4	-19%
NU	0.58	0.65	0.74	0.75	0.74	0.73	0.60	3.2%

Note: Totals may not add up due to rounding.

Executive Summary References

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[OPG] Ontario Power Generation Inc. 2015. *Sustainable Development Report 2014* [accessed 2022 Jan 6]. Available online at: https://archive.opg.com/?collection=Performance%20and%20Environmental%20Reports%2FSustainability%20Reports.

[StatCan] Statistics Canada. No date (a). Table 36-10-0369-01 (formerly CANSIM 380-0106): Gross domestic product, expenditure-based, at 2012 constant prices, annual (x 1,000,000). [last updated 2021 Nov 30; accessed 2021 Dec 29]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610036901.

[StatCan] Statistics Canada. No date (b). Table 17-10-0005-01 (formerly CANSIM 051-0001): Population estimates on July 1st, by age and sex. [last updated 2021 Sep 29; accessed 2021 Dec 29]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000501.

[StatCan] Statistics Canada. No date (c). Table 25-10-0025-01 (formerly CANSIM 128-0006): Manufacturing industries, total annual energy fuel consumption in gigajoules, 31-33. [accessed 2022 Jan 6]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510002501.

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CHAPTER 1

INTRODUCTION

1.1. Greenhouse Gas Inventories and Climate Change

Climate change is one of the most important environmental issues of our time. There is a very strong body of evidence, based on a wide range of indicators, that the climate is changing and the climate system is warming. Although climate change can be caused by both natural processes and human activities, human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases (GHGs) are the highest in history (IPCC, 2014).

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

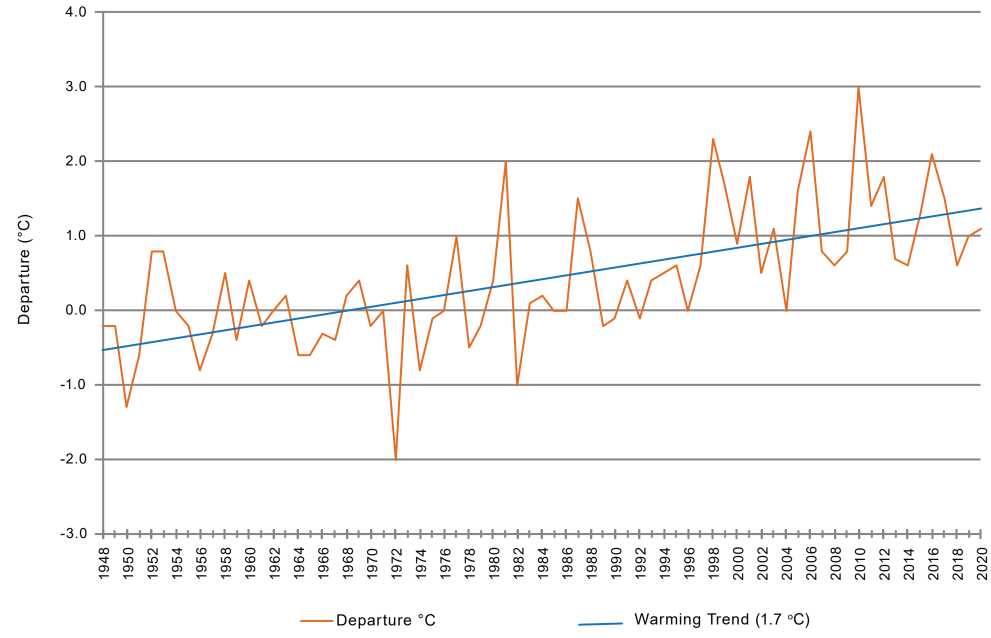
It is now well known that atmospheric concentrations of GHGs have grown significantly since pre-industrial times across the globe. Since 1750, the concentration of atmospheric carbon dioxide (CO_2) has increased by 148%, methane (CH_4) by 260% and nitrous oxide (N_2O) by 123%. There are numerous anthropogenic activities and economic sectors involved. Important CO_2 increases are caused primarily by the use of fossil fuels as a source of energy and cement production. Main CH_4 outpouring are agriculture, fossil fuel exploitation and biomass burning. Finally, N_2O emissions are released predominantly by biomass burning, fertilizer use, and various industrial processes (WMO, 2020).

Recent climate changes have had widespread impacts on human and natural systems (IPCC, 2014). In Canada, the impact of climate change may be felt in extreme weather events, the reduction of fresh water resources, increased risk and severity of forest fires and pest infestations, a reduction in Arctic ice, and an acceleration of glacial melting. Canada's national average temperature for 2020 was 1.1°C above normal (see Figure 1–1). The averaged annual temperatures have remained above the baseline average since 1996, with a warming trend of 1.7°C over the past 72 years (ECCC, 2021).

1.1.1. Canada's National Greenhouse Gas Inventory

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC) in December 1992, and the Convention came into force in March 1994. The ultimate objective of the UNFCCC is to stabilize atmospheric GHG concentrations at a level that would prevent dangerous interference with the climate system. To facilitate the achievement of its objective and implementation of its provisions, the UNFCCC sets out a number of guiding principles and commitments. It requires governments to gather and share information on GHG emissions, national policies and best practices; to launch national strategies for reducing GHG emissions and adapting to expected impacts of climate change; and to cooperate in adapting to those impacts. Specifically, Articles 4 and 12 and Decision 24/CP.19 of the Convention commit all Parties to

Figure 1–1 **Annual Canadian Temperature Departures and Long-Term Trend, 1948–2020**



Note:
Data source = ECCC (2021)

develop, periodically update,[1] publish, and make available to the Conference of the Parties (COP) their national inventories of anthropogenic[2] emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol[3] according to the specific requirements, with the exception of hydrofluorocarbons (HFCs).

This National Inventory Report (NIR) documents Canada's annual GHG emissions estimates for the period 1990−2020. The NIR, along with the Common Reporting Format (CRF) tables, comprise Canada's 2022 submission to the UNFCCC. The NIR and CRF tables have been prepared in accordance with the revised Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: *UNFCCC reporting guidelines on annual greenhouse gas inventories* (UNFCCC Reporting Guidelines), adopted by the Conference of the Parties at its nineteenth session in 2013.

1.1.2. Greenhouse Gases

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

Carbon Dioxide

CO_2 is a naturally occurring, colourless, odourless, incombustible gas formed during respiration, combustion, decomposition of organic substances, and the reaction of acids with carbonates. It is present in the Earth's atmosphere at low concentrations and acts as a GHG. The global carbon cycle is made up of large carbon flows and reservoirs. Through these, CO_2 is constantly being removed from the air by its direct absorption into water and by plants through photosynthesis and, in turn, is naturally released into the air by plant and animal respiration, decay of plant and soil organic matter, and outgassing from water surfaces. Small amounts of CO_2 are also injected directly into the atmosphere by volcanic emissions and through slow geological processes such as the weathering of rock (Hengeveld et al., 2005). Although human-caused releases of CO_2 are relatively small (1/20) compared to the amounts that enter and leave the atmosphere due to the natural active flow of carbon (Hengeveld et al., 2005), human influences now appear to be significantly affecting this natural balance. This is

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

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

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

evident in the measurement of the steady increase of atmospheric CO_2 concentrations since pre-industrial times across the globe (Hengeveld et al., 2005). Anthropogenic sources of CO_2 emissions include the combustion of fossil fuels and biomass to produce energy, building heating and cooling, transportation, land-use changes including deforestation, the manufacture of cement, and other industrial processes.

Methane

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

Nitrous Oxide

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

Perfluorocarbons

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

Hydrofluorocarbons

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

Sulphur hexafluoride

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

Nitrogen Trifluoride

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

1.1.3. Global Warming Potentials

Each GHG has a unique atmospheric lifetime and heat-trapping potential. The radiative forcing[4] effect of a gas within the atmosphere is a quantification of its ability to cause atmospheric warming. Direct effects occur when the gas itself is a GHG, whereas indirect radiative forcing occurs when chemical transformation of the original gas produces a gas or gases that are GHGs or when a gas influences the atmospheric lifetimes of other gases.

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

By definition, a global warming potential (GWP) is the time-integrated change in radiative forcing due to the instantaneous release of 1 kg of the substance expressed relative to the radiative forcing from the release of 1 kg of CO_2. The GWP of a GHG takes into account both the instantaneous radiative forcing due to an incremental concentration increase and 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 concept of a GWP has been developed to allow some comparison of the ability of each GHG to trap heat in the atmosphere relative to CO_2. It also allows characterization of GHG emissions in terms of how much CO_2 would be required to produce a similar warming effect over a given time period. This is called the carbon dioxide equivalent (CO_2 eq) value and is calculated by multiplying the amount of the gas by its associated GWP. This normalization to CO_2 eq enables the quantification of “total national emissions” expressed as CO_2 eq.

The Intergovernmental Panel on Climate Change (IPCC) develops and updates the GWPs for all GHGs. As GWP values are based on background conditions of GHG concentrations and climate, they need to be adjusted on a regular basis to capture the increase of gases already existing in the atmosphere and changing atmospheric conditions. Consistent with Decision 24/CP19, the 100-year GWP values provided by the IPCC in its Fourth Assessment Report (Table 1–1) are used in this report. For example, the 100-year GWP for CH_4 used in this inventory is 25; as such, an emission of 100 kilotonnes (kt) of CH_4 is equivalent to 25 x 100 kt = 2500 kt CO_2 eq.

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

GHG	Formula	100-Year GWP	Atmospheric Lifetime (years)
Carbon dioxide	CO_2	1	Variable
Methane [a]	CH_4	25	12 ± 1.8
Nitrous oxide	N_2O	298	114
Sulphur hexafluoride	SF_6	22 800	3 200
Nitrogen trifluoride	NF_3	17 200	740
Hydrofluorocarbons (HFCs)			
HFC-23	CHF_3	14 800	270
HFC-32	CH_2F_2	675	4.9
HFC-41	CH_3F	92	2.4
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1 640	15.9
HFC-125	CHF_2CF_3	3 500	29
HFC-134	CHF_2CHF_2	1 100	9.6
HFC-134a	CH_2FCF_3	1 430	14
HFC-143	CH_2FCHF_2	353	3.5
HFC-143a	CH_3CF_3	4 470	52
HFC-152	CH_2FCH_2F	53	0.60
HFC-152a	CH_3CHF_2	124	1.4
HFC-161	CH_3CH_2F	12	0.3
HFC-227ea	CF_3CHFCF_3	3 220	34.2
HFC-236cb	$CH_2FCF_2CF_3$	1 340	13.6
HFC-236ea	CHF_2CHFCF_3	1 370	10.7
HFC-236fa	$CF_3CH_2CF_3$	9 810	240
HFC-245ca	$CH_2FCF_2CHF_2$	693	6.2
HFC-245fa	$CHF_2CH_2CF_3$	1 030	7.6
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794	8.6
Perfluorocarbons (PFCs)			
Perfluoromethane	CF_4	7 390	50 000
Perfluoroethane	C_2F_6	12 200	10 000
Perfluoropropane	C_3F_8	8 830	2 600
Perfluorobutane	C_4F_{10}	8 860	2 600
Perfluorocyclobutane	$c\text{-}C_4F_8$	10 300	3 200
Perfluoropentane	C_5F_{12}	9 160	4 100
Perfluorohexane	C_6F_{14}	9 300	3 200
Perfluorodecalin	$C_{10}F_{18}$	7 500	1 000
Perfluorocyclopropane	$c\text{-}C_3F_6$	17 340	1 000

Notes:

Data source: IPCC’s Fourth Assessment Report – Errata (IPCC, 2012).

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

1.2. Canada’s National Inventory Arrangements

Canada’s inventory arrangements for the estimation of anthropogenic emissions from sources and removals by sinks of all GHGs not controlled by the Montreal Protocol encompasses the institutional, legal and procedural arrangements necessary to ensure that Canada meets its reporting obligations. These arrangements, including formal agreements and descriptions of the roles and responsibilities of the various contributors to the preparation and submission of the national GHG inventory, are fully documented in Canada’s inventory archives.

The national entity responsible for Canada’s inventory arrangements is the Pollutant Inventories and Reporting Division of Environment and Climate Change Canada (ECCC). The National Inventory Focal Point is:

1

Lindsay Pratt, Acting Director
Pollutant Inventories and Reporting Division
Science and Risk Assessment Directorate
Science and Technology Branch
Environment and Climate Change Canada
351 Saint-Joseph Boulevard, 7th floor
Gatineau, QC K1A 0H3
Email: ges-ghg@ec.gc.ca
Telephone: 1-877-877-8375

An overview of the inventory process of the Pollutant Inventories and Reporting Division is provided in section 1.2.2 “Process for Inventory Preparation”.

1.2.1. Institutional Arrangements

As the federal agency responsible for preparing and submitting the national inventory to the UNFCCC, ECCC has established all aspects of the arrangements supporting the GHG inventory and manages them.

Sources and sinks of GHGs originate from a tremendous range of economic sectors and activities. Leveraging the best available technical and scientific expertise and information, ECCC has defined 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. They include partnerships with other government departments, namely Statistics Canada, Natural Resources Canada (NRCan), 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 and contributors to the inventory agency and their contribution to the development of Canada’s national inventory.

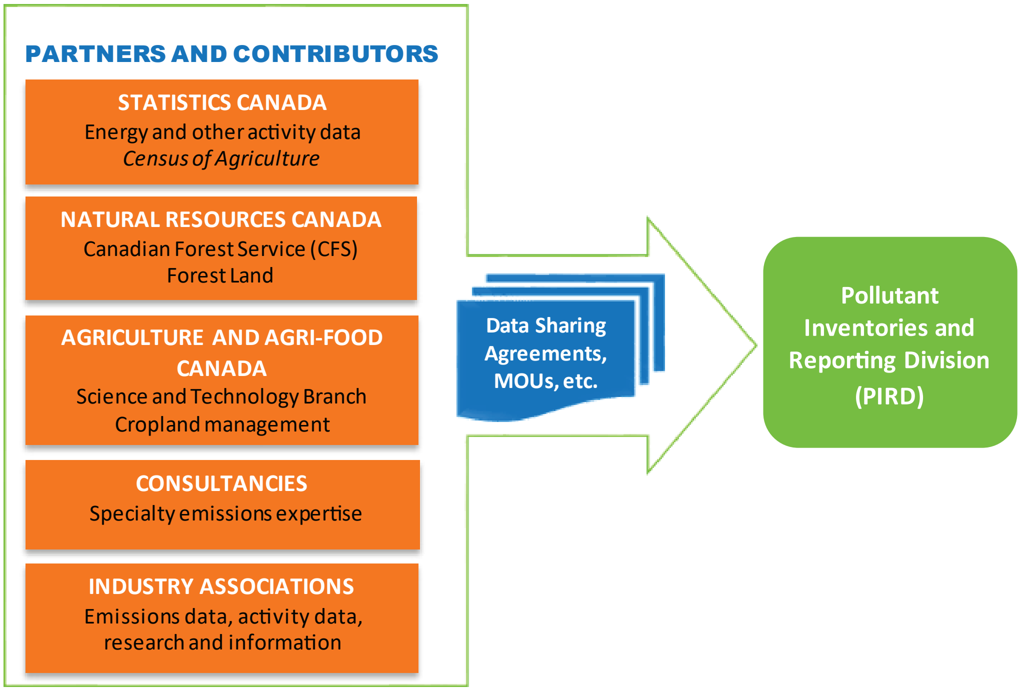
1.2.1.1. Statistics Canada

As Canada’s national statistical agency, Statistics Canada provides ECCC with a large portion of the underlying activity data to estimate GHG emissions for the Energy and the Industrial Processes and Product Use (IPPU) sectors. Statistics Canada is responsible for the collection, compilation and dissemination of Canada’s energy balance in its annual *Report on Energy Supply and Demand in Canada* (RESD). The energy balance is transmitted annually to ECCC according to the terms of a Letter of Agreement between the two departments. Statistics Canada also conducts an annual *Industrial Consumption of Energy* (ICE) survey, which is a comprehensive survey of industries whose results feed into the development of the energy balance.

Statistics Canada’s quality management system for the energy balance includes an internal and external review process. Owing to the complexity of energy 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 RESD and ICE data and provide advice, direction and recommendations on improvements to the energy balance. Refer to Annexes 3 and 4 of this report for additional information on the use of the energy balance in the development of energy estimates.

Statistics Canada also collects other energy data, such as mining and electricity information, and other non-energy-related industrial information, including urea and ammonia production information, as well as activity data on petrochemicals. In addition, it collects agricultural activity data (related to crops, crop production and management practices) through the Census of Agriculture and provides animal population data.

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



1.2.1.2. NRCan and AAFC: Canada's Monitoring System for Land Use, Land-use Change and Forestry

ECCC has officially designated responsibilities to AAFC and the Canadian Forest Service of NRCan (NRCan/CFS) for the development of key components of the Land Use, Land-Use Change and Forestry (LULUCF) sector. This has been formalized through memoranda of understanding (MOUs).

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

ECCC manages and coordinates the annual inventory development process, develops all other LULUCF estimates, undertakes cross-cutting quality control and quality assurance, and ensures the consistency of land-based estimates through an integrated land representation system.

1.2.1.3. Other Agreements

In addition to its support to Canada's LULUCF estimates (see section 1.2.1.2), NRCan provides energy expertise and analysis, serves as expert reviewer for the Energy sector data, and collects and provides activity data on mineral production, ethanol consumption and wood residues. Road vehicle data, such as fuel efficiency and driving rates, are provided by both Transport Canada and NRCan.

ECCC annually collects GHG emissions data from facilities that emit large amounts of GHGs under its GHG Reporting Program (GHGRP). The facility-level GHG data are used directly in the national inventory estimates in a few specific sectors. In addition, the facility data acts as an important component of the overall inventory development process in comparing and verifying certain inventory estimates in the NIR. For more information on the facility data reported under the GHGRP, refer to section 1.3.4.1.

A bilateral amended agreement with the Aluminium Association of Canada (AAC) was signed in 2013, under which the initial intent was to have process-related emission estimates for CO_2, PFCs and SF_6 provided annually to ECCC. As part of the data needed for the inventory preparation is made available through the GHGRP since 2017, the purpose of the agreement has evolved to provide, upon request, to ECCC supporting data and information on emission factors and parameters used to derive emission estimates. Another agreement has also been signed with the Canadian Electricity Association (CEA) for provision of SF_6 emissions and supplementary data relating to power transmission systems.

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

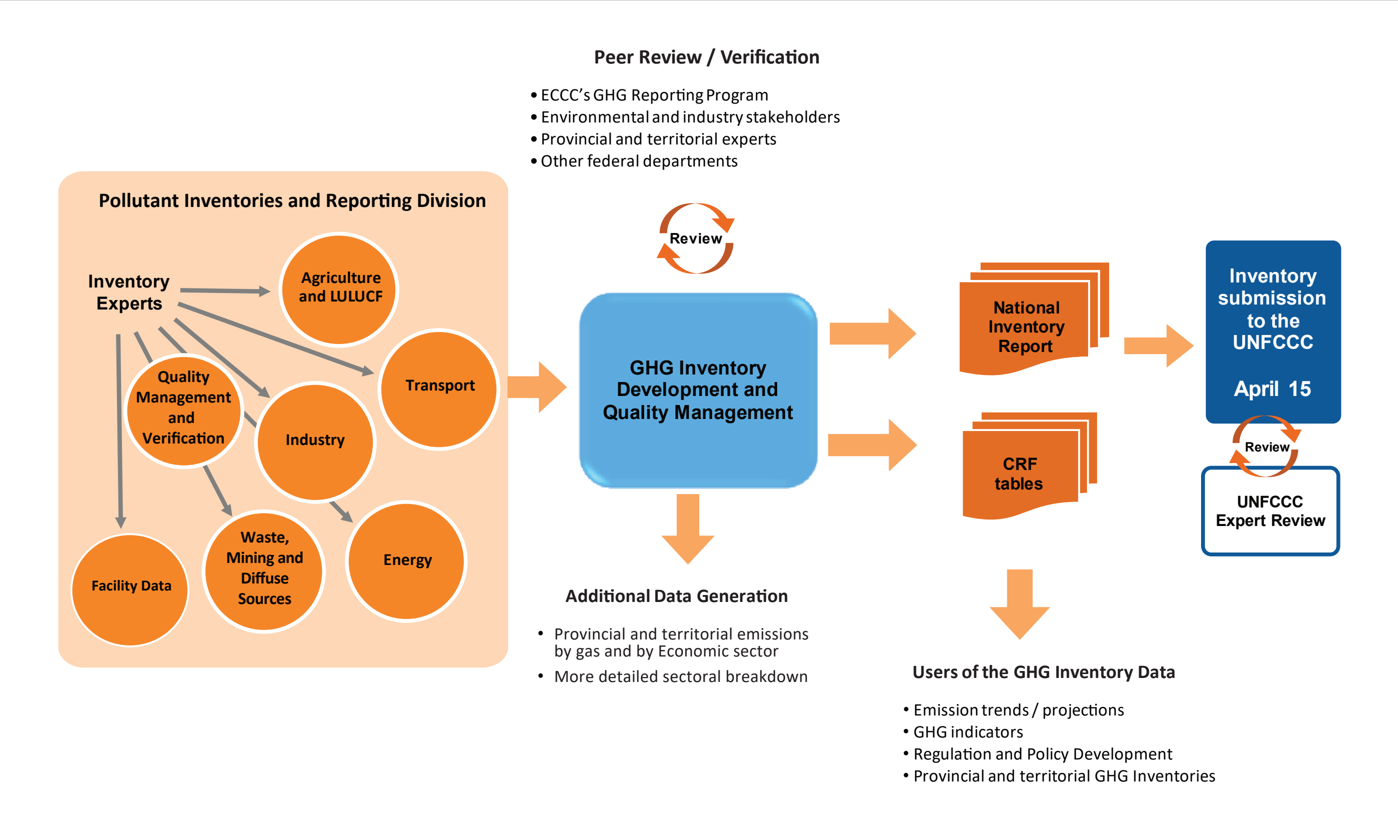
1.2.2. Process for Inventory Preparation

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

The inventory builds from a continuous process of methodological improvements, refinements and review, in accordance with quality management and improvement plans. The Quality Management and Verification Section is responsible for preparing the inventory development schedule, which may be adjusted each year based on the results of the lessons-learned review of the previous inventory cycle, quality assurance/quality control (QA/QC) follow-up, the UNFCCC review report, context of data collection, and collaboration with provincial and territorial governments. This process is done with ongoing collaboration and consultation with other inventory experts (see Figure 1–3).

Inventory development generally starts in February, when inventory experts plan their work on methodologies and EFs that will be reviewed, develop and/or refine during the next cycle, based on the outcomes of the steps mentioned above. QA reviews of methodologies and EFs are typically undertaken for categories for which a change in methodology or emission factor is proposed and for categories that are scheduled for a QA review of methodology or emission factor. Then, from May to October, collection of the required data begins while roles and responsibilities are finalized. Methodologies are finalized by the end of September and the data collection process is completed by mid November. The data used to compile the national inventory are generally taken from published sources, but some require confidentiality. Data are collected from

Figure 1–3 **Inventory Preparation Process**



the source agencies, controlled for quality and entered into emission quantification tools: spreadsheets, databases and other forms of models. In November and December, draft estimates are developed by designated inventory experts and internally reviewed. In the following few months, NIR text and CRF tables are prepared by inventory experts and by other members of PIRD, according to UNFCCC guidelines. QC checks and estimates are performed before the report and emission estimates are published. The inventory process also involves key category assessment, completeness assessment, recalculations and uncertainty calculation, which are all completed before March, along with their respective documentation.

Between January and March, the compiled inventory is first reviewed internally and components of it are reviewed externally by experts, government agencies and provincial and territorial governments, after which the NIR is finalized. Comments from the reviews are documented and, where appropriate, incorporated in the NIR and CRF, which are submitted to the UNFCCC electronically prior to April 15 of each year. Once finalized, the NIR is then translated and made available in French.

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

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

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

In the process of considering the national inventory and the results, senior officials from different departments are briefed on several occasions prior to the report being sent to the Minister of Environment and Climate Change Canada. Once reviewed and/or approved, the National Inventory Focal Point prepares a letter of submission to accompany the NIR and CRF tables, which are then sent electronically.

1.2.4. Treatment of Confidentiality Issues

Confidential information is defined as information that could directly or indirectly identify an individual person, business or organization. During the development of the inventory, procedures are in place to ensure confidentiality of source data, when required. For instance, some emissions are aggregated to a level such that confidentiality is no longer an issue. For example, in certain cases, emissions from Croplands 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 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 is to ensure that the statistical aggregates which 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 non-disclosure of facility-specific information considered confidential by individual facilities.

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

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

1.3. Quality Assurance, Quality Control and Verification

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

1.3.1. Overview of Canada's Quality Management System

The development of Canada's GHG inventory is based on a continuous process of data collection, methodological refinement and review. QA/QC procedures take place at all stages of the inventory development cycle.

In order to ensure that an inventory of high quality is produced each and every year, a national inventory quality management system has been developed and implemented for the annual compilation and publication of the national GHG inventory. The quality management system includes a QA/QC plan, an inventory improvement plan, processes for creation, documentation and archiving of information, a standardized process for implementing methodological change, identification of key roles and responsibilities, as well as a timeline for completing the various NIR-related tasks and activities.

1.3.2. Canada's Quality Assurance / Quality Control Plan

Canada's QA/QC plan uses an integrated approach to managing the inventory quality and works towards achieving continuously improved emission and removal estimates. It is designed so that QA/QC and verification procedures are implemented throughout the entire inventory development process, from initial data collection through development of emission and removal estimates to publication of the National Inventory Report in English and French.

Documentation of QA/QC procedures is at the core of the plan. Standard checklists are used for the consistent, systematic documentation of all QA/QC activities in the annual inventory preparation and submission. QC checks are completed during each stage of the annual inventory preparation and archived along with other procedural and methodological documentation, by inventory category and by submission year.

1.3.2.1. Quality Control Procedures

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

A series of systematic Tier 1 QC checks in line with the 2006 IPCC Guidelines (IPCC, 2006), Volume 1, Section 6.6, are performed annually by inventory experts on the key categories and across sectors. Prior to submission, cross-cutting QC checks are conducted on the final NIR documents (English and French). Also prior to submission, quality checks are performed on the data entered into the CRF online tool by the national inventory compiler and reviewer, and the tables are reviewed by the sector experts, for the entire time series of CRF tables. Category-specific Tier 1 QC procedures complement general inventory QC procedures, and are directed at specific types of data used. These procedures require knowledge of the specific category, including the methodology, the types of data available and the parameters associated with emissions or removals.

To facilitate these Tier 1 checks, QC checklists have been developed to standardize and document QC procedures that are performed. The QC checklists include a record of any corrective action taken and refer to supporting documentation. Minor updates to the QC checklist were made in 2015 (Environment Canada, 2015).

A Tier 2 QC assessment is an opportunity to critically review a specific category or categories. There is a need for a comprehensive assessment to ensure that the category will remain current and relevant for a number of years beyond the year of analysis. The investigation is typically broad and uses a variety of sector specific approaches, including performing assessments of continued applicability of methods, EFs, activity data, uncertainty, etc., and laying the foundation for future activities, including developing and prioritizing recommendations for improvement and making preparations for subsequent QA. Documentation of the Tier 2 QC checks may be done through a standard checklist or with an in-depth study to complete a comprehensive assessment.

1.3.2.2. Quality Assurance Procedures

As per the 2006 IPCC Guidelines (IPCC, 2006), QA activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process, and is performed in parallel with QC procedures. QA helps to ensure that the inventory represents the best possible estimates of emissions and removals given the current state of scientific knowledge and data availability, and it supports the effectiveness of the QC program. As with QC, QA is undertaken every year on components of the inventory. Selected underlying data and methods are independently assessed each year by various groups and individual experts in industry, provincial governments, academia and other federal government departments. QA is undertaken for the assessment of the activity data, methodology and EF utilized for developing estimates, and is preferably carried out prior to making a decision on implementing a methodological change.

1.3.3. Planning and Prioritization of Improvements

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

As many improvements will stretch over multiple years, Canada has developed an *Inventory Improvement Plan*, which identifies and tracks planned improvements to both the emission estimates (including the underlying activity data, EFs and methodologies) and components of the national inventory arrangements (including the QA/QC plan, data infrastructure and management, archiving processes, uncertainty analysis and key category assessment). The *Inventory Improvement Plan* contains all planned improvement activities that will further refine and enhance the transparency, completeness, accuracy, consistency and comparability of Canada's GHG inventory and is updated on an annual basis. Improvements are prioritized by each section based on the outcomes of the QA/QC and verification activities (as outlined in the QA/QC Plan), key category and uncertainty analysis, resource availability and assessment of potential impacts. Additional information on inventory improvements can be found in Chapter 8.

1.3.4. Verification

Inventory verification[5] activities in accordance with the 2006 IPCC Guidelines, typically include comparing inventory estimates to 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 to inventory estimates. For this reason, verification activities are often conducted on subsets of inventory categories. Consistency between the national inventory and independent estimates leads to an increase in the confidence level and reliability of the inventory estimates.

Details on verification activities are available in Chapters 3 to 7.

1.3.4.1. The GHG Reporting Program

In March 2004, the Government of Canada established the Greenhouse Gas Reporting Program (GHGRP) to collect GHG emissions information annually from facilities across the country. Under this mandatory reporting program, reporting requirements are described in the legal notice issued under section 46(1) of the *Canadian Environmental Protection Act, 1999* and published annually in the *Canada Gazette*.[6] The GHGRP has provided a way for the Government of Canada to continuously track GHG emissions from individual facilities to inform the public, the national GHG inventory and regulatory initiatives.

In December 2016, the Government of Canada published a Notice of Intent to inform stakeholders of its intention to expand the GHGRP using a phased approach. It is pursuing this expansion in order to: enable the direct use of the reported data in the national GHG inventory; increase the consistency and comparability of GHG data across jurisdictions; and obtain a more comprehensive picture of Canadian facility emissions. In 2017, the Government of Canada implemented Phase 1 of the expansion by lowering the reporting threshold from 50 kt to 10 kt for all facilities. Phase 1 also required manufacturers of lime, cement, aluminum, iron and steel as well as facilities involved in CO_2 capture, transport, injection and geological storage activities to use prescribed methods consistent with the IPCC guidelines to quantify their emissions and to provide additional information on their calculations. Under Phase 2 of the expansion (2018 data), facilities in nine additional industry sectors were required to report additional information and use prescribed quantification methods. These sectors are manufacturers of ethanol, ammonia, nitric acid and hydrogen, facilities involved in electricity and heat generation, mining operations, petroleum refineries, pulp and paper production as well as base metal production.

Facilities not covered by the expansion can choose the quantification methodologies most appropriate for their particular industry or application. However, these reporting facilities must use methods for estimating emissions that are 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 accepted.

To date, facility-reported GHG information has been collected and published through Environment and Climate Change Canada's GHGRP for the period 2004 to 2020. In 2020, a total of 1704 facilities (mostly industrial) reported their GHG emissions to the program. Environment and Climate Change Canada's GHGRP website[7] provides public access to the reported GHG emission information (GHG totals by gas by facility).

It is important to note that the GHGRP applies to specific emission sources that exist at facilities and does not cover all sources of GHG emissions (e.g., road transportation, combustion of fuels from residential sources, and agricultural sources), whereas the NIR is a complete accounting of all GHG sources and sinks in Canada. In 2020, the total facility-reported GHG

5 In accordance with the 2006 IPCC Guidelines, Volume 1, Chapter 6.10: Verification.

6 The notice that required the reporting of 2020 emissions information published in the *Canada Gazette* can be found at: https://canadagazette.gc.ca/rp-pr/p1/2021/2021-02-13/html/sup1-eng.html

7 The Greenhouse Gas Reporting Program website can be found at: https://www.canada.ca/ghg-reporting.

emissions represent 41% of Canada's total GHG emissions (672 Mt) and 63% of Canada's industrial GHG emissions. The degree of coverage from the facility-reported data of industrial GHG emissions at the provincial level varies significantly from province to province, depending on the size and number of industrial facilities in each province that have emissions above the 10 kt reporting threshold (Figure 1–4).

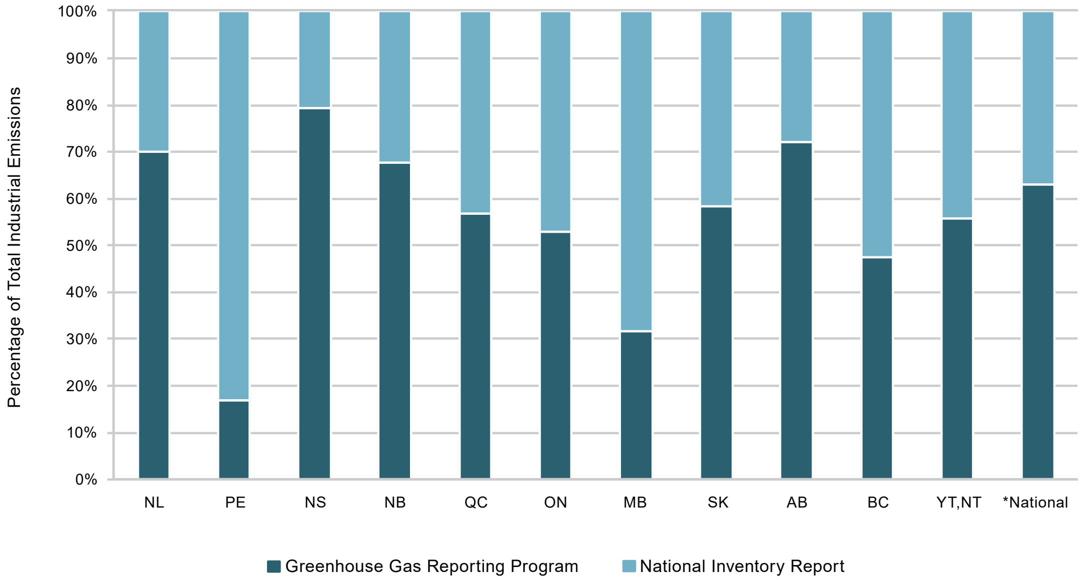
The GHGRP provides Canadians with information about large GHG emitters across Canada and yearly changes in their emission levels. This facility-reported GHG information is shared with provincial and territorial jurisdictions. In accordance with the IPCC guidelines, facility-reported data (FRD) which is inclusive of all specified data and supporting information reported by those under the expanded reporting requirements (see Schedule 3),[8] is used by inventory experts for improvements (e.g. to transparency, accuracy, comparability, consistency, or completeness) when it is assessed to be of good quality, refer to Table 1–2.

The objective for the use of 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 where possible such as industry-specific operation and process changes (e.g. process specific or fuel specific emission factors) following the 2006 IPCC Guidelines and the 2019 IPCC Refinement to the 2006 IPCC Guidelines. Continuous improvements are underway to consider inventory integration approaches for FRD while addressing time series consistency and completeness issues along with coverage of each specific industry as the collection of additional data under the GHGRP expansion only started with the 2017 data for a subset of industries as noted above.

Prior to any integration of FRD, a number of quality assurance and control assessment, and analysis are performed to ensure the quality of reported emission estimates in terms of transparency, accuracy, completeness, consistency, and comparability. In response to the recommendations of the ERT from the 2021 review cycle, explanations were added to the corresponding categories to reflect that the time series consistency of the reported GHG emission estimates was addressed where FRD were used. For every category, the most suitable method provided in the 2006 IPCC Guidelines (vol. 1, chapter 5) was applied. More details are provided in the corresponding sections in Chapters 3 (Energy), 4 (IPPU) and 7 (Waste). As FRD cover a significant part of industrial emissions in some provinces and territories (Figure 1–4), the enhanced FRD collected to date as part of the GHGRP expansion will continue to be reviewed, with the intent for further NIR integration in the coming years.

For more information on the facility data reported under Canada's GHGRP, including short- and long-term changes observed in facility emissions, refer to the publication *Facility Greenhouse Gas Reporting Program—Overview of 2020 Reported Emissions* (ECCC, 2022).

Figure 1–4 **2020 Facility-Reported Emissions as a Percentage of Industrial GHG Emissions by Province and Territory**



Notes:

For Figure 1–4, Canada's industrial GHG emissions include the following GHG categories from the *National Inventory Report, Greenhouse Gas Sources and Sinks in Canada 1990–2020*: Stationary Combustion Sources (except Residential), Other Transportation, Fugitive Sources, Industrial Processes and Product Use, and Waste.

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

8 The notice that required the reporting of 2020 emissions information can be found at: https://canadagazette.gc.ca/rp-pr/p1/2021/2021-02-13/html/sup1-eng.html.

Table 1–2 **Use of FRD under the GHGRP in the NIR by corresponding IPCC Sector and CRF Category**			
IPCC Sector and CRF Category	Type of FRD used under the GHGRP	Uses in NIR	NIR Reference for additional Details
Energy			
1.A.1.ai Electricity generation, solid fuels	Amount of CO_2 captured	Direct reporting	CRF Table 1.A(a)s1
1.A.1.c Manufacture of solid fuels and other energy industries	Combustion emissions reported by Oil Sands industry	Used to disaggregate stationary combustion emissions from Oil and Gas Extraction and Mining categories – fuel consumption is modelled, adjusted such that resultant emissions align with Oil Sands facility reporting	- Chapter 3, section 3.2 - Annex 10
1.C.1 Transport of CO_2	Amount of captured CO_2 transported by pipelines	Input data for calculated values	- Chapter 3, section 3.4 - CRF Table 1s2
1.C.2 CO_2 injection and storage	Amount of captured CO_2 injected or stored	Input data for calculated values	- Chapter 3, section 3.4 - CRF Table 1s2
IPPU			
2.A.1 Cement production	- CO_2 emissions - Clinker production, CaO content of clinker - CKD quantities, CaO content of CKD	- Direct reporting, - Input data for emission estimates - Quality control	Chapter 4, section 4.2
2.A.2 Lime production	- CO_2 emissions - Lime production, CaO content of lime - By-product and waste quantities, CaO contents of by-product and waste	- Direct reporting, - Input data for emission estimates - Quality control	Chapter 4, section 4.3
2.B.1 Ammonia production	- Natural gas feedstock, carbon contents of natural gas - Urea production, CO_2 recovered for urea production	- Input data for emission estimates - Quality control	Chapter 4, section 4.5
2.B.2 Nitric acid production	- Nitric acid production - N_2O emission factors - N_2O emissions	Quality control	Chapter 4, section 4.6
2.C.1 Iron and steel production	- National production quantities of iron and steel - Carbon contents of pig iron, crude steel produced in basic oxygen furnace (BOF) and electric arc furnace (EAF), and scrap steel - Emission factors for coke use, and electrode consumption in BOF and EAF	- Input data for emission estimates - Quality control	Chapter 4, section 4.10
2.C.3 Aluminium production	- Aluminium production; - CO_2, CF_4, C_2F_6 and SF_6 emissions	Direct reporting	Chapter 4, section 4.11
Waste			
5.A.2 Industrial wood waste landfills	GHG emissions	GHG emissions	- Chapter 7, section 7.3 - Annex 3.6.1
5.C.1 Waste incineration	GHG emissions	Direct reporting	- Chapter 7, section 7.5 - Annex 3, section 3.6.3
5.D Wastewater treatment	GHG emissions	Direct reporting of industrial wastewater emissions	- Chapter 7, section 7.6 - Annex 3, section 3.6.4

1.4. Annual Inventory Review

Since 2003, except for 2018 and 2020, Canada's national GHG inventory has been reviewed annually by independent ERTs following the *UNFCCC Review Guidelines for Annual Inventories for Annex I Parties*. The review process plays a key role in ensuring that inventory quality is improved over time, and that Parties to the Convention comply with agreed-upon reporting requirements. The completeness, accuracy, transparency, comparability and consistency of inventory estimates can also be attributed to the well-established review process. Canada's inventory has been subjected to both centralized and in-country reviews, with the last in-country review taking place in 2014.[9] Review reports are posted on-line by the UNFCCC Secretariat once finalized.[10]

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

10 Annual Inventory Review Reports are available online at https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports-2021.

1.5. Methodologies and Data Sources

The inventory is structured to match the reporting requirements of the UNFCCC and is divided into the following five main sectors: Energy, IPPU, Agriculture, LULUCF, and Waste. Each of these sectors is further subdivided in subsectors or categories. The methods described have been grouped, as closely as possible, by UNFCCC sector and subsector.

The methodologies contained in the 2006 IPCC Guidelines (IPCC, 2006) are followed to estimate emissions and removals of each of the following direct GHGs: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3.

While not mandatory, the UNFCCC Reporting Guidelines encourage Parties to provide information on the following indirect GHGs: SO_x, NO_x, CO and NMVOCs (see Annex 7: Ozone and Aerosol Precursors). For all sectors except LULUCF, these gases are inventoried and reported separately to the United Nations Economic Commission for Europe.[11]

1

In general, an inventory of emissions and removals 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 "top-down," "bottom-up," or using a combination of approaches. Canada's national inventory is prepared using a "top-down" approach, providing estimates at a sectoral and provincial/territorial level, without attribution to individual emitters.

Emissions and removals are usually calculated or estimated using mass balance, stoichiometry or emission factor relationships under average conditions. In many cases, activity data are combined with average EFs to produce a "top-down" national inventory. Large-scale regional estimates, based on average conditions, have been compiled for spatially diffuse sources, such as transportation. Emissions from landfills are determined using a simulation model to account for the long-term slow generation and release of these emissions.

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

The methodologies (Annex 3) and EFs (Annex 6) described in this document are considered to be the best available to date, given the available activity data. Limitations to the use of more accurate methods or EFs often arise due to the lack of activity data. Over time, numerous methods have undergone revision and improvement and some new sources have been added to the inventory.

Methodology and data improvement activities, which take into account results of QA/QC procedures, reviews and verification, are planned and implemented on a continuous basis. It should be noted that planned improvements are often implemented over the course of several years. These methodology and data improvement activities are carried out with a view to further refining and increasing the transparency, completeness, accuracy, consistency and comparability of the national inventory. As a result, changes in data or methods often lead to the recalculation of GHG estimates for the entire time series, from 1990 to the most recent year available. Further discussion of recalculations and improvements can be found in Chapter 8.

1.6. Key Categories

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

In this context, a key category is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct GHG emissions in terms of the absolute level of emissions (level assessment), the trend in emissions from the base year to the current year (trend assessment), or both. Wherever feasible, key categories should be estimated with more refined country-specific methods and be subjected to enhanced QA/QC.

For the 1990–2020 GHG inventory, level and trend key category assessments were performed according to the recommended IPCC Tier 1 approach found in Volume 1, Section 4.3.1, of the 2006 IPCC Guidelines. The emission and removal categories used for the key category assessment generally follow those in the CRF. However, they have been aggregated in some cases and are specific to the Canadian inventory.

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

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

1. Fuel Combustion – Road Transportation, CO_2
2. Stationary Fuel Combustion – Manufacturing Industries and Construction, CO_2
3. Stationary Fuel Combustion – Energy Industries, CO_2
4. Fuel Combustion – Other Transport (Off Road), CO_2
5. IPPU – Product Uses as Substitutes for Ozone Depleting Substances, HFCs

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

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

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

1

1.7. Inventory Uncertainty

While national GHG inventories should be accurate, complete, comparable, transparent and consistent, estimates will always inherently carry some uncertainty. Uncertainties[12] in the inventory estimates may be caused by systematic and/or random uncertainties present within 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 evaluation of EFs and other model parameters. In a limited number of cases, uncertainty may be reduced through a validation exercise using an independent data set, such as the total emissions reported by individual facilities in a given industry sector. The IPCC 2006 Guidelines (IPCC, 2006) specify that the primary purpose of quantitative uncertainty information is to assist in setting priorities to improve future inventories and to guide decisions about which methods to use. Typically, the uncertainties associated with the trends and the national totals are much lower than those associated with individual gases and sectors.

Annex 2 presents the uncertainty assessment for Canadian GHG emissions for both the base year and the latest year (2020). While more complex methods (Approach 2) are in some cases applied to develop uncertainty estimates at the sectoral or category level, for the inventory as a whole these uncertainties were combined with the simple (Approach 1) error propagation method, using Table 3.3 in the IPCC 2006 Guidelines (IPCC, 2006). Separate analyses were conducted for the inventory as a whole with and without LULUCF. For further details on uncertainty related to specific sectors, see the uncertainty sections throughout Chapters 3 to 7.

Based on the error propagation method, the uncertainty for the national inventory, not including the LULUCF sector, is ±3% for both base year and 2020. For 2020, the Energy sector had the lowest uncertainty, at ±1%, while the Waste sector had the highest uncertainty, at ±63%. The IPPU and Agriculture sectors had uncertainties of ±5% and ±15%, respectively.

The five emissions source categories that make the largest contribution to uncertainty at the national level, for 2020, when LULUCF is not included are:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
2. Agriculture – Direct Agriculture Soils, N_2O
3. Agriculture – Enteric Fermentation, CH_4
4. Agriculture – Indirect Agriculture Soils, N_2O
5. Waste – Solid Waste Disposal – Unmanaged Waste Disposal Sites – Wood Waste Lanfills, CH_4

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

When the LULUCF emissions and removals are included, the uncertainty in the national total was found to be ±8% for 2020 and ±14% for the base year. The top five contributors influencing the national uncertainty, for 2020, when LULUCF is included were:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
2. LULUCF – Harvested Wood Products, CO_2
3. Agriculture – Direct Agriculture Soils, N_2O
4. Agriculture – Enteric Fermentation, CH_4
5. Agriculture – Indirect Agriculture Soils, N_2O

1.8. Completeness Assessment

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

- Categories that are not occurring in Canada
- Data unavailability at the category level
- Methodological issues specific to national circumstances
- Emission estimates are considered insignificant[13]

As part of the NIR improvement plans, efforts are continuously being made to identify new or improved data sources or methodologies to provide estimates for those categories that are "not estimated". Further details on the completeness of the inventory can be found in Annex 5 and in individual sector chapters (Chapters 3 to 7).

13 An emission should only be considered insignificant if the likely level of emissions is below 0.05% of the national total GHG emissions, and does not exceed 500 kt CO_2 eq. The total national aggregate of estimated emissions for all gases and categories considered insignificant shall remain below 0.1% of the national total GHG emissions (UNFCCC, 2014).

CHAPTER 2

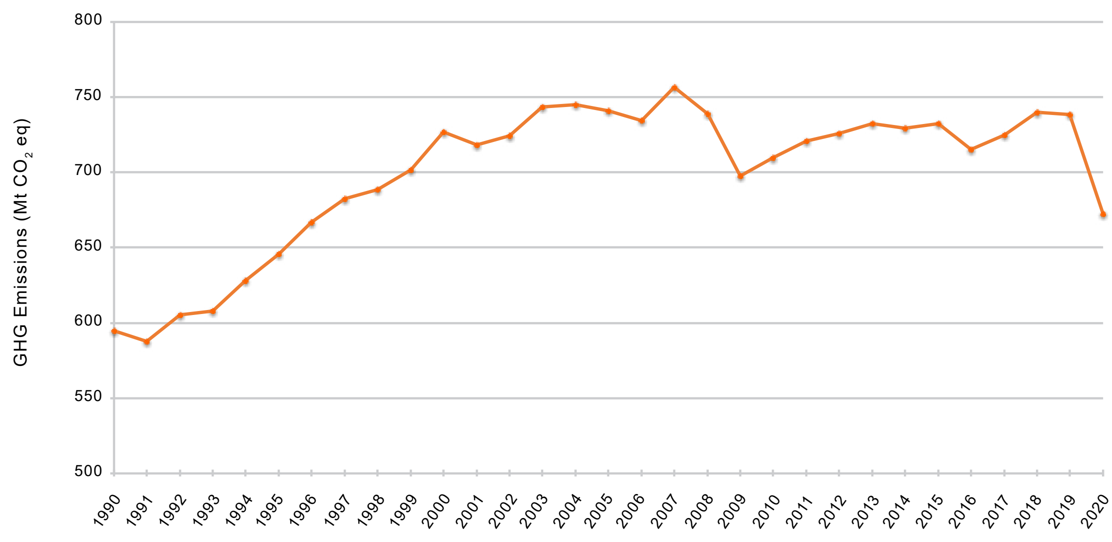
GREENHOUSE GAS EMISSIONS TRENDS

2.1. Summary of GHG Emissions Trends

In 2020, the most recent year for which data are available for this report, Canada's greenhouse gas (GHG) emissions were 672 megatonnes of carbon dioxide equivalent (Mt CO_2 eq)[1] a net decrease of 69 Mt or 9.3% from 2005 emissions (Figure 2–1).[2] In terms of overall trend since 1990, annual emissions steadily increased for 10 years, fluctuated between 2000 and 2008, dropped in 2009, gradually increased until 2019, and dropped between 2019 and 2020.

Of note is a decrease of 66 Mt between the years 2019 and 2020 which coincided with the first year of the COVID-19 pandemic. This decrease occurred in numerous sectors, most notably Transport (-27 Mt or -12%), Stationary Combustion (-22 Mt or -6.8%), and Fugitive Sources (-17 Mt or -25%). The decrease in Transport emissions includes decreases in Light-Duty Gasoline Vehicles and Trucks (-15 Mt or -17%) and domestic Aviation (-3.8 Mt or -44%). These are linked to a decrease in the vehicle kilometres traveled (VKT) in the light-duty vehicles and trucks categories, and a decrease in air

Figure 2–1 **Canadian GHG Emission Trend (excluding Land Use, Land-Use Change and Forestry) (1990–2020)**



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

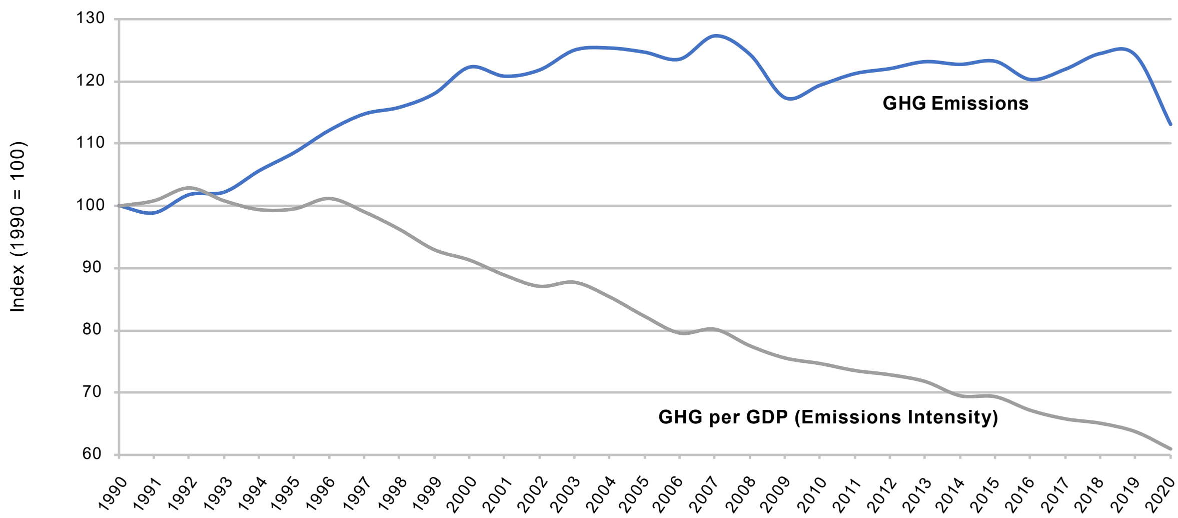
2 Throughout this report, data are presented in the form of rounded figures. However, all calculations (including those done to obtain percentages) were performed using unrounded data.

traffic in 2020 relative to 2019. The decrease in fugitive oil and gas includes emissions decreases from venting (-11 Mt), and leaks from oil (-3 Mt) and natural gas production and processing facilities (-2 Mt). Within Stationary Combustion Sources, decreases in Public Electricity and Heat Production (-7.4 Mt or -11%) were due to decreased coal consumption partially offset by an increase in natural gas consumption; decreases in Manufacturing Industries (-4.5 Mt or -11%) can be partially attributed to plants that closed, temporarily and permanently, during the first year of the pandemic. Temporary shut-down of some plants can also only partially explain the decrease in the Industrial and Processes and Product Use sector (-3.1 Mt or -6.0%) between 2019 and 2020.

Over the long term, Canada's economy grew more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (or GHGs per gross domestic product [GDP]) has declined by 39% since 1990 and by 26% since 2005 (Figure 2–2 and Table 2–1). The decline in emissions intensity since 1996 can be attributed to fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.

Although Canada accounted for approximately 1.6% of global GHG emissions in 2018 (Climate Watch, 2021), it is one of the highest per capita emitters. However, since 2005, Canada's per capita emissions have declined from 23.0 t CO_2 eq/capita to a new low of 17.7 t CO_2 eq/capita in 2020 (Figure 2–3).

Figure 2–2 **Indexed Trend in GHG Emissions and GHG Emissions Intensity (1990–2020)**



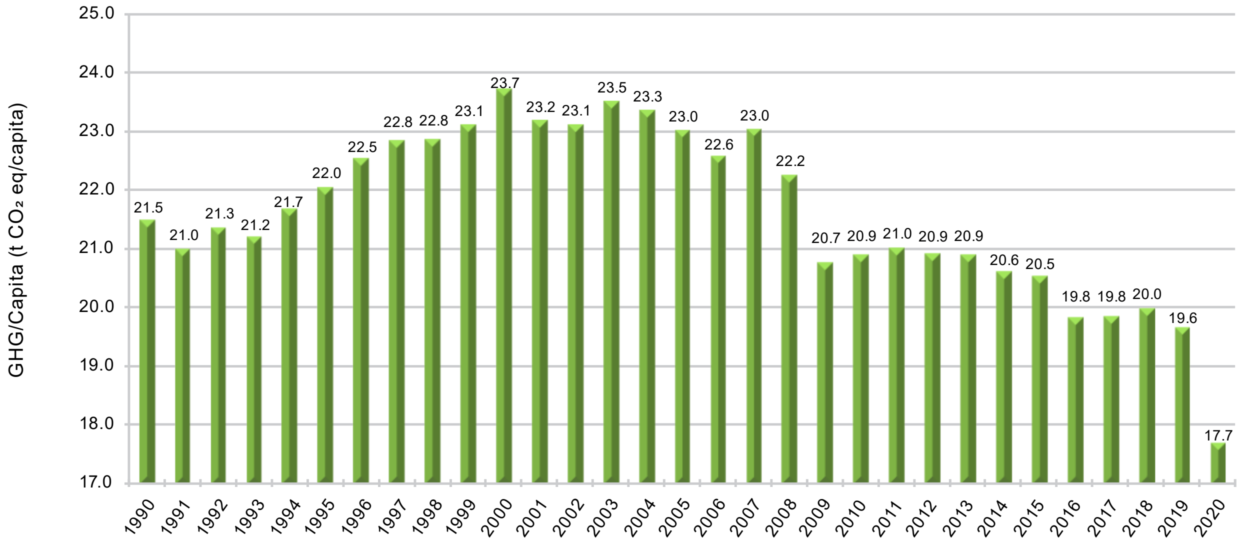
Note:
GDP data source = StatCan (n.d.[a])

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

Year	1990	2005	2015	2016	2017	2018	2019	2020
Total GHG (Mt)	**595**	**741**	**733**	**715**	**725**	**740**	**738**	**672**
Change since 2005 (%)	NA	NA	-1.2%	-3.5%	-2.2%	-0.2%	-0.4%	-9.3%
Change since 1990 (%)	NA	25%	23%	20%	22%	24%	24%	13%
GDP[a] (Billion 2012$)	**1 092**	**1 654**	**1 938**	**1 953**	**2 022**	**2 086**	**2 126**	**2 024**
Change since 2005 (%)	NA	NA	17%	18%	22%	26%	29%	22%
Change since 1990 (%)	NA	51%	78%	79%	85%	91%	95%	85%
GHG Intensity (Mt/$B GDP)	**0.54**	**0.45**	**0.38**	**0.37**	**0.36**	**0.35**	**0.35**	**0.33**
Change since 2005 (%)	NA	NA	-16%	-18%	-20%	-21%	-23%	-26%
Change since 1990 (%)	NA	-18%	-31%	-33%	-34%	-35%	-36%	-39%

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

Figure 2–3 **Canadian Per Capita GHG Emissions (1990–2020)**



Note:
Population data source = StatCan (n.d.[b])

2.1.1. Provincial and Territorial GHG Emissions Trends

Emissions vary significantly by province and territory as a result of such factors as population, energy sources and economic structure (Figure 2–4). 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, wind turbines, solar photovoltaic cells and tidal power.

Figure 2–4 **GHG Emissions by Province and Territory in 2005, 2010, 2015 and 2020**

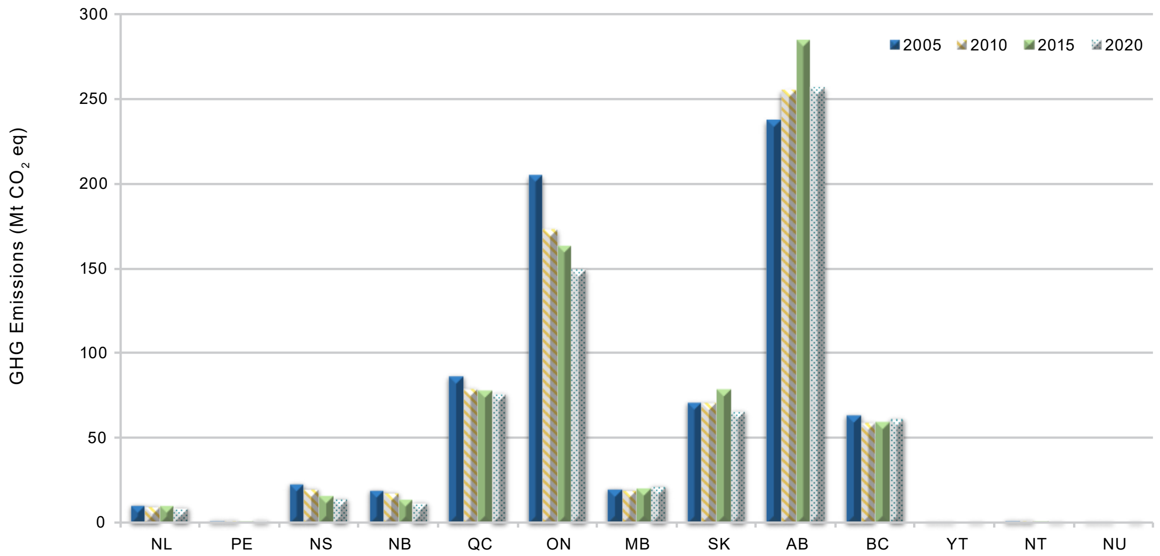


Table 2–2 **GHG Emissions by Province and Territory, Selected Years**

	GHG Emissions (Mt CO_2 eq)								Change (%)
Year	1990	2005	2015	2016	2017	2018	2019	2020	2005–2020
GHG Total (Canada)	**595**	**741**	**733**	**715**	**725**	**740**	**738**	**672**	**-9.3%**
NL	9.6	10	11	11	11	11	11	9.5	-9.1%
PE	1.8	1.9	1.6	1.6	1.6	1.6	1.7	1.6	-15%
NS	20	23	17	15	16	17	16	15	-36%
NB	16	20	14	15	14	14	13	12	-37%
QC	85	86	79	78	80	82	84	76	-12%
ON	180	204	164	162	159	167	166	150	-27%
MB	18	21	21	21	22	23	22	22	5.6%
SK	45	71	79	77	79	80	78	66	-7.6%
AB	166	237	284	268	276	277	279	256	8.2%
BC	52	64	60	62	63	66	65	62	-2.9%
YT	0.55	0.57	0.53	0.53	0.56	0.65	0.69	0.60	5.6%
NT	NA	1.7	1.6	1.5	1.6	1.6	1.6	1.4	-19%
NU	NA	0.58	0.65	0.74	0.75	0.74	0.73	0.60	3.2%

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

2

Historically, Alberta and Ontario have been the highest-emitting provinces. Since 2005, emission patterns in these two provinces have diverged. Emissions in Alberta have increased by 19 Mt (8.2%) since 2005, primarily as a result of the expansion of oil and gas operations (Table 2–2). In contrast, Ontario's emissions have decreased by 55 Mt (27%) since 2005, owing primarily to the closure of the last coal-fired electricity generation plants in 2014.

Quebec's emissions decreased by 10 Mt (12%) between 2005 and 2020 and those in Saskatchewan and British Columbia also decreased by 5.4 Mt (7.6%) and 1.8 Mt (2.9%), respectively, over the same time period. Emissions in Manitoba have increased since 2005, but to a lesser extent (1.1 Mt or 5.6%). Other provinces that have seen significant decreases in emissions include New Brunswick (7.3 Mt or a 37% reduction), Nova Scotia (8.4 Mt or a 36% reduction), Newfoundland and Labrador (1.0 Mt or a 9.1% reduction) and Prince Edward Island (0.29 Mt or a 15% reduction). Furthermore, emissions in the Northwest Territories have also decreased (0.32 Mt or 19%), and Yukon and Nunavut have seen increases in emissions (0.03 Mt or 5.6%, and 0.02 Mt or 3.2%, respectively).

2.2. GHG Emissions Trends by Gas

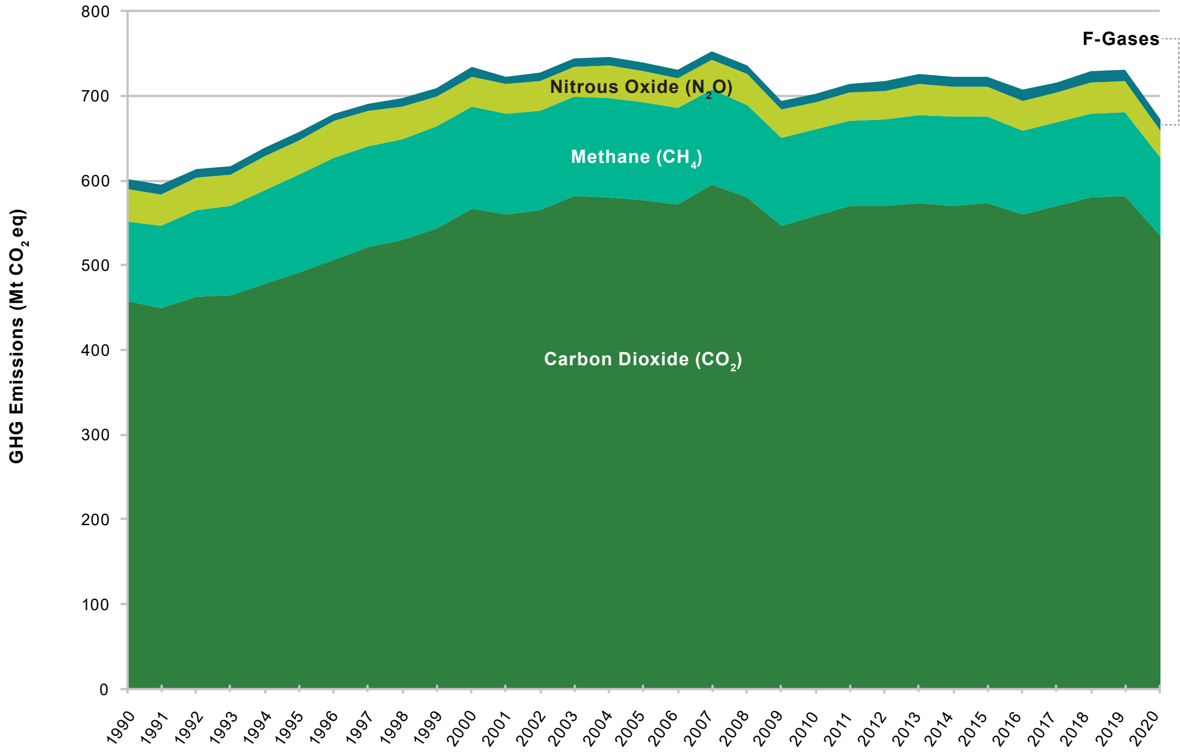
Canada's GHG emissions profile is similar to that of most industrialized countries in that carbon dioxide (CO_2) is the largest contributor to its GHG emissions, accounting for 535 Mt (80% of total emissions) in 2020. As a result, trends in CO_2 emissions follow the same pattern as total GHG emissions. The majority of the CO_2 emissions in Canada result from the combustion of fossil fuels (Figure 2–5).

Methane (CH_4) emissions in 2020 amounted to 92 Mt or 14% of Canada's total emissions. These emissions are largely from fugitive sources in oil and natural gas systems (35% of total CH_4 emissions), agriculture (30% of total CH_4 emissions) and solid waste disposal (municipal landfills) and industrial wood waste landfills (27% of total CH_4 emissions). Nationally, CH_4 emissions in 2020 were roughly equivalent to 1990 (92 Mt). Although emissions in 1990 and 2020 are the lowest two years in the time series, emissions increased steadily from 1990, peaking in 2006 at 126 Mt (38% increase) (Figure 2–6). Over this period emissions from fugitive oil and gas increased by 24 Mt, agriculture by 8.9 Mt and landfills by 3.7 Mt. The increase in fugitive oil and gas emissions is consistent with a 60% increase in natural gas production and an 11% increase in conventional oil production over the same 1990–2006 period.[3]

From 2006 to 2019, emissions slowly decreased to 109 Mt. Of this 17 Mt decrease in emissions, 9.6 Mt of the decrease occurred in the oil and gas industry due to increased gas conservation leading to reductions in venting emissions (-5.9 Mt), and the combination of improved leak detection and repair (LDAR) programs and a 9% decrease in natural gas production,

3 From 1990 to 2020, production of crude bitumen and synthetic crude oil from Canada's Oil Sands increased by over 700% with CO_2-eq emissions increasing by over 400%. However, CH_4 emissions from the Oil Sands increased by only 90% and the contribution to total Oil and Gas CH_4 emissions increased from 4.7% in 1990 to 9.4% in 2020, showing that the Oil Sands is not a significant source of fugitive oil and gas CH_4 as compared to conventional oil and gas production.

Figure 2–5 **Trends in Canadian GHG Emissions by Gas (1990–2020)**



Note: F-gases consist of HFCs, PFCs, SF_6 and NF_3.

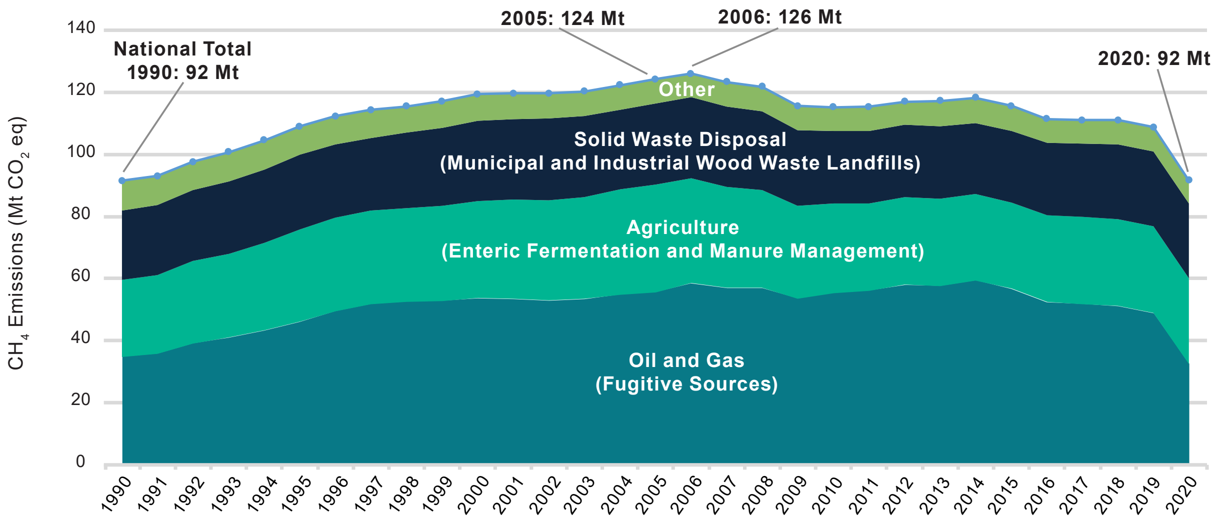
both of which contributed to a decrease in fugitive leak emissions (-3.8 Mt). Agricultural CH_4 emissions decreased by 5.6 Mt between 2006 and 2011, mainly due to a 20% decline in beef cattle populations that led to a reduction in enteric fermentation emissions, but populations and emissions have since stabilized. The decrease in landfill emissions of 2.1 Mt (8%) over this period is from a mixture of decreases in methane generation from wood waste landfills (1.0 Mt or 30% decrease), and from increased capture and recovery of landfill gas from municipal landfills (2.2 Mt or 27% decrease), offset by an increase in methane generated (1.0 Mt or 3% increase).

The 17.2 Mt decrease in CH_4 emissions between 2019 and 2020 coincides with federal regulations to reduce methane emissions from the upstream oil and gas industry and equivalent provincial regulations in Saskatchewan, Alberta and British Columbia as fugitive CH_4 emissions from oil and gas operations decreased by 16.5 Mt over this period. Please see section 2.3.1.3 for more detailed discussion of the trends in emissions from fugitive sources.

Nitrous oxide (N_2O) emissions accounted for 33 Mt (4.9%) of Canada's emissions in 2020, down 0.43 Mt (1.3%) from 1990 levels and up 0.91 Mt (2.8%) from 2005 levels. The primary source of N_2O emissions is the application of nitrogen fertilizers to agricultural soils. In 2020, the Agriculture sector accounted for 75% of national N_2O emissions, up from 45% in 1990 and 56% in 2005. Since 2005, nitrogen fertilizer use has increased by 89% and N_2O emissions from nitrogen fertilizer use have increased by 92%. Furthermore, since 1990, a 10-Mt decrease in N_2O emissions has also occurred due to the cessation of adipic acid production in Canada.

Together, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), SF_6 and NF_3 accounted for 13 Mt, or 1.9%, of Canada's emissions in 2020. From 1990 to 2020, emissions of HFCs rose by 11 Mt (1131%), while emissions of PFCs and SF_6 decreased by 6.7 Mt (89%) and 2.9 Mt (91%), respectively. Similar to the trends from 1990 to 2020, HFC emissions have increased by 6.8 Mt (134%) since 2005 and emissions of PFCs and SF_6 have decreased by 3.0 Mt (79%) and 1.1 Mt (79%), respectively. The increase in HFC emissions can be explained by the replacement of ozone-depleting substances (ODSs)—specifically chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)—with HFCs for refrigeration and air conditioning before the gradual phase-out of HFCs mandated under the Kigali Amendment to the Montreal Protocol, which came into force in 2019. The decreases in emissions of PFCs are largely due to the aluminium industry's efforts to

Figure 2–6 **Methane Emissions Trends in Canada (1990–2020)**



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

modernize existing facilities and improve production efficiency. The decline in the number of magnesium smelters and casters has contributed to the decreased SF_6 emissions. Three primary magnesium production facilities had been in operation during the 1990 to 2008 time period, but the last facility closed in 2008. Additionally, of the 11 magnesium casting facilities that were in operation during the 1990 to 2004 period, only 5 were in operation in 2020. For the remaining magnesium casting facilities, the use of alternative cover gases has also played a role in decreasing SF_6 emissions.

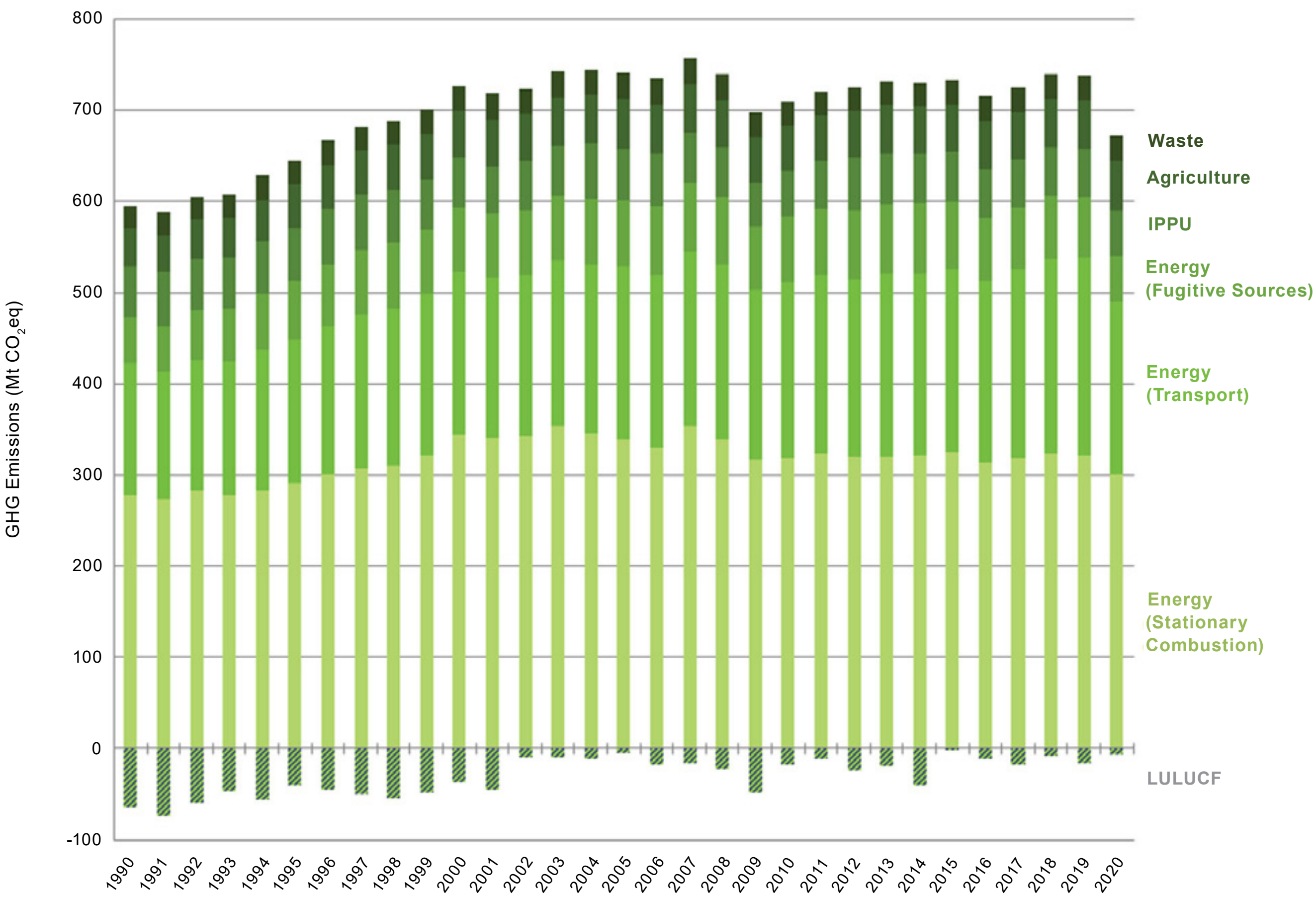
2.3. GHG Emissions Trends by IPCC Sector

In 2020, the IPCC (Intergovernmental Panel on Climate Change) Energy sector (consisting of Stationary Combustion, Transport and Fugitive Sources) accounted for 540 Mt, or 80%, of Canada's total GHG emissions (Figure 2–7). The remaining emissions were largely generated by the Agriculture (55 Mt or 8.2%) and Industrial Processes and Product Use (IPPU) sectors (50 Mt or 7.5%), with contributions from the Waste sector (27 Mt or 4.1%).

The Energy sector dominated the long-term trend over the 1990–2020 period, with increases of 45 Mt (31%) in Transport, 22 Mt (8.0%) in Stationary Combustion and 0.12 Mt (0.2%) in Fugitive Sources. Over the same period, emissions in the Agriculture sector increased by 14 Mt (34%), while the IPPU sector saw a decrease of 6.6 Mt (12%). Emissions in the Waste sector have increased by 2.9 Mt (12%) since 1990. In 1990, net removals from the Land Use, Land-Use Change and Forestry (LULUCF) sector were 64 Mt, but the net sink has declined since then amounting to net removals of only 6.8 Mt in 2020. Over the time series, the net decrease in LULUCF net removals was 57 Mt (89%) (Figure 2–7 and Table 2–3).

Over the 2005–2020 period, total emissions have decreased by 69 Mt or 9.3%. Two sources of the Energy sector dominated this trend, with emission decreases of 39 Mt (12%) in Stationary Combustion Sources and 23 Mt (32%) in Fugitive Sources. Over the same period, emissions have decreased by 6.3 Mt (11%) in the IPPU sector and 1.4 Mt (4.8%) in the Waste sector. Moreover, emissions from Transport (also in the Energy sector) have generally increased from 2005 to 2019 and decreased between 2019 and 2020, bringing the 2020 emissions to a level similar to 2005 (0.07 Mt or 0.0% increase). The Agriculture sector emissions have remained relatively stable with a 0.98 Mt or 1.8% increase (Figure 2–8). The net removals in the LULUCF sector have fluctuated between relatively low values of 4.2 Mt in 2005, 0.1 Mt in 2015 and 6.8 Mt in 2020, and high peaks of 49 Mt in 2009 and 39 Mt in 2014, representing a net increase of 2.5 Mt between 2005 and 2020 (Figure 2–7).

Figure 2–7 **Trends in Canadian GHG Emissions by IPCC Sector (1990–2020)**



The contribution of several emission sources, while not major contributors to Canada's overall GHG emissions, has changed significantly since 1990. Between 1990 and 2020, these include an 11-Mt (or 1130%) increase in emissions from the Production and Consumption of Halocarbons, SF_6 and NF_3, a 4.1-Mt (71%) increase from the Non-Energy Products from Fuels and Solvent Use, a 1.8-Mt (155%) increase in CO_2 emissions from the application of lime, urea and carbon-containing fertilizers, a 0.29-Mt (389%) increase in emissions from Biological Treatment of Solid Waste. Theses changes in emissions also include decreases of 0.78 Mt (81%) from Nitric Acid Production and of 0.17 Mt (76%) from Field Burning of Agricultural Residues.

Between 2005 and 2020, some of the significant changes in emission sources that are minor contributors to the national total include a 6.9-Mt (or 135%) increase in emissions from the Production and Consumption of Halocarbons, SF_6 and NF_3, a 1.6-Mt (114%) increase in CO_2 emissions from the application of lime, urea and carbon-containing fertilizers, a 0.9-Mt (42%) increase in Agriculture and Forestry Stationary Combustion Sources, a 1.0-Mt (84%) decrease in Nitric Acid Production emissions, and a 1.1-Mt (92%) decrease in emissions of SF_6 Used in Magnesium Smelters and Casters.

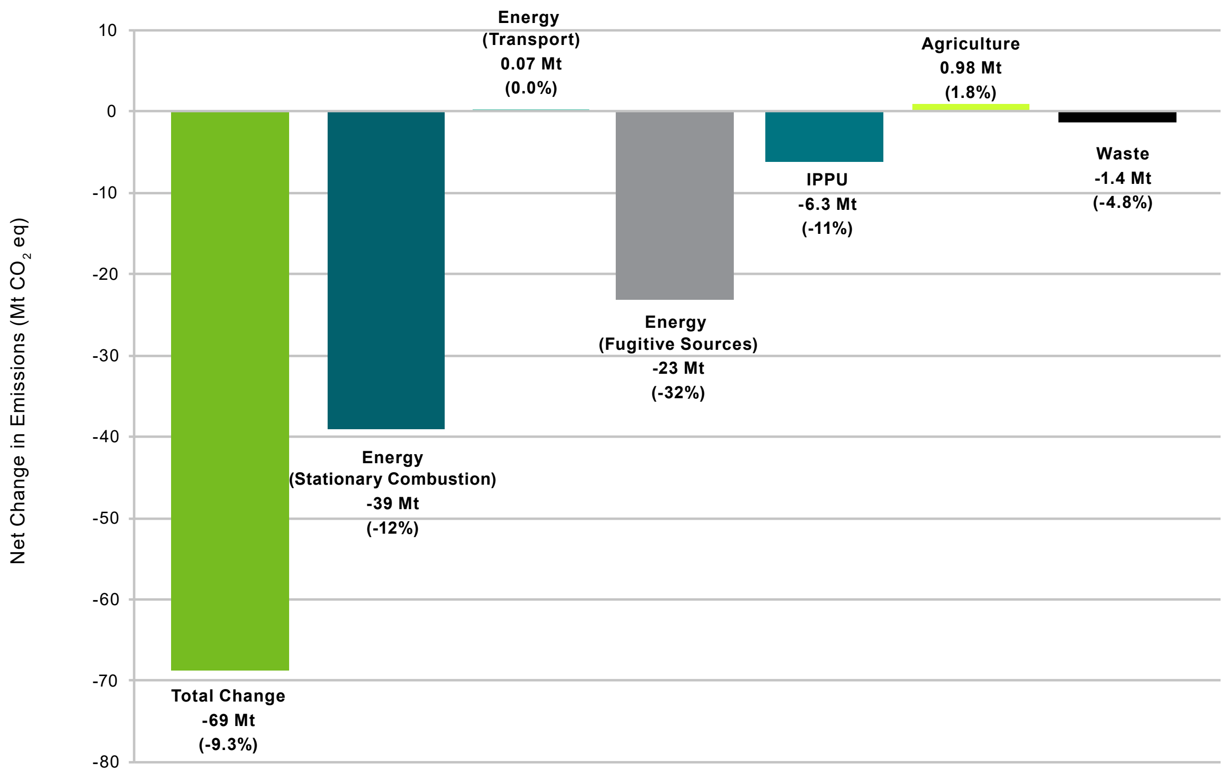
Table 2–3 **Canada's GHG Emissions by IPCC Sector (1990–2020)**

Greenhouse Gas Categories	1990	2005	2015	2016	2017	2018	2019	2020
	Mt CO_2 equivalent							
TOTAL[a, b]	**595**	**741**	**733**	**715**	**725**	**740**	**738**	**672**
ENERGY	**472**	**602**	**600**	**581**	**594**	**606**	**604**	**540**
a. Stationary Combustion Sources	**278**	**339**	**325**	**313**	**318**	**323**	**322**	**300**
Public Electricity and Heat Production	95	125	88	81	79	71	70	62
Petroleum Refining Industries	17	20	16	16	15	15	16	14
Oil and Gas Extraction	31	63	98	94	98	104	104	100
Mining	4.7	4.4	4.6	4.4	5.0	6.5	6.4	6.0
Manufacturing Industries	56	48	44	42	43	43	43	39
Construction	1.9	1.4	1.3	1.3	1.3	1.4	1.4	1.4
Commercial and Institutional	26	32	30	32	34	36	38	36
Residential	44	43	41	38	40	44	41	38
Agriculture and Forestry	2.4	2.2	3.0	3.2	3.1	3.2	3.5	3.1
b. Transport	**145**	**190**	**201**	**200**	**208**	**215**	**216**	**190**
Aviation	7.5	7.7	7.6	7.5	7.9	8.7	8.6	4.8
Domestic Aviation (Civil)	7.3	7.5	7.4	7.3	7.7	8.4	8.3	4.6
Military	0.23	0.26	0.24	0.26	0.23	0.25	0.24	0.19
Road Transportation	84	130	142	145	148	152	153	131
Light-Duty Gasoline Vehicles	42	41	34	35	34	33	32	25
Light-Duty Gasoline Trucks	20	38	45	48	49	51	53	45
Heavy-Duty Gasoline Vehicles	6.3	12	12	13	13	13	14	13
Motorcycles	0.09	0.20	0.27	0.29	0.30	0.30	0.30	0.24
Light-Duty Diesel Vehicles	0.47	0.61	0.90	0.84	0.84	0.81	0.78	0.49
Light-Duty Diesel Trucks	0.15	0.35	0.81	0.90	1.1	1.2	1.2	1.0
Heavy-Duty Diesel Vehicles	14	37	48	47	49	52	52	46
Propane and Natural Gas Vehicles	1.2	0.38	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Railways	6.9	6.6	7.1	6.5	7.5	7.6	7.7	7.2
Marine	3.1	4.0	3.4	3.5	3.6	3.8	4.4	4.2
Domestic Navigation	2.2	3.1	3.1	3.2	3.4	3.6	4.1	3.8
Fishing	0.87	0.87	0.22	0.23	0.21	0.19	0.21	0.23
Military Water-Borne Navigation	<0.05	<0.05	0.11	0.08	0.06	<0.05	0.07	0.11
Other Transportation	44	42	41	38	41	43	43	43
Off-Road Agriculture and Forestry	9.0	11	10	9.7	10	11	11	12
Off-Road Commercial and Institutional	1.5	2.4	2.7	2.6	2.8	2.9	3.0	2.9
Off-Road Manufacturing, Mining and Construction	9.2	10	13	12	14	14	14	14
Off-Road Residential	0.24	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Off-Road Other Transportation	17	6.4	4.8	4.9	5.1	5.3	5.0	5.0
Pipeline Transport	6.9	10	8.3	7.7	7.6	8.4	8.5	7.7
c. Fugitive Sources	**50**	**73**	**74**	**68**	**68**	**68**	**66**	**50**
Coal Mining	2.8	1.4	1.1	1.3	1.2	1.3	1.4	1.1
Oil and Natural Gas	47	71	73	67	67	67	65	49
d. CO_2 Transport and Storage	**-**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**
INDUSTRIAL PROCESSES AND PRODUCT USE	**57**	**57**	**54**	**55**	**53**	**54**	**53**	**50**
a. Mineral Products	**8.5**	**10**	**8.0**	**7.9**	**8.6**	**8.6**	**8.8**	**8.1**
Cement Production	5.8	7.6	6.2	6.1	6.8	6.9	7.1	6.6
Lime Production	1.8	1.8	1.4	1.4	1.4	1.4	1.3	1.2
Mineral Product Use	0.86	0.91	0.41	0.39	0.33	0.32	0.31	0.30
b. Chemical Industry	**18**	**10**	**6.8**	**7.0**	**6.4**	**6.8**	**6.7**	**6.6**
c. Metal Production	**24**	**20**	**14**	**15**	**15**	**15**	**14**	**13**
d. Production and Consumption of Halocarbons, SF_6 and NF_3	**1.0**	**5.1**	**11**	**11**	**11**	**12**	**12**	**12**
e. Non-Energy Products from Fuels and Solvent Use	**5.8**	**10**	**13**	**12**	**11**	**11**	**11**	**10**
f. Other Product Manufacture and Use	**0.37**	**0.54**	**0.54**	**0.60**	**0.63**	**0.70**	**0.66**	**0.73**
AGRICULTURE	**41**	**54**	**52**	**53**	**52**	**53**	**53**	**55**
a. Enteric Fermentation	**22**	**31**	**24**	**24**	**24**	**24**	**24**	**24**
b. Manure Management	**6.1**	**8.7**	**7.7**	**7.8**	**7.9**	**7.8**	**7.8**	**7.8**
c. Agricultural Soils	**11**	**13**	**18**	**18**	**17**	**19**	**19**	**21**
d. Field Burning of Agricultural Residues	**0.22**	**<0.05**	**0.06**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**
e. Liming, Urea Application and Other Carbon-Containing Fertilizers	**1.2**	**1.4**	**2.6**	**2.5**	**2.4**	**2.6**	**2.7**	**3.0**
WASTE	**24**	**29**	**26**	**26**	**27**	**27**	**27**	**27**
a. Solid Waste Disposal (Landfills)	**20**	**23**	**21**	**21**	**21**	**22**	**22**	**22**
b. Biological Treatment of Solid Waste	**0.07**	**0.24**	**0.31**	**0.32**	**0.33**	**0.36**	**0.36**	**0.36**
c. Wastewater Treatment and Discharge	**1.6**	**1.9**	**2.6**	**2.4**	**2.5**	**2.5**	**2.5**	**2.5**
d. Incineration and Open Burning of Waste	**0.27**	**0.35**	**0.20**	**0.20**	**0.19**	**0.18**	**0.18**	**0.16**
e. Industrial Wood Waste Landfills	**2.9**	**3.3**	**2.5**	**2.4**	**2.4**	**2.3**	**2.2**	**2.2**
LAND USE, LAND-USE CHANGE AND FORESTRY	**-64**	**-4.2**	**-0.08**	**-11**	**-17**	**-8.5**	**-16**	**-6.8**
a. Forest Land	**-202**	**-135**	**-135**	**-136**	**-137**	**-134**	**-138**	**-130**
b. Cropland	**0.38**	**-22**	**-10**	**-17**	**-23**	**-19**	**-14**	**-9.6**
c. Grassland	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**
d. Wetlands	**5.4**	**3.1**	**3.0**	**3.1**	**3.1**	**2.8**	**2.9**	**2.9**
e. Settlements	**1.9**	**1.7**	**2.5**	**2.5**	**2.4**	**2.2**	**2.2**	**2.2**
f. Harvested Wood Products	**131**	**148**	**140**	**137**	**137**	**140**	**131**	**128**

Notes:
Totals may not add up due to rounding.

a. National totals calculated in this table do not include removals reported in LULUCF.
b. This summary data is presented in more detail at open.canada.ca.

Figure 2–8 **Changes in GHG Emissions by IPCC Sector (2005–2020)**



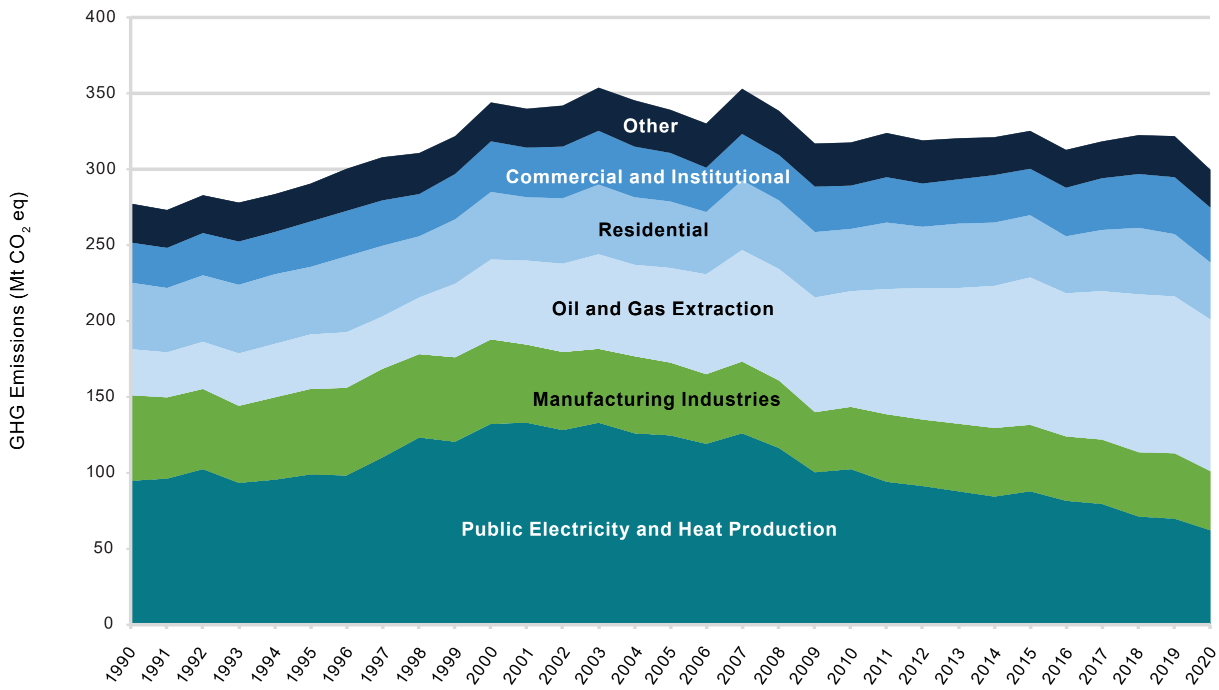
2.3.1. Energy Sector (2020 GHG emissions, 540 Mt)

In 2020, the Energy sector contributed 80% of Canada's total GHG emissions. In line with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), sources in the Energy sector are grouped under Stationary Combustion Sources, Transport, Fugitive Sources, and CO_2 Transport and Storage. Chapter 3 provides a detailed description of each category.

2.3.1.1. Stationary Combustion Sources (2020 GHG Emissions, 300 Mt)

Stationary Combustion Sources accounts for 56% of emissions from the Energy sector. In 2020, emissions totalled 300 Mt, an increase of 8% from the 1990 emissions level of 278 Mt and a decrease of 12% from the 2005 emissions level of 339 Mt (Figure 2–9, Table 2–4). Dominant categories in Stationary Combustion Sources are Oil and Gas Extraction and Public Electricity and Heat Production, which in 2020 contributed 33% and 21%, respectively, of the total Stationary Combustion emissions. Manufacturing Industries, Residential Buildings, and Commercial and Institutional Buildings contributed 13%, 13% and 12%, respectively, of total Stationary Combustion emissions in 2020.

Figure 2–9 **Trends in Canadian GHG Emissions from Stationary Combustion Sources (1990–2020)**



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

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

	GHG Emissions (Mt CO_2 eq)								Change (%)	
GHG Source Category	1990	2005	2015	2016	2017	2018	2019	2020	1990–2020	2005–2020
Stationary Combustion Sources	**278**	**339**	**325**	**313**	**318**	**323**	**322**	**300**	**8%**	**-12%**
Public Electricity and Heat Production	**95**	**125**	**88**	**81**	**79**	**71**	**70**	**62**	**-34%**	**-50%**
Petroleum Refining	**17**	**20**	**16**	**16**	**15**	**15**	**16**	**14**	**-17%**	**-28%**
Oil and Gas Extraction	**31**	**63**	**98**	**94**	**98**	**104**	**104**	**100**	**225%**	**59%**
Mining	**4.7**	**4.4**	**4.6**	**4.4**	**5.0**	**6.5**	**6.4**	**6.0**	**30%**	**39%**
Manufacturing Industries	**56**	**48**	**44**	**42**	**43**	**43**	**43**	**39**	**-31%**	**-19%**
Iron and Steel	4.9	5.5	5.8	5.6	6.0	6.4	6.1	4.7	-5%	-15%
Non-Ferrous Metals	3.3	3.6	3.1	3.2	3.3	2.8	3.3	3.0	-8%	-16%
Chemicals	8.3	8.3	12	11	10	9.5	10	9.4	13%	14%
Pulp, Paper and Print	14	8.6	6.0	6.0	6.4	7.1	7.2	6.5	-55%	-25%
Cement	4.0	5.4	3.9	3.9	4.2	4.2	4.0	3.1	-21%	-42%
Other Manufacturing	21	16	13	13	13	13	13	12	-44%	-27%
Construction	**1.9**	**1.4**	**1.3**	**1.3**	**1.3**	**1.4**	**1.4**	**1.4**	**-24%**	**-1%**
Commercial and Institutional	**26**	**32**	**30**	**32**	**34**	**36**	**38**	**36**	**38%**	**12%**
Residential	**44**	**43**	**41**	**38**	**40**	**44**	**41**	**38**	**-13%**	**-12%**
Agriculture/Forestry/Fishing	**2.4**	**2.2**	**3.0**	**3.2**	**3.1**	**3.2**	**3.5**	**3.1**	**29%**	**42%**

Note: Totals may not add up due to rounding.

Public Electricity and Heat Production (2020 GHG emissions, 62 Mt)

Emissions from the Public Electricity and Heat Production category decreased by 34% between 1990 and 2020.

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 2020, electricity generation (driven by demand) increased by 34% (StatCan, 1990–), from 474 TWh[4] to 634 TWh. Despite the increase in demand over this period, GHG emissions dropped by 34% (33 Mt) between 1990 and 2020. Likewise, between 2005 and 2020, electricity generation rose by 5%, while corresponding emissions fell by 50% (63 Mt). Over both time periods, the principal cause of the decrease in emissions is a considerably less GHG-intensive mix of sources used to generate electricity (Figure 2–10).

Low-emitting non-combustion sources—hydroelectric generation, nuclear power, wind turbines, solar photovoltaic cells and tidal power—accounted for 91% of the increased generation between 1990 and 2020 and for 84% of the total electricity generated in Canada in 2020. Hydroelectric generation alone accounted for 62%, followed by nuclear power generation at 16% and non-hydro-based renewables at 6%. The increased level of non-combustion sources in the generation mix in 2020 was the largest contributor to emission reductions since 1990 (26 Mt) (Figure 2–10) and 2005 (41 Mt) (Figure 2–11).

In addition, the fuel mix used for combustion generation has been steadily moving to less GHG-intensive fossil fuels. Between 2005 and 2020, the quantity of electricity generated by natural gas-fired units increased by 61% (18 TWh), while the amount generated by coal and refined petroleum products decreased by about 62% (58 TWh) and 80% (8.7 TWh), respectively. Natural gas combustion is about half as carbon-intensive as coal and approximately 25% less carbon-intensive than most refined petroleum products. The overall impact of the displacement of coal and refined petroleum products by natural gas is a decrease of about 18 Mt between 1990 and 2020 and about 14 Mt between 2005 and 2020.

The efficiency of combustion equipment has also played a role in the GHG emission reductions. Energy efficiency improvements resulted in an approximately 5.8-Mt reduction in GHG emissions between 1990 and 2020 and a 10-Mt reduction between 2005 and 2020.

Oil and Gas Extraction (2020 GHG emissions, 100 Mt)

Stationary combustion emissions from Oil and Gas Extraction increased by 69 Mt (225%) between 1990 and 2020 and by 37 Mt (59%) between 2005 and 2020. This category includes emissions associated with fuel combustion from Natural Gas Production and Processing, Conventional Oil Production, and Oil Sands Mining, Extraction and Upgrading. Increases in emissions are consistent with a 188% increase in the production of crude bitumen and synthetic crude oil from the oil sands industry since 2005 (StatCan, n.d.[c], n.d.[d]) and the increased use of more energy-intensive extraction techniques, such as horizontal drilling, hydraulic fracturing and enhanced oil recovery.

In the oil sands industry, the steam-assisted gravity drainage (SAGD) process used to extract crude bitumen involves injecting large amounts of steam into the producing formation. The steam is generally produced by combusting natural gas, resulting in emissions. Since 2005, total natural gas consumption in the Oil and Gas Extraction category has increased by approximately 74% (StatCan, 1990–), and SAGD production has increased by almost 1300% (AER, 2021). In general, while increases from Oil and Gas Extraction may originate from multiple activities, they tend to be consistent with the 266% increase in the production of non-upgraded bitumen in Canada's oil sands area, particularly in SAGD production. In contrast, since 2005, natural gas production has decreased by 10% (StatCan, 1990–) and conventional oil production by 12% (StatCan, n.d.[c], n.d.[d]).

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

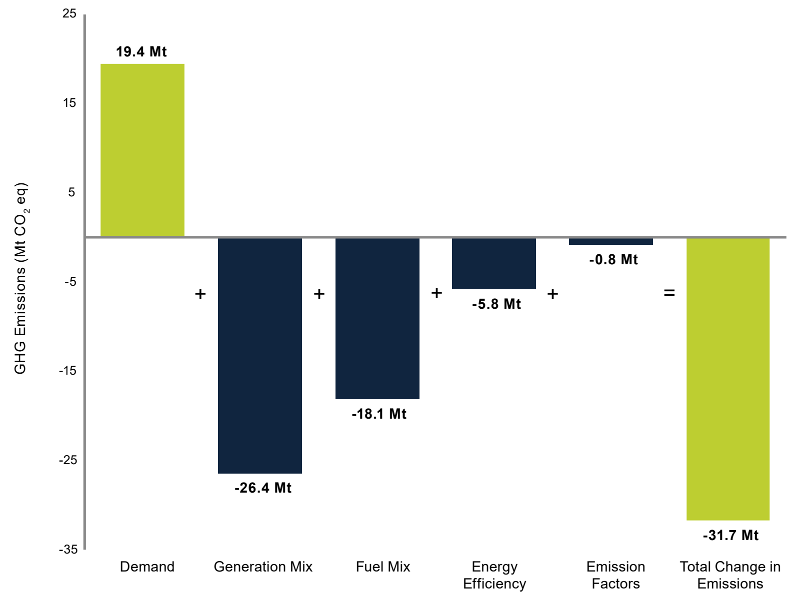
Manufacturing Industries (2020 GHG emissions, 39 Mt)

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

In 2020, GHG emissions from the Manufacturing Industries category were 39 Mt, which represents a 31% decrease from 1990 and a 19% decrease since 2005. This includes a decrease of -5.0 Mt between 2005 and 2019, and an additional -4.5 Mt between 2019 and 2020. While the decrease between 2005 and 2019 is based on decreases in certain sectors (-3.4 Mt from Other Manufacturing, -1.4 Mt in both Cement, and Pulp, Paper and Print), offset by increases in others (1.4 Mt in Chemicals), the decrease between 2019 and 2020 occurred in all Manufacturing Industries. The largest decreases are from Iron and Steel (-1.4 Mt), Other Manufacturing (-1.0 Mt) and Cement (-0.9 Mt).

4 1 TWh is 1 billion kWh. It is the amount of electricity consumed by about 90,000 households in Canada in approximately one year.

Figure 2–10 Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 1990–2020 (Mt CO_2 eq)



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.

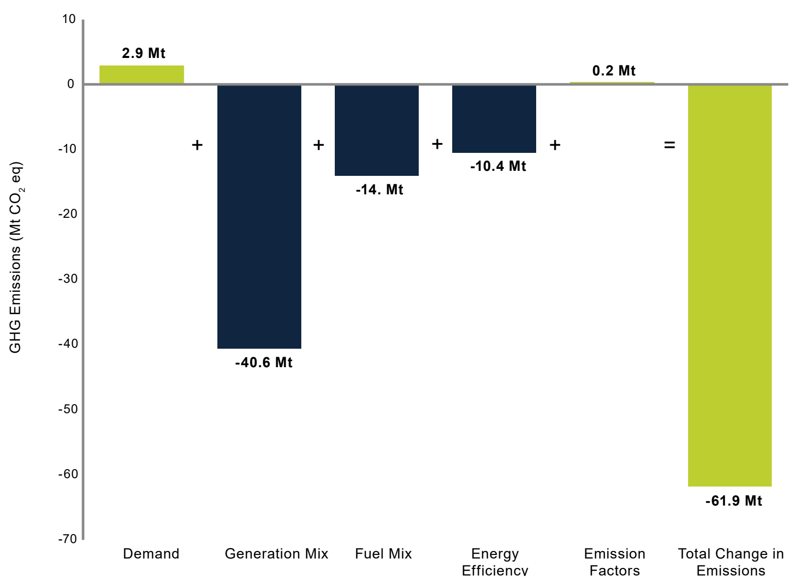
Generation mix – The generation mix refers to the relative share of combustion and non-combustion sources in generation activity.

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.

Figure 2–11 Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 2005–2020 (Mt CO_2 eq)



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.

Within the Manufacturing Industries category, the Other Manufacturing and Pulp, Paper and Print subcategories showed the largest emissions decreases; both of which showed decreases in fuel combustion and fuel switching from high to lower GHG-intensive fuels. Emissions from the Other Manufacturing subcategory decreased by 9.4 Mt (44%) between 1990 and 2020, in keeping with a 23% decrease in fuel combustion along with switches in the fuel mix. In 1990, natural gas made up 89% of the mix, while in 2020 it only made up 69%; replacing the natural gas with wood combustion. Between 1990 and 2020, the Pulp, Paper and Print subcategory decreased by 8.0 Mt (55%), based on a 23% reduction in fuel combustion, 70% of which was a decrease in heavy fuel oil. In 1990, heavy fuel oil made up 17% of the fuel mix in the Pulp, Paper and Print subcategory, with the remainder made of less GHG-intensive fuels such as natural gas and spent pulping liquor and wood waste. In 2020, 98% of the fuel mix consists of these less GHG-intensive fuels. In contrast, combustion emissions from chemical industries showed the largest increase in emissions within the category, increasing by 1.1 Mt (13%). This is generally consistent with a 22%[5] growth in the production of chemicals between 1990 and 2020.

Residential, Commercial and Institutional (2020 GHG emissions, 74 Mt)

GHG emissions in the Residential and the Commercial and Institutional categories come from the combustion of fuels such as natural gas, home heating oil and biomass fuels (non-CO_2 only), primarily to heat residential, commercial and institutional buildings. Emissions in these categories contributed about 74 Mt of GHG emissions in 2020, a 6.1% increase since 1990.

Overall, Residential emissions decreased by 5.7 Mt (13%) between 1990 and 2020 and by 5.3 Mt (12%) between 2005 and 2020. Commercial and Institutional emissions increased by 10 Mt (38%) from 1990 to 2020 and by 3.9 Mt (12%) from 2005 to 2020. Energy efficiency improvements, new home construction and increases in commercial floor space are the major factors that influenced the changes in energy-related emissions in the Residential and the Commercial and Institutional categories (Figure 2–12 and Figure 2–13).

In the Residential category, population and floor space per capita are the most significant upward drivers of emissions. Since 1990, the 37% increase in population accounts for an emissions increase of 12.5 Mt, while a 31%[6] increase in floor space per capita accounts for an emissions increase of 10.8 Mt (Figure 2–12). These increases have been more than offset by improvements in energy efficiency, which are equivalent to a 25.12.7 Mt decrease in emissions between 1990 and 2020. Note, this pattern of increasing population and floor space per capita being offset by improvements in energy efficiency can also be seen between 2005 and 2020. Decreasing consumption of light fuel oil in all provinces and territories, except Newfoundland and Labrador (4% increase) between 2005 and 2020 is the largest driver of the 5.3 Mt decrease in emissions. Quebec and Ontario account for 88% of the decrease in emissions from light fuel oil, with the remaining provinces and territories making up the remaining 12%.

In the long term, floor space was the most significant upward driver of emissions in the Commercial and Institutional category, having increased by 49% since 1990.[7] The resulting 11.9-Mt increase in emissions was partially offset by improvements in the fuel mix, equivalent to a 0.9 Mt decrease in GHG emissions (Figure 2–13).

Weather patterns can have a non-negligible effect on emissions when comparing one year to another, as suggested by the close tracking between heating degree-days (HDDs) and GHG emissions (Figure 2–14). The impact that weather can have on space heating requirements and fuel demand results in emission patterns that mirror inter-annual weather variability.

Other Stationary Combustion Sources (2020 GHG emissions, 25 Mt)

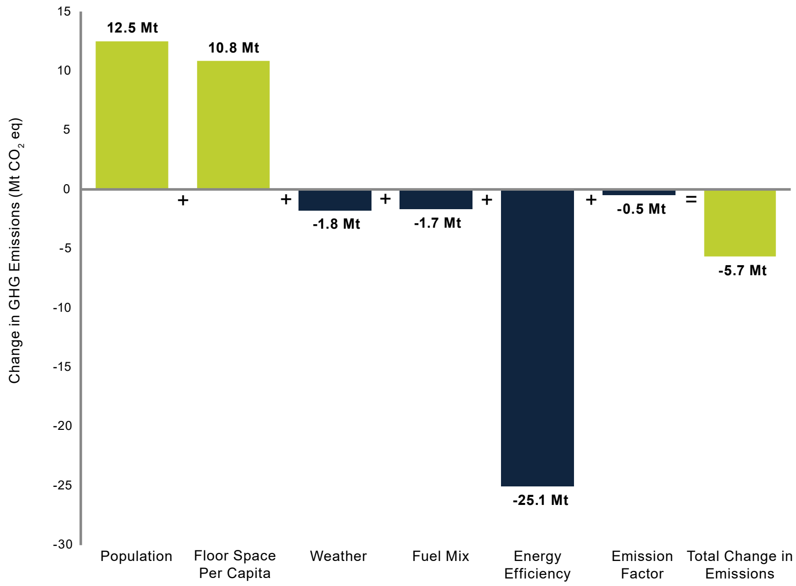
Other Stationary Combustion Sources comprise fuel combustion emissions from the Petroleum Refining Industries, Mining, Construction, and Agriculture and Forestry categories. From 1990 to 2020, the Petroleum Refining Industries category showed a decrease in GHG emissions of 2.9 Mt (17%), the Mining category showed an increase of 1.4 Mt (30%), the Construction category showed a decrease of 0.50 Mt (24%), and the Agriculture and Forestry category showed an increase of 0.69 Mt (29%).

5 Griffin B. 2022. Personal communication (email from Griffin B. to Kay J., Physical Scientist, PIRD, dated January 18, 2022). Canadian Energy and Emissions Data Centre.

6 Wang, J. 2021. Personal communication (email from Wang J. to Kay J., Physical Scientist, PIRD, dated November 29, 2021). Office of Energy Efficiency, Natural Resources Canada.

7 Kaymak, D. 2021. Personal communication (email from Kaymak D. to Kay J., Physical Scientist , PIRD, dated November 29, 2021). Economic Analysis Directorate, Environment and Climate Change Canada.

Figure 2–12 **Factors Contributing to the Change in Stationary GHG Emissions from the Residential Category between 1990 and 2020**



Notes:

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

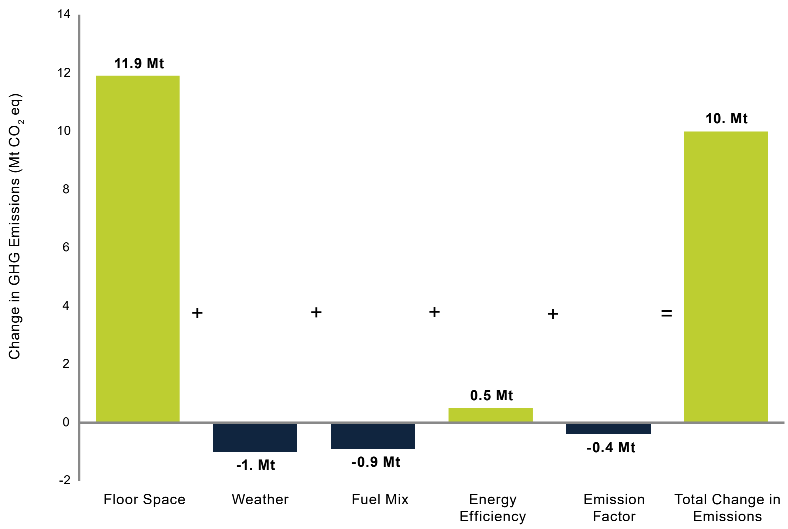
Weather – Weather refers to the fluctuations in weather conditions, particularly outdoor winter temperature.

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

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

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

Figure 2–13 **Factors Contributing to the Change in Stationary GHG Emissions from the Commercial and Institutional Category between 1990 and 2020**



Notes:

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

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

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

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

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

Figure 2–14 **Heating Degree-Days (HDDs) and GHG Emissions from the Residential and the Commercial and Institutional Subcategories (1990–2020)**

2.3.1.2. Transport (2020 GHG emissions, 190 Mt)

Transport is a large and diverse sector, accounting for 190 Mt of GHG emissions or 35% of Canada's Energy sector emissions in 2020. 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 2020, Transport emissions rose by 31% (45 Mt), accounting for a significant portion of Canada's emissions growth. From 2019 to 2020, Transport emissions dropped by 12% (27 Mt), the first notable year-to-year decrease to occur in the 1990–2020 time series for the sector since 2008–2009, which had a year-to-year decrease of 2.6% (5.0 Mt).

Emissions from Transport result primarily from Road Transportation, which includes personal transportation (light-duty gasoline vehicles and trucks) and heavy-duty diesel vehicles (Figure 2–15). Other Transportation (Off-road and Pipelines) is the second-largest category, accounting for 22% of Transport emissions, mainly through the combustion of diesel fuel used in off-road applications. The Aviation category was relatively stable over the reported time series until 2020, undergoing a 44% (3.8 Mt) decrease of emissions from 2019 levels. The Marine and Railways categories combined contributed to approximately 6.0% of the Transport emissions in 2020 and, overall, were stable over the 1990–2020 time series.

Road Transportation (2020 GHG emissions, 131 Mt)

The growth trend since 1990 in Road Transportation emissions is largely due to more driving as measured in vehicle kilometres travelled (VKT). However in 2020, total VKT decreased by 17% relative to 2019 levels, driven by reductions to both kilometers driven per vehicle and the total vehicle fleet.

The total vehicle fleet has increased by 81% since 1990 (39% since 2005) most notably for light-duty trucks and heavy-duty vehicles (Table 2–6). Both of these subclasses have steadily increased throughout the 1990–2020 time series, unlike light-duty cars which have decreased in recent years. Absolute growth in vehicles was greater in the period 2005–2020 than in the period 1990–2005, consistent with Canada's human population trend when the same periods are compared (StatCan, n.d.[b]).

Despite the drop in total vehicle kilometres travelled in 2020, the steady expansion of the overall fleet throughout the 1990–2020 time series resulted in the 2020 total being 61% and 4.8% 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 2020, approximately 110 000 fully electric vehicles were in the vehicle fleet, a 55% growth from 2019.

Figure 2–15 **Trends in Canadian GHG Emissions from Transport (1990–2020)**

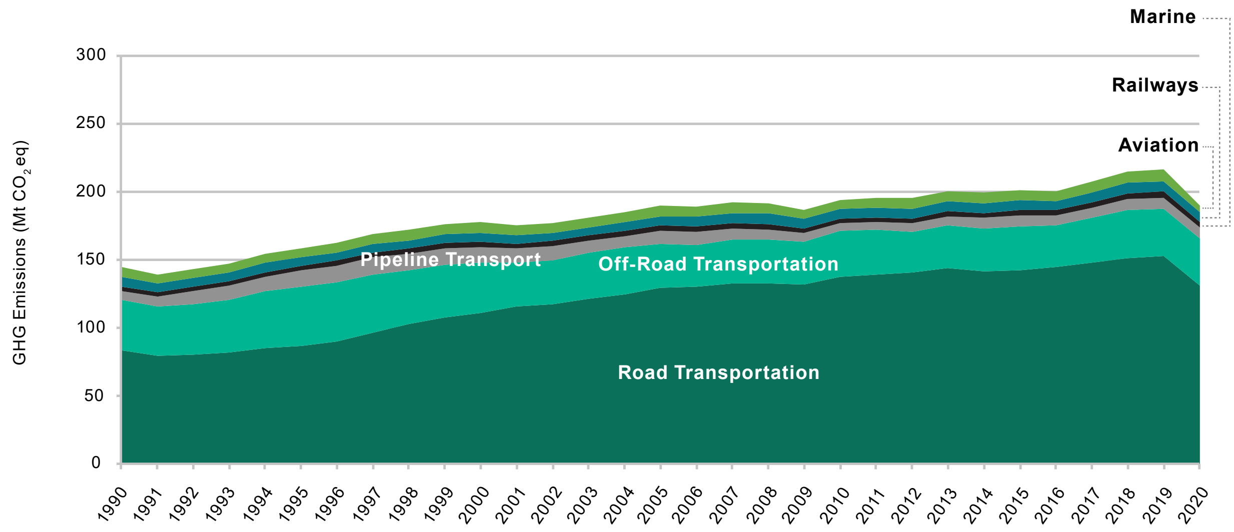


Table 2–5 **GHG Emissions from Transport, Selected Years**

CRF Code		GHG Emissions (Mt CO_2 eq)								Change (%)	
		1990	2005	2015	2016	2017	2018	2019	2020	1990–2020	2005–2020
1.A.3	**Transport**	**145**	**190**	**201**	**200**	**208**	**215**	**216**	**190**	**31%**	**0%**
	Aviation	**7.5**	**7.7**	**7.6**	**7.5**	**7.9**	**8.7**	**8.6**	**4.8**	**-36%**	**-38%**
1.A.3.a	Domestic Aviation (Civil)	7.3	7.5	7.4	7.3	7.7	8.4	8.3	4.6	-37%	-38%
1.A.5.b	Military	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.2	-20%	-28%
	Road Transportation	**84**	**130**	**142**	**145**	**148**	**152**	**153**	**131**	**57%**	**1%**
1.A.3.b.i	Light-Duty Gasoline Vehicles	42	41	34	35	34	33	32	25	-40%	-40%
1.A.3.b.ii	Light-Duty Gasoline Trucks	20	38	45	48	49	51	53	45	124%	19%
1.A.3.b.iii	Heavy-Duty Gasoline Vehicles	6.3	12	12	13	13	13	14	13	100%	8%
1.A.3.b.iv	Motorcycles	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.2	171%	20%
1.A.3.b.i	Light-Duty Diesel Vehicles	0.5	0.6	0.9	0.8	0.8	0.8	0.8	0.5	5%	-19%
1.A.3.b.ii	Light-Duty Diesel Trucks	0.2	0.3	0.8	0.9	1.1	1.2	1.2	1.0	547%	187%
1.A.3.b.iii	Heavy-Duty Diesel Vehicles	14	37	48	47	49	52	52	46	240%	26%
1.A.3.b.v	Propane and Natural Gas Vehicles	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	-100%	-99%
1.A.3.c	**Railways**	**6.9**	**6.6**	**7.1**	**6.5**	**7.5**	**7.6**	**7.7**	**7.2**	**4%**	**9%**
	Marine	**3.1**	**4.0**	**3.4**	**3.5**	**3.6**	**3.8**	**4.4**	**4.2**	**36%**	**5%**
1.A.3.d	Domestic Navigation	2.2	3.1	3.1	3.2	3.4	3.6	4.1	3.8	77%	25%
1.A.4.c.iii	Fishing	0.9	0.9	0.2	0.2	0.2	0.2	0.2	0.2	-73%	-73%
1.A.5.b	Military Water-Borne Navigation	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1	283%	303%
	Other Transportation	**44**	**42**	**41**	**38**	**41**	**43**	**43**	**43**	**-2%**	**2%**
1.A.4.c.ii	**Off-Road Agriculture and Forestry**	**9.0**	**11**	**10**	**9.7**	**10**	**11**	**11**	**12**	**29%**	**2%**
1.A.4.a.ii	Off-Road Commercial and Institutional	1.5	2.4	2.7	2.6	2.8	2.9	3.0	2.9	89%	20%
1.A.2.g.vii	Off-Road Manufacturing, Mining and Construction	9.2	10	13	12	14	14	14	14	54%	36%
1.A.4.b.ii	Off-Road Residential	0.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	411%	-2%
1.A.3.e.ii	Off-Road Other Transportation	17	6.4	4.8	4.9	5.1	5.3	5.0	5.0	-70%	-22%
1.A.3.e.i	Pipeline Transport	6.9	10	8.3	7.7	7.6	8.4	8.5	7.7	12%	-23%

Table 2–6 **Trends in Vehicle Populations for Canada, 1990–2020**				
Year	Number of Vehicles (000s)			
	Light-Duty Vehicles		Heavy-Duty Vehicles	All Vehicles
	Cars	Trucks		
1990	10 759	3 392	908	15 410
2005	11 009	6 920	1 618	20 061
2015	12 860	11 783	2 304	27 751
2016	12 376	12 035	2 379	27 611
2017	11 916	12 299	2 459	27 509
2018	11 793	12 879	2 534	28 053
2019	11 610	13 426	2 571	28 461
2020	10 859	13 593	2 513	27 817
Change since 1990	1%	301%	177%	81%
Change since 2005	-1%	96%	55%	39%

Notes:
Light-duty trucks include most pickups, minivans and sport utility vehicles.
All Vehicles also include motorcycles and natural gas and propane vehicles.

2

Light-Duty Gasoline Vehicles (2020 GHG emissions, 25 Mt)

Total light-duty vehicle emissions are influenced by several factors, including total vehicle kilometres travelled, vehicle type, fuel efficiency, fuel type, emissions control technology and biofuel consumption. Within this category, emissions in 1990 and 2005 are relatively the same, with emissions in 2005 being only 0.4% (159 kt) lower than emissions in 1990. This similarity is the net result of the increase in the total number of light-duty gasoline vehicles and kilometres travelled per vehicle and the decrease in the fleet average fuel consumption ratio between 1990 and 2005. This offsetting of emissions is more apparent when comparing 2005 levels to 2020 levels, with the exception that kilometres travelled per vehicle decreased instead of increased over that period. While the total number of light-duty gasoline vehicles in 2020 increased relative to 2005, the continued decrease in the fleet average fuel consumption ratio, in addition to an 18% decrease to kilometres travelled per vehicle relative to 2019, resulted in a net 40% (16 Mt) decrease. As new model year vehicles replace older, less efficient vehicles, the overall fleet fuel efficiency improves. This gradual improvement in efficiency offsets emissions increases resulting from increased total kilometres travelled and shifts in vehicle type (Figure 2–16). Implementation of emission control technologies and increased use of biofuels since the 1990s have also resulted in decreased emissions.

Light-Duty Gasoline Trucks (2020 GHG emissions, 45 Mt)

On average, light-duty trucks—including sport utility vehicles (SUVs), many pickups and all minivans—emitted 30% more GHGs per kilometre than cars in 2020. Emissions from Light-Duty Gasoline Trucks in 2020 have increased by 124% (33 Mt) relative to 1990 and by 19% (15 Mt) relative to 2005, despite a 15% decrease to kilometres travelled per truck in 2020 relative to 2019. While a decrease in the associated fleet fuel consumption ratios was observed between 1990 and 2020, this was offset by an increase in both vehicle population and associated total kilometres travelled, reflecting the trend towards the increasing use of SUVs, minivans and pickups for personal transportation.

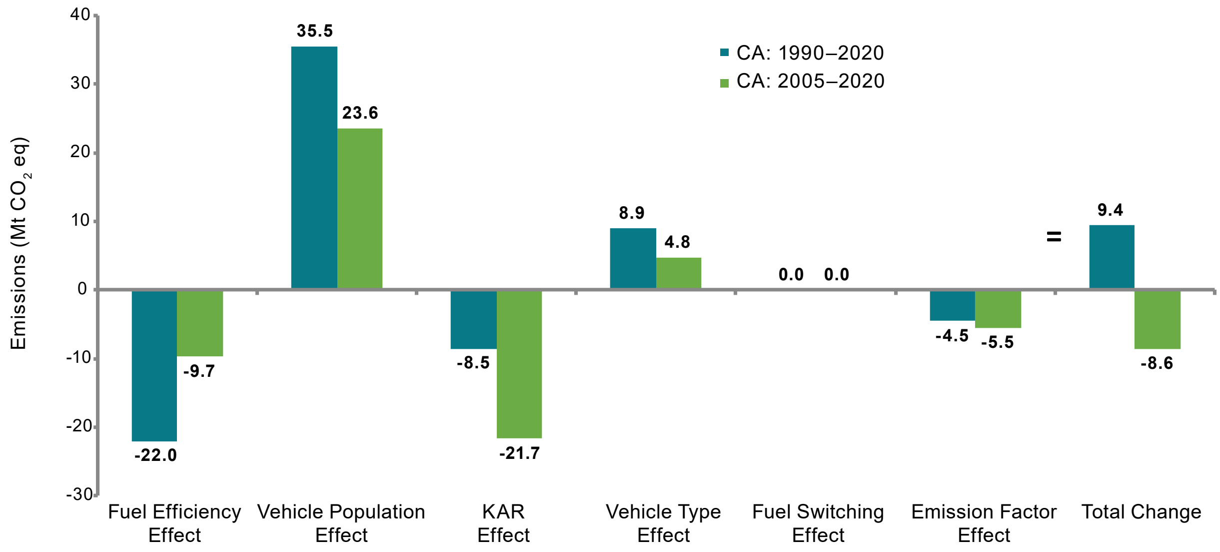
Heavy-Duty Diesel Vehicles (2020 GHG emissions, 46 Mt)

In 2020, emissions from Heavy-Duty Diesel Vehicles contributed 46 Mt to Canada’s total GHG emissions (an increase of about 240% from 1990 and 26% from 2005). The trends in data from major for-hire truck haulers in Canada show that freight hauling by heavy trucks has increased substantially over time and that this activity is the primary task performed by heavy-duty vehicles (StatCan, n.d.[e]). Further, the adoption of “just-in-time” delivery by many businesses has resulted in reliance on heavy trucks in the freight transportation sector, which sometimes act as virtual warehouses (NRCan, 2013).

Other Transportation (Off-Road) (2020 GHG emissions, 35 Mt)

Off-road emissions 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 2020, the Off-Road Manufacturing, Mining and Construction subcategory and the Off-Road Agriculture and Forestry subcategory accounted for 41% and 33% of off-road emissions, respectively. The net emissions for all off-road subcategories have decreased by 5% since 1990 and increased by 10% since 2005.

Figure 2–16 **Factors Contributing to Change in Light-Duty Vehicle Emissions, 1990–2020 and 2005–2020**



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, 1990–2020 and 2005–2020.

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

Vehicle population effect refers to the change in emissions attributable to the change in the total number of light cars and trucks on Canadian roads.

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

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

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

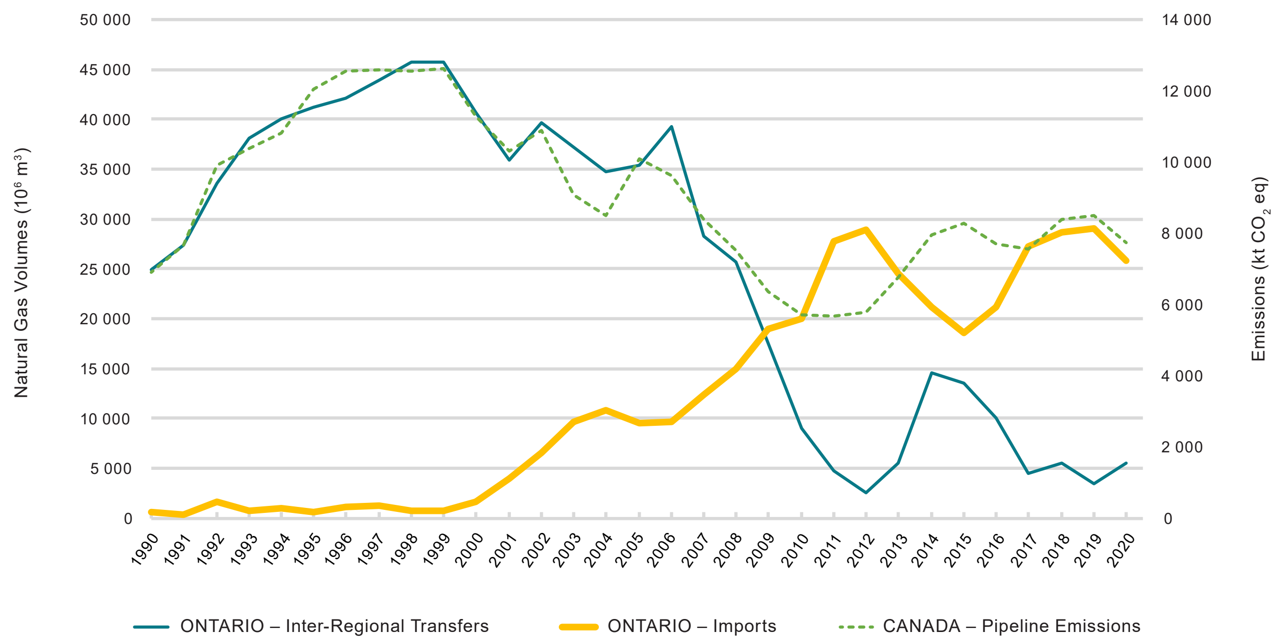
Overall emission factor effect refers to the change in emissions from emission control technologies on CH_4 and N_2O emissions as well as the use of biofuels.

Other Transportation (Pipeline Transport) (2020 GHG emissions, 7.7 Mt)

Pipeline emissions result from the combustion of natural gas at compressor stations used for natural gas transport. In 2020, over 99% of marketable natural gas production occurred in western Canada: Alberta (68.1%), British Columbia (28.7%) and Saskatchewan (2.6%). While these provinces account for approximately 63% of marketable natural gas consumption in Canada, Ontario, the most populous province, accounts for approximately 26% of natural gas consumption but produces less than 0.05% of natural gas (StatCan, 1990–). The natural gas demand in Ontario, along with the geographical separation from producing regions, necessitates the long-range transport of natural gas through transmission pipelines. For that reason, the source of the natural gas consumed in Ontario has a large impact on pipeline emissions.

Historically, inter-regional transfers of large quantities of Western Canadian natural gas to eastern Canada, especially Ontario, has been the main driver of pipeline emissions. The amount of gas transported from west to east has decreased somewhat since 1990. The decrease started in the early 2000s as western Canadian natural gas was displaced by shale gas imports from the United States (StatCan, 1990–) and as more natural gas was consumed in Alberta's oil sands industry. In general, as imports into Ontario increase, inter-regional transfers of gas from western Canada decline, resulting in a decrease in combustion emissions from pipelines (Figure 2–17).

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



2.3.1.3. **Fugitive Sources (2020 GHG Emissions, 50 Mt)**

Fugitive emissions are intentional or unintentional releases of GHGs from the production, processing, transmission, storage and delivery 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, are also considered fugitive emissions. Fugitive Sources are broken down into two main categories: Oil and Natural Gas (98% of fugitive emissions) and Coal Mining (2%).

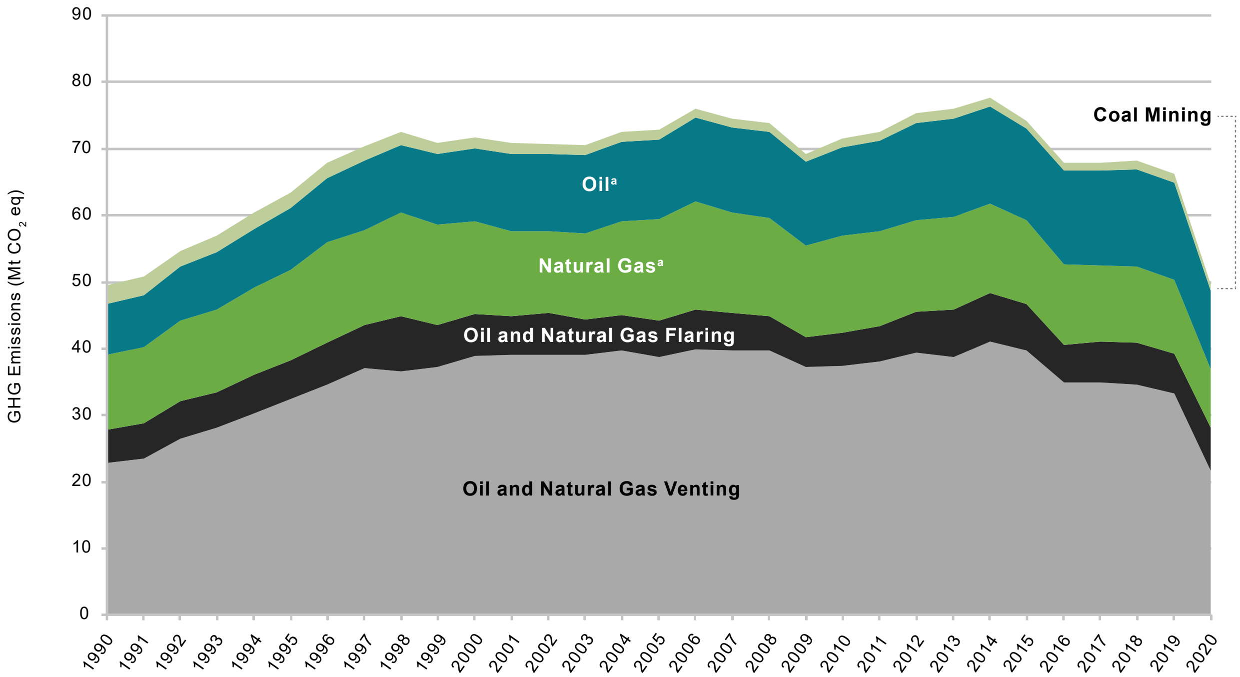
Although fugitive emissions in 1990 (50 Mt) and 2020 (50 Mt) are roughly equivalent (Table 2–7), emissions have varied considerably over the time series. Fugitive emissions peaked in 2014 at 78 Mt (Figure 2–18) contributing 21% to the growth in total Canadian emissions between 1990 and 2014. Fugitive emissions from Oil and Natural Gas alone increased by 30 Mt (64%) over this period, while releases from Coal Mining decreased by 1.5 Mt (-54%), mainly due to mine closures in eastern Canada.

The 63% growth in Oil and Natural Gas fugitive emissions between 1990 and 2014 (Figure 2–18) is a result of increased activity in the Oil and Gas sector. From 1990 to 2014, approximately 378,000 oil and gas wells were drilled. Furthermore, the number of producing oil and gas wells was at an all-time high in 2014 (CAPP, 2021), 220% higher than in 1990. As the number of facilities in the oil and gas industry has grown, the number of potential sources of fugitive emissions has also increased significantly, driving the increase in emissions.

Although oil sands production represented approximately 70% of total oil production in Canada in 2020, it accounted for only 21% of total oil and gas fugitive emissions. Since the vast majority of fugitive emissions originate from conventional production and processing activities, the increase in bitumen production from the oil sands has little impact on fugitive emissions.

Fugitive oil and gas emissions increased steadily from 47 Mt in 1990 to 70 Mt in 2000 (+44%) (Figure 2–18) as the sector grew from approximately 75,000 operating wells in 1990 to almost 125,000 in the year 2000. However, even as the oil and gas industry continued to grow substantially from 2000 to 2014, fugitive emissions did not grow at the same rate. This was the result of the combined effect of improved inspection and maintenance programs, better industry practices, technological improvements and initiatives by provincial regulators. For example, in 1999, the province of Alberta introduced *Directive 060: Upstream Petroleum Industry Flaring, Incinerating, and Venting* to reduce flaring and venting emissions from

Figure 2–18 **Trends in Canadian GHG Emissions from Fugitive Sources (1990–2020)**



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_2 eq)								Change (%)	
	1990	2005	2015	2016	2017	2018	2019	2020	1990–2020	2005–2020
Fugitive Sources[a]	**50**	**73**	**74**	**68**	**68**	**68**	**66**	**50**	**0%**	**-32%**
Coal Mining	**2.8**	**1.4**	**1.1**	**1.3**	**1.2**	**1.3**	**1.4**	**1.1**	**-62%**	**-23%**
Oil and Natural Gas	**47**	**71**	**73**	**67**	**67**	**67**	**65**	**49**	**4%**	**-32%**
Oil[b]	7.7	12	14	14	14	15	15	12	52%	-2%
Natural Gas[b]	11	15	13	12	11	11	11	8.7	-22%	-43%
Venting	23	39	40	35	35	35	33	22	-5%	-44%
Flaring	5.1	5.5	6.9	5.7	6.0	6.3	6.1	6.4	27%	17%

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.

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 5.9 Mt (8%) between 2000 and 2014 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 industry programs, technological improvements and provincial initiatives had a positive impact on emission reductions, they were not enough to counteract the rapid 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, 2021; StatCan, n.d.[c], n.d.[d]) and the average production per natural gas well decreased by 62% in western Canada (CAPP, 2021; StatCan, n.d.[g], n.d.[h]).

From 2014 to 2019, emissions dropped by 12 Mt (15%), mainly due to reductions in venting and flaring, as more gas was conserved. There was also contraction within the sector as the number of operating wells decreased by 10% and the number of wells drilled between 2015 and 2019 was over 50% less than the previous 5-year period.

From 2019 to 2020, emissions dropped by 16 Mt (25%). This drop coincides with several contributing factors, including:

1. Federal (ECCC, 2018) and equivalent[8] provincial regulations (AB, 2018; BC, 2021; SK, 2020) to reduce CH_4 emissions from oil and gas operations
2. Overall contraction of the industry, which experienced a 9% reduction in conventional oil production, a 1% reduction in natural gas production, and an 11% reduction in the number of operating oil and gas wells
3. Effective January 1, 2020, updated requirements for the reporting of vent gas volumes in Alberta and Saskatchewan came into effect. New sources (e.g., venting from pneumatics, compressor seals, etc.), not previously required to be included in reported vent gas volumes, are now reported in the total vented volume. In order to avoid double counting, emissions from these sources are no longer estimated separately, resulting in a methodological inconsistency between 2019 and 2020. See Annex 3.2, section A3.2.2.1.5 for more details.
4. A drastic decrease in the price of oil at the onset of the COVID-19 pandemic

Of the 16 Mt decrease, approximately 5.1 Mt is the result of enhanced leak detection and repair (LDAR) requirements in the federal and provincial regulations. Venting emissions also decreased by 11.5 Mt, however, because of data limitations it is currently impossible to differentiate between the reductions that occurred due to the regulations (item 1 in the preceding list) with those that may have resulted from the changes to vent gas reporting guidelines (item 3). The methodological inconsistency introduced as a result of the changes to provincial reporting guidelines is a priority and is being actively investigated.

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

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

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

Historically, atmospheric measurements have only produced large-scale regional or facility-level estimates and have not been able to resolve the specific emission sources within a facility responsible for the emissions. Fully understanding the discrepancies between “bottom-up” and “top-down” approaches requires this level of detail. Recent advances in measurement technology are now able to identify specific sources in the atmospheric measurements (e.g. Johnson et al., 2021).

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

8 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).

2.3.1.4. Trends in CO_2 Transport and Storage

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

Almost all other current CO_2 transport and storage activities in Canada are associated with enhanced oil recovery operations at Weyburn, Saskatchewan. Beginning in 2014, the Weyburn operations began receiving most of the CO_2 captured at the Boundary Dam coal-fired power plant in Saskatchewan. In addition, the Aquistore Project and its Basal Cambrian storage complex inject a small amount of CO_2 from Boundary Dam into long-term permanent storage.

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

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

2.3.2. Industrial Processes and Product Use (2020 GHG emissions, 50 Mt)

The IPPU sector includes GHG emissions that result from manufacturing processes and use of products. Subsectors include: Mineral Products; Chemical Industry; Metal Production; Production and Consumption of Halocarbons, SF_6 and NF_3; Non-Energy Products from Fuels and Solvent Use; and Other Product Manufacture and Use. Emissions from the IPPU sector contributed 50 Mt (7.5%) to Canada's 2020 emissions, compared with 57 Mt (7.6%) in 2005, a decrease of approximately 6.3 Mt, or 11%. Total emissions in this sector result from activities in several diverse industries. Trends in emissions reflect the combined effects of multiple drivers on various industries.

Emission reductions have occurred since 2005 in Iron and Steel Production (CO_2), Aluminium Production (PFCs), Adipic Acid Production (N_2O), Use of SF_6 in Magnesium Production (SF_6), Nitric Acid Production (N_2O), and Cement Production (CO_2). These reductions were mainly offset by increases observed in the Production and Consumption of Halocarbons, SF_6 and NF_3 (mostly HFCs) (Figure 2–19 and Table 2–8).

Figure 2–19 **Trends in Canadian GHG Emissions from Industrial Processes and Product Use Sources (1990–2020)**

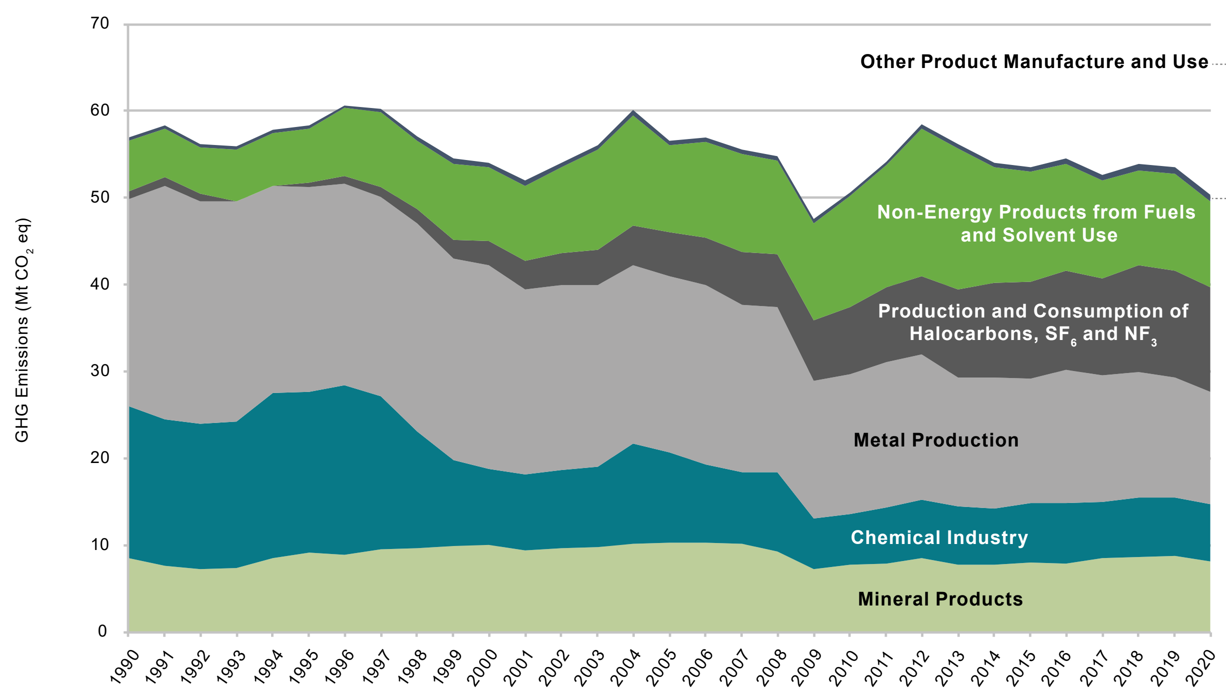


Table 2–8 **GHG Emissions from Industrial Processes and Product Use Categories, Selected Years**										
GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2015	2016	2017	2018	2019	2020	1990–2020	2005–2020
Total – Industrial Processes	**57**	**57**	**54**	**55**	**53**	**54**	**53**	**50**	**-12%**	**-11%**
Mineral Products	**8.5**	**10**	**8.0**	**7.9**	**8.6**	**8.6**	**8.8**	**8.1**	**-4%**	**-21%**
Cement Production	5.8	7.6	6.2	6.1	6.8	6.9	7.1	6.6	14%	-13%
Lime Production	1.8	1.8	1.4	1.4	1.4	1.4	1.3	1.2	-34%	-32%
Mineral Product Use	0.9	0.9	0.4	0.4	0.3	0.3	0.3	0.3	-65%	-67%
Chemical Industry	**18**	**10**	**6.8**	**7.0**	**6.4**	**6.8**	**6.7**	**6.6**	**-62%**	**-37%**
Ammonia Production	2.8	2.7	2.9	2.9	2.6	2.4	2.5	2.5	-10%	-10%
Nitric Acid Production	1.0	1.2	0.2	0.3	0.2	0.3	0.3	0.2	-81%	-84%
Adipic Acid Production	10	2.5	-	-	-	-	-	-	-100%	-100%
Petrochemical Production & Carbon Black Production	3.5	4.0	3.6	3.9	3.5	4.1	3.9	3.9	12%	-1%
Metal Production	**24**	**20**	**14**	**15**	**15**	**15**	**14**	**13**	**-45%**	**-36%**
Iron and Steel Production	10	10	8.5	9.2	8.5	8.9	8.3	7.0	-33%	-32%
Aluminium Production	10	8.7	5.7	6.0	6.0	5.5	5.3	5.9	-43%	-32%
SF_6 Used in Magnesium Smelters and Casters	3.0	1.2	0.2	0.1	0.1	0.1	0.3	0.1	-97%	-92%
Production and Consumption of Halocarbons, SF_6 and NF_3	**1.0**	**5.1**	**11**	**11**	**11**	**12**	**12**	**12**	**1130%**	**135%**
Non-Energy Products from Fuels and Solvent Use	**5.8**	**10**	**13**	**12**	**11**	**11**	**11**	**10**	**70%**	**-1%**
Other Product Manufacture and Use	**0.4**	**0.5**	**0.5**	**0.6**	**0.6**	**0.7**	**0.7**	**0.7**	**94%**	**33%**

Note: Totals may not add up due to rounding.

2

Reductions in process emissions from 2019 to 2020 of 3.1 Mt (5.9%) were observed in some sub-sectors and categories, notably, the Iron and Steel Industry due to a decrease in the production pig iron, the Non-Energy Products from Fuels and Solvent Use due to a decrease in demand for fuels related to the manufacturing and commercial sectors and Cement and Lime Production due to the temporary shut downs of certain facilities. In 2020, the largest contributions to emissions in the sector originated from Metal Production (13 Mt), followed by the Consumption of Halocarbons, SF_6 and NF_3 (mostly HFCs) (12 Mt), and Non-Energy Products from Fuels and Solvent Use (9.9 Mt) (Table 2–8).

2.3.2.1. Mineral Products (2020 GHG Emissions, 8.1 Mt)

The Mineral Products subsector includes Cement Production, Lime Production and Mineral Product Use, which consists of Glass Production, Other Uses of Soda Ash, Non-Metallurgical Magnesia Production, and Other Limestone and Dolomite Use. Emission reductions in this subsector contributed an overall reduction of 2.2 Mt (21%) from 2005 to 2020.

Cement Production dominates this subsector, accounting for 82% of emissions from Mineral Products in 2020. Fluctuations over the years largely result from variations in clinker production, especially circa 2009, with some gradual recovery with the opening of a new facility in Québec in 2017.

2.3.2.2. Chemical Industry (2020 GHG Emissions, 6.6 Mt)

From 2005 to 2020, an emissions decrease of 3.8 Mt (37%) is observed in the Chemical Industry as a whole. The main driver of emission reductions in this industry was the discontinuation of adipic acid production in 2009; this alone represents a decrease of 2.5 Mt from 2005.[9] N_2O emissions abatement installations at a nitric acid production facility are mainly responsible for a decrease of 1.0 Mt (84%) in the subsector since 2005. Other changes included a small decrease (0.26 Mt) in Ammonia Production and a small decrease in Petrochemical and Carbon Black Production (0.024 Mt).

2.3.2.3. Metal Production (2020 GHG Emissions, 13 Mt)

Emission reductions in the production of magnesium, aluminium, and iron and steel contributed to Metal Production overall reductions of 7.2 Mt (36%) between 2005 and 2020.

The aluminium industry decreased its PFC emissions by 3.1 Mt (80%), while maintaining its production relatively constant between 2005 and 2020 (AAC, 2019; ECCC, 2021), largely due to technological improvements. The Magnesium Production and Magnesium Casting industries also showed a decrease in emissions as a result of the replacement of SF_6 with alternatives and the closure of plants over the years. Primary magnesium production in Canada ceased in 2009.

From 2005 to 2020, emissions in the iron and steel industry decreased by 3.3 Mt (32%). The main drivers behind the decrease in emissions was reductions in the use of metallurgical coke as reductant for iron production and a notable decrease in production levels from 2019 to 2020 (StatCan, 2004–2012; CSPA, 2013–2019; ECCC, 2021).

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

2.3.2.4. Production and Consumption of Halocarbons, SF_6 and NF_3 (2020 GHG Emissions, 12 Mt)

There is currently no production of HFCs, PFCs, SF_6 or NF_3 in Canada. HFC-23 was generated as a by-product of HCFC-22 production, which ended in 1992. Hence, all emissions in this subsector are associated with the consumption of HFCs, PFCs, SF_6 and NF_3 only. Emissions from the consumption of HFCs increased by 6.8 Mt (134%) from 2005 to 2020. This can be explained by the replacement of ODSs by HFCs within the refrigeration and air-conditioning markets since the Montreal Protocol came into effect in 1996. The other sources of emissions (PFCs, SF_6 and NF_3) in this subsector do not have a significant impact on emissions trends as the next largest source (SF_6) has emissions of less than 1% of the HFC emissions value.

2.3.2.5. Non-Energy Products from Fuels and Solvent Use (2020 GHG Emissions, 9.9 Mt)

The Non-Energy Products from Fuels and Solvent Use category is one of the largest emission sources in the IPPU sector; however, its emissions decreased by 84 kt (1%) from 2005 to 2020. The observed change is attributable to the significant decrease in emissions by 1.4 Mt (11.5%) from 2019 to 2020, from the feedstock use of butane, petroleum coke, lubricating oils and greases in the transportation and manufacturing sectors, and waxes, paraffin and unfinished product in the commercial sector.

2

2.3.3. Agriculture Sector (2020 GHG Emissions, 59 Mt)

In 2020, emissions from the Agriculture sector accounted for 55 Mt, or 8.2%, of total GHG emissions in Canada, an increase of 1.0 Mt and 0.9% from 2005 levels, but corresponding to an increase of 14 Mt or 34% since 1990 (Figure 2–20 and Table 2–9). In 2020, the Agriculture sector accounted for 30% of national CH_4 emissions and 75% of national N_2O emissions, up from 27% and 45% in 1990, respectively.

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

The main economic sectors in Canadian agriculture are livestock and crop production. GHG emissions from the livestock sector include CH_4 emissions from enteric fermentation and emissions of CH_4 and N_2O from the storage and handling of animal manure. The crop production sector includes N_2O emissions from the application of inorganic nitrogen fertilizers,

Figure 2–20 **Trends in Canadian GHG Emissions from Agriculture Sources (1990–2020)**

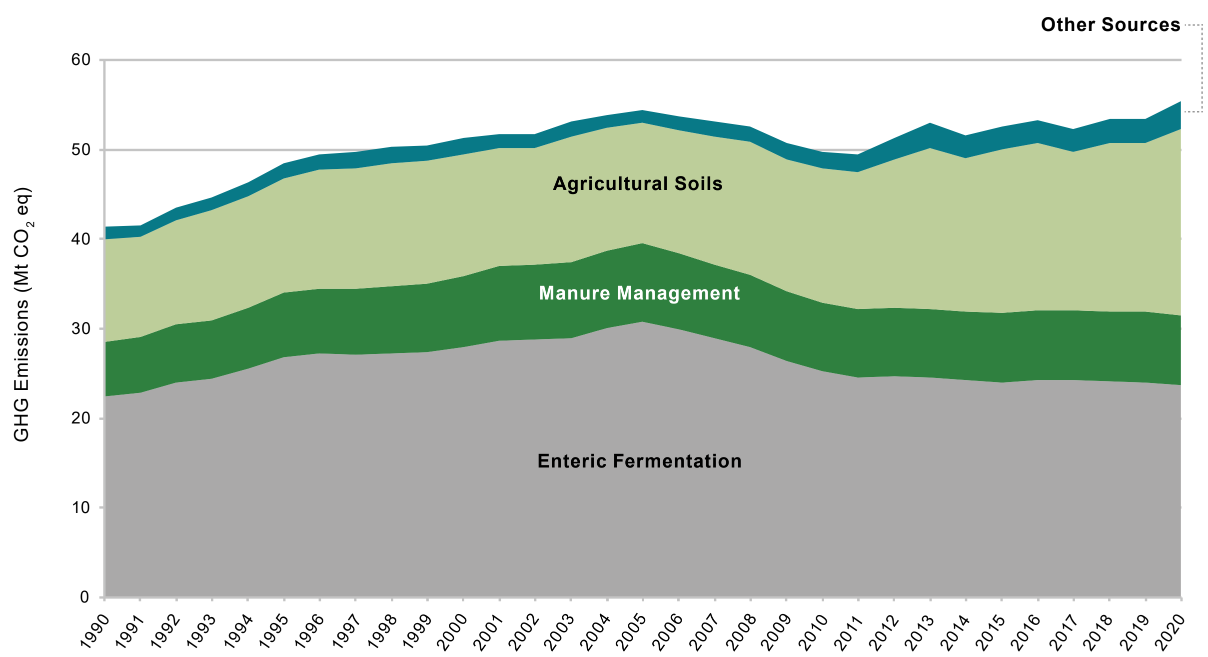


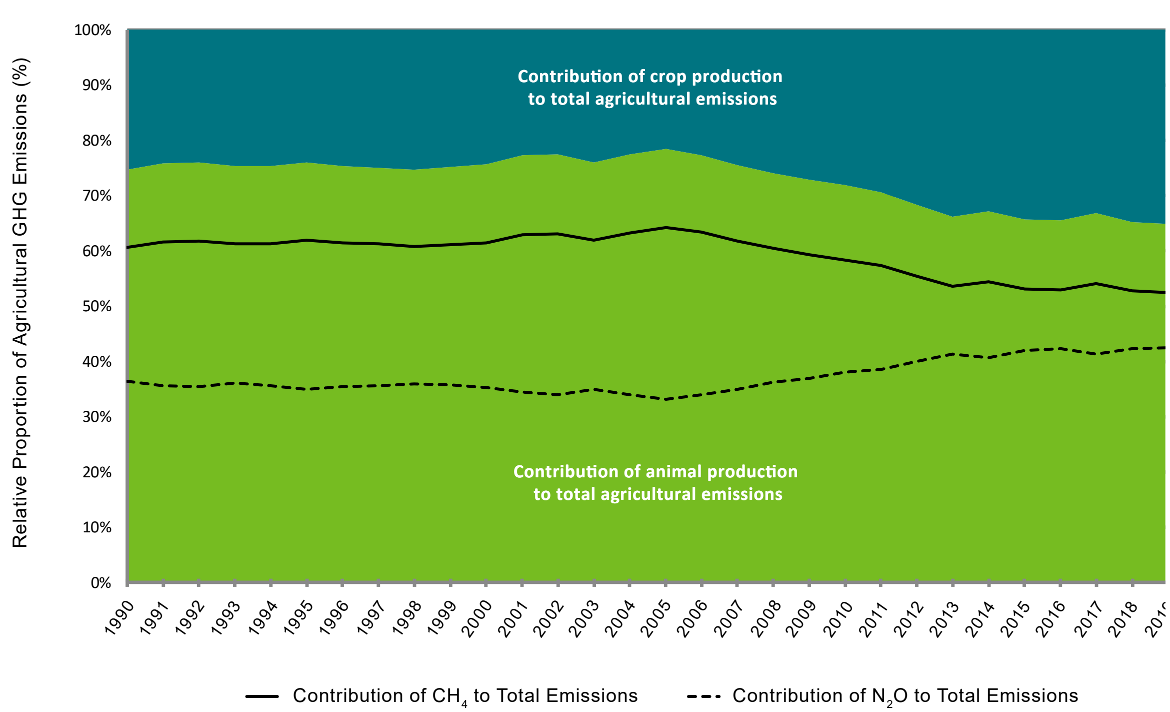
Table 2–9 **GHG Emissions from Agriculture, Selected Years**										
GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2015	2016	2017	2018	2019	2020	1990–2020	2005–2020
Agriculture	**41**	**54**	**52**	**53**	**52**	**53**	**53**	**55**	**34%**	**2%**
Enteric Fermentation	22	31	24	24	24	24	24	24	6%	-23%
Manure Management	6.1	8.7	7.7	7.8	7.9	7.8	7.8	7.8	28%	-11%
Agricultural Soils	11	13	18	18	17	19	19	21	82%	56%
Field Burning of Agricultural Residues	0.22	0.04	0.06	0.05	0.05	0.05	0.05	0.05	-76%	25%
Liming, Urea Application and Other Carbon-Containing Fertilizers	1.2	1.4	2.6	2.5	2.4	2.6	2.7	3.0	155%	114%

Note: Totals may not add up due to rounding.

crop residue decomposition, animal manure and biosolids applied as fertilizers and crop management practices; CH_4 and N_2O emissions from the burning of agricultural residues; and CO_2 emissions from agricultural use of lime and urea-based nitrogen fertilizers. In Canada, the livestock sector is dominated by beef, dairy, poultry and swine production, while crop production is mainly dedicated to the production of cereals and oilseeds.

The main drivers of the emission trend in the Agriculture sector are the fluctuations in livestock populations and continuous increases in the application of inorganic nitrogen fertilizers in the Prairie provinces. Beef, swine and poultry populations in Canada in 2020 are 4%, 38% and 52% 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 their lowest proportion of total agricultural emissions (62%), considerably lower than the proportion in 2005 (78%) (Figure 2–21). As a result of this shift, total agricultural emissions are approaching equivalent proportions of N_2O (mainly from crop production) and CH_4 (from livestock production), which is unprecedented. The shift in the industry from grazing cattle production to the production of annual crops is also reflected in a decreased carbon sink in agricultural soils observed in a land management change from perennial to annual crops reported in the LULUCF sector (Liang et al. 2020).

Figure 2–21 **Proportions of Canadian Agricultural GHG Emissions Emitted as CH_4 and N_2O, or attributed to Livestock and Crop Production (1990–2020)**



2.3.3.1. Enteric Fermentation (2020 GHG Emissions, 24 Mt)

Emissions from enteric fermentation originate almost entirely (96%) from Cattle Production in Canada. From 1990 to 2020, emissions increased from 22 Mt to 24 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 by 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, animal commodity prices have remained strong, and animal populations and livestock emissions have stabilized.

At the same time, emissions associated with dairy cows have fallen by approximately 12% since 1990, mainly due to a 29% reduction in the dairy cow population from 1990 to 2020 (StatCan, n.d.[f]). However, the average dairy cow today also consumes more feed and produces 54% 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 24% increase in per-animal emissions since 1990.

2

2.3.3.2. Manure Management (2020 GHG emissions, 7.8 Mt)

Emissions from animal manure management systems increased from 6.1 Mt in 1990 to 7.8 Mt in 2020 (or 28%), driven by increases in livestock populations of beef, swine and poultry. The storage of manure results in both CH_4 (14% total agricultural CH_4) and N_2O (16% total agricultural N_2O). The management of beef and poultry manure produces predominantly N_2O, whereas pork manure produces predominantly CH_4. Emissions from dairy manure have shifted from mainly N_2O to mainly CH_4 due to changes in manure storage practices. As a result, CH_4 emissions correspond closely to changes in populations and practices in the swine and dairy sectors, increasing from 2.5 Mt in 1990 to 3.9 Mt (58%) in 2020. N_2O emissions closely follow the trend in beef populations, increasing from 3.6 Mt in 1990 to 4.8 Mt (34%) in 2005 and subsequently declining to 3.9 Mt (8%) in 2020. As was the case with enteric fermentation, the increase in beef cattle weights also contributed to the increase in N_2O emissions from manure.

2.3.3.3. Agricultural Soils (2020 GHG Emissions, 21 Mt)

Emissions from Agricultural Soils originate from the application of inorganic and organic nitrogen fertilizers to annual and perennial cropland and from crop residue decomposition; these emissions can be modified by crop management practices. Emissions increased from 11 Mt in 1990 to 21 Mt in 2020, an increase of 82%, primarily due to an increase in inorganic nitrogen fertilizer use and relative reduction in the proportion of N applied to perennial cropland.

Total emissions from the application of inorganic nitrogen fertilizers increased from 5.5 Mt in 1990 to 13 Mt in 2020, an increase of 109%, as inorganic nitrogen fertilizer consumption increased steadily from 1.2 Mt N to 2.9 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 2020. 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 (256%) increase in emissions of CO_2 from urea and urea ammonium nitrate.

Emissions from crop residue decomposition ranged from a minimum of 2.2 Mt in 2002 (a drought year) to a maximum of 4.5 Mt in 2020, mainly depending on the impact of weather conditions on crop yield, and changes in the proportion of annual and perennial crops. Though crop production demonstrates high inter-annual variability, production has tended to increase over the reporting period and, as a result, so have emissions from crop residue.

In 1990, cropland management practices, specifically irrigation and the adoption of conservation tillage, contributed a net 0.15 Mt to total emissions from soils. In 2020, the adoption of conservation tillage (approximately 18 million hectares of cropland since 1990) reduced emissions by 2.5 Mt, while increases in irrigation increased emissions by 1.3 Mt, for a net reduction in emissions of 1.2 Mt.

2.3.4. Land Use, Land-Use Change and Forestry Sector (2020 Net GHG Removals, 6.8 Mt, Not Included in National Totals)

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

In 2020, LULUCF was estimated to remove 6.8 Mt from the atmosphere, compared with net removals of 64 Mt in 1990 and 4.2 Mt in 2005. The net fluxes reported in the LULUCF sector were negative (removals) for all years of the time series with a generally decreasing trend between 1990 and 2005 mainly driven by the decrease in net CO_2 removals from Forest Land from 1990 to 2007 (Table 2–10), partially attenuated by increasing net CO_2 removals, on average in Cropland and a decrease in emissions from the conversion of forest to other land use over the first two decades of the time series. Net removals from the LULUCF sector have fluctuated over recent years between 4.2 Mt in 2005, 0.1 Mt in 2015 and 6.8 Mt in 2020, and high peaks of 49 Mt in 2009 and 39 Mt in 2014. Relative to the strong sink observed in the land sector throughout the 1990s, Canada's recent tendency towards lower net removals from the atmosphere by the land sector are driven by a diminished Forest Land sink from sustained forest harvest and increased insect mortality as well as decreases in perennial cover in Cropland, and recent increases in rates of deforestation in some sectors (Figure 2–22).

National totals are reported to the United Nations Framework Convention on Climate Change (UNFCCC) with and without emissions and removals in the LULUCF sector. The estimated net GHG fluxes in the LULUCF sector when included account for a decrease of 11% in 1990, 0.6% in 2005 and 1.0% in 2020 (Figure 2–7).

2.3.4.1. Forest Land and Harvested Wood Products (2020 GHG Removals, 6.5 Mt)

The Forest Land and Harvested Wood Products categories combined include GHG fluxes between the atmosphere and Canada's managed forests and emissions from harvested wood products (HWP) originating from domestic harvest. The total net flux from managed forests and resulting HWP amounted to an estimated net removal of 6.5 Mt in 2020 (Figure 2–22), which combines net removals of 130 Mt from Forest Land and net emissions of 124 Mt from HWP originating from domestic harvest in managed forests.

Net removals from Forest Land—after separating GHG fluxes associated with severe natural disturbances from anthropogenic fluxes—decreased from 200 Mt in 1990 to 130 Mt in 2007. The predominant anthropogenic trend directly associated with human activities in managed forests is the 34% increase in the carbon removed from forests through harvest and transferred to HWP between 1990 and the peak harvest year, 2004. Since 2005, net removals have fluctuated between 150 and 130 Mt. Harvest levels increased after 2009, but have remained relatively constant in recent years, with 2020 harvest levels still 33% below their peak in 2004. This recent trend is the combined effect of shifting global markets for traditional forest products as well as growing demand for non-traditional products, e.g., bioproducts (NRCan, 2020) and, more recently, due to the indirect effect of exceptionally high wildfires in 2018 and 2019 that have reduced the commercially mature forest area and as a consequence carbon removals.

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

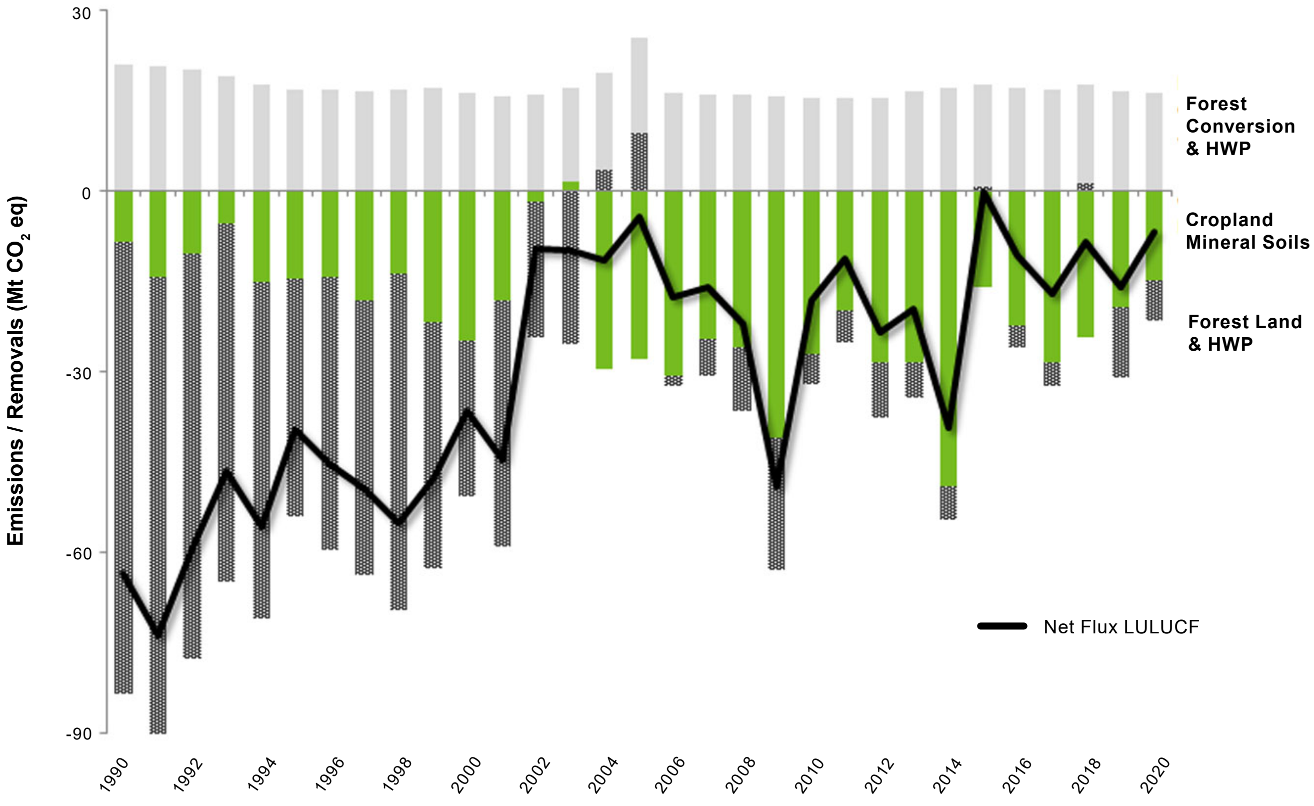
Sectoral Category		Net GHG Flux (Mt CO_2 eq)[a]								Change (Mt CO_2 eq)	
		1990	2005	2015	2016	2017	2018	2019	2020	1990–2020	2005–2020
Land Use, Land-Use Change and Forestry TOTAL		**-64**	**-4.2**	**-0.1**	**-11**	**-17**	**-8.5**	**-16**	**-6.8**	**57**	**-2.5**
a.	Forest Land	-200	-130	-130	-140	-140	-130	-140	-130	72	4.7
b.	Cropland	0.4	-22	-10	-17	-23	-19	-14	-9.6	-10	12
c.	Grassland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d.	Wetlands	5.4	3.1	3.0	3.1	3.1	2.8	2.9	2.9	-2.5	-0.2
e.	Settlements	1.9	1.7	2.5	2.5	2.4	2.2	2.2	2.2	0.3	0.5
g.	Harvested Wood Products	130	150	140	140	140	140	130	130	-2.7	-20

Notes:

Totals may not add up due to rounding.

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

Figure 2–22 **LULUCF Sector Net GHG Flux and Major Emission and Removal Components, 1990–2020**



The decrease in forest removals nationally is dominated by trends in the Montane Cordillera and Boreal Plains. Severe insect outbreaks in the Montane Cordillera in the early 2000s and subsequent high rates of harvest on impacted forest stands reset large areas of previously productive forest to younger age-classes, when trees absorb and store less biomass carbon. In addition, forest stands in the Montane Cordillera ecozone were affected by insect infestations that caused low levels of tree mortality over large areas resulting in a generalized increase in emissions of CO_2 from decomposition. On the Boreal Plains, sustained harvest, insect outbreaks and fire combined to reset large areas of previously productive forest to younger age-classes. The combination of reduced net rates of storage of CO_2 in biomass and increased emissions of CO_2 from decomposition resulted in a net decrease in removals from forest of these regions—primarily between 1997 and 2007—that was significant enough to influence the national trend. More recently, insect infestations that have impacted large areas in the Boreal Shield East and Atlantic Maritime in the 2010s are starting to have an effect on net emissions and removals in these regions that will likely continue over the next few decades. Although emissions and removals associated with severe natural disturbances are differentiated from anthropogenic fluxes, disturbances nevertheless influence reported GHG fluxes.

Emissions from HWP reflect the long-term storage of carbon in wood harvested in Canada's forests. Approximately one-third of HWP emissions (33% in 2020) result from long-lived wood products reaching the end of their useful life decades after the wood was harvested. End-of-life emissions for short-lived products, namely pulp and paper and bioenergy products, accounted for 29% and 37% of HWP emissions, respectively, in 2020. Short-lived wood products more closely track recent trends in forest harvest rates. Emissions from HWP originating from domestic harvest in managed forests fluctuated between 120 Mt in 2009 (lowest harvest year) and 2020, and a peak of 150 Mt in 1995.

2.3.4.2. **Forest Conversion (2020 GHG Emissions, 16 Mt)**

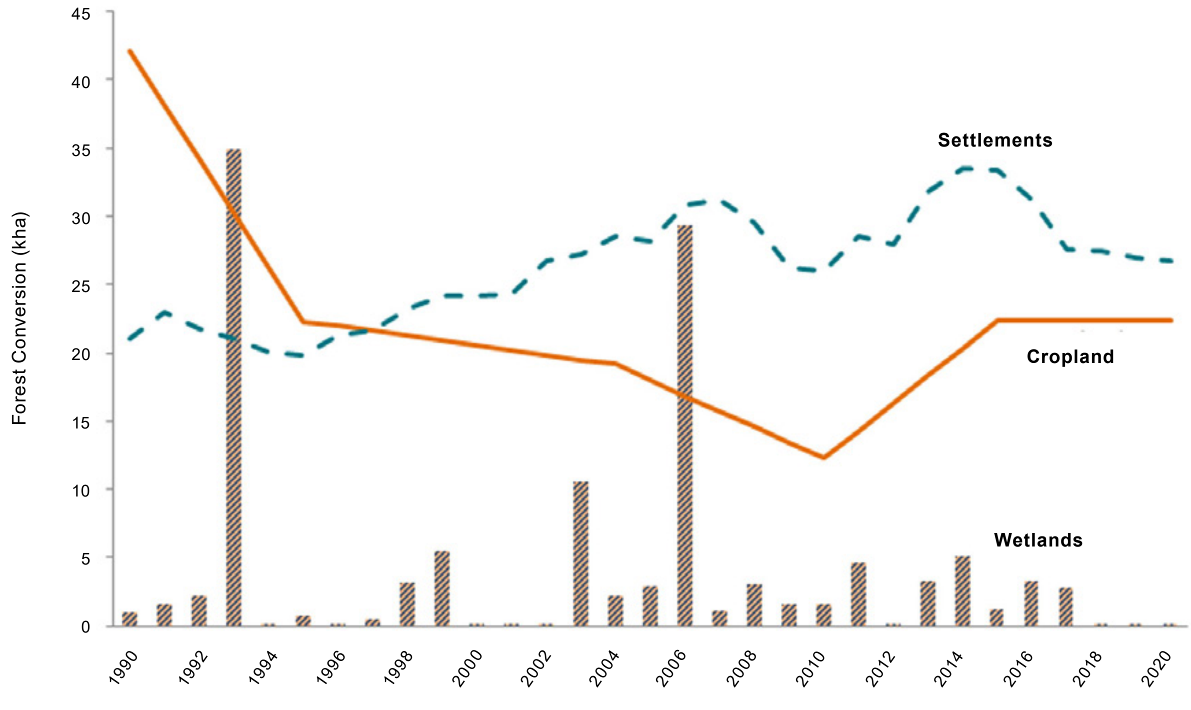
Forest conversion[10] is not a reporting category per se, since it overlaps with the subcategories of Land Converted to Cropland, Land Converted to Wetlands and Land Converted to Settlements. It also includes the emissions from HWP resulting from forest conversion activities since 1990. Emissions due to forest conversion fell from 21 Mt in 1990 to 16 Mt in 2020.

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, 1.6 million hectares of forest have been converted to other land uses in Canada. Geographically, the highest average annual rates of forest conversion occur in the Boreal Plains (23 kha per year) and the Boreal Shield East (8 kha per year), which account for 45% and 15%, respectively, of the total loss of forest area in Canada.

With a current annual conversion rate of 27 kha, Forest Land Converted to Settlements now accounts for the largest share of forest loss, comprising 54% in 2020, up from 33% in 1990 and slightly down from 57% in 2005. Forest clearing for agricultural expansion (Cropland) is the second-largest driver of forest conversion, accounting for 45% of all forest area lost in 2020. 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.

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 2–23). Cumulative areas of forest converted for the creation of hydro reservoirs since 1990 and the associated infrastructure equal 197 kha, accounting for 12% of total forest conversion areas over the reporting period. Hydroelectric development occurs mainly in the Taiga Shield East and the Boreal Shield East.

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



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

2.3.4.3. Cropland (2020 GHG Removals, 9.6 Mt)

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

Cropland has contributed net removals of 7.2 Mt, 22 Mt and 9.6 Mt in the land sector in 1990, 2005 and 2020, respectively. This land category has observed net removals over the reporting period with the exception of important drought years on the prairies in early 2000s that resulted in a peak emissions in 2003 (7.6 Mt). Interannual variability is high throughout the time series, reflecting weather-related impacts to crop production. Net removals have increased, on average, as a result of improved soil management practices including conservation tillage and an overall gradual increase in crop productivity and reduced summerfallow acreage and, as a result, carbon inputs to the soils. Since 2005, the decline in net removals that results from a decrease in perennial land cover has largely offset removals resulting from increasing yields and there is subsequently no clear trend. Recent trends are impacted by periodic high crop production and subsequently peak removals in 2009 (-36 Mt) and 2014 (-44 Mt).

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 in the period from 1990 to 2006. Since 2006 an opposite trend can be 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).

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 has since increased to mid-1990s levels (see section 2.3.4.2).

2.3.4.4. Other LULUCF Sources/Sinks (2020 GHG emissions, 5.1 Mt)

Other LULUCF sources/sinks include Wetlands, Settlements and Grassland, which contributed 2.9 Mt, 2.2 Mt and 0.001 Mt, respectively, to their combined net emissions of 5.1 Mt reported in 2020, down from 7.3 Mt in 1990. The Settlements category includes the growth of urban trees (annual removals of 4.3 Mt on average throughout the reporting period) and Land Converted to Settlements. 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 (2020 GHG Emissions, 27 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from the Waste sector contributed 27 Mt (4%) to Canada's total emissions in 2020, comparable to emission levels of 24 Mt in 1990 (4.1% of total emissions) and of 29 Mt (3.8%) in 2005 (Figure 2–24 and Table 2–11). In 2020, landfilling (including municipal

Figure 2–24 **Trends in Canadian GHG Emissions from Waste (1990–2020)**

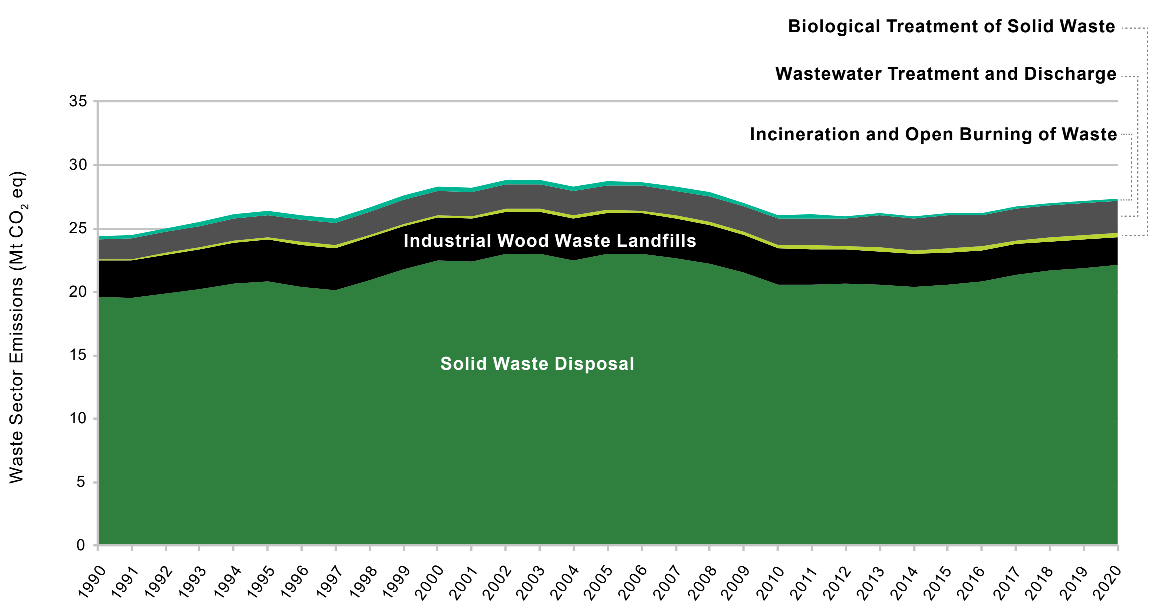


Table 2–11 **GHG Emissions from Waste, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2015	2016	2017	2018	2019	2020	1990–2020	2005–2020
Waste Sector	**24**	**29**	**26**	**26**	**27**	**27**	**27**	**27**	**12%**	**-5%**
Biological Treatment of Solid Waste	0.07	0.24	0.31	0.32	0.33	0.36	0.36	0.36	389%	47%
Incineration and Open Burning of Waste	0.27	0.35	0.20	0.20	0.19	0.18	0.18	0.16	-40%	-52%
Industrial Wood Waste Landfills	2.9	3.3	2.5	2.4	2.4	2.3	2.2	2.2	-24%	-33%
Solid Waste Disposal	20	23	21	21	21	22	22	22	13%	-4%
Wastewater Treatment and Discharge	1.6	1.9	2.6	2.4	2.5	2.5	2.5	2.5	56%	32%

Note: Totals may not add up due to rounding.

solid waste and industrial wood waste disposal) accounted for 24 Mt (or 89% of total Waste sector emissions), while Biological Treatment of Solid Waste (composting and anaerobic digestion), Wastewater Treatment and Discharge, and Incineration and Open Burning of Waste (excluding CO_2 emissions from incineration of biomass material) contributed 0.36 Mt, 2.5 Mt and 0.16 Mt, respectively.

2

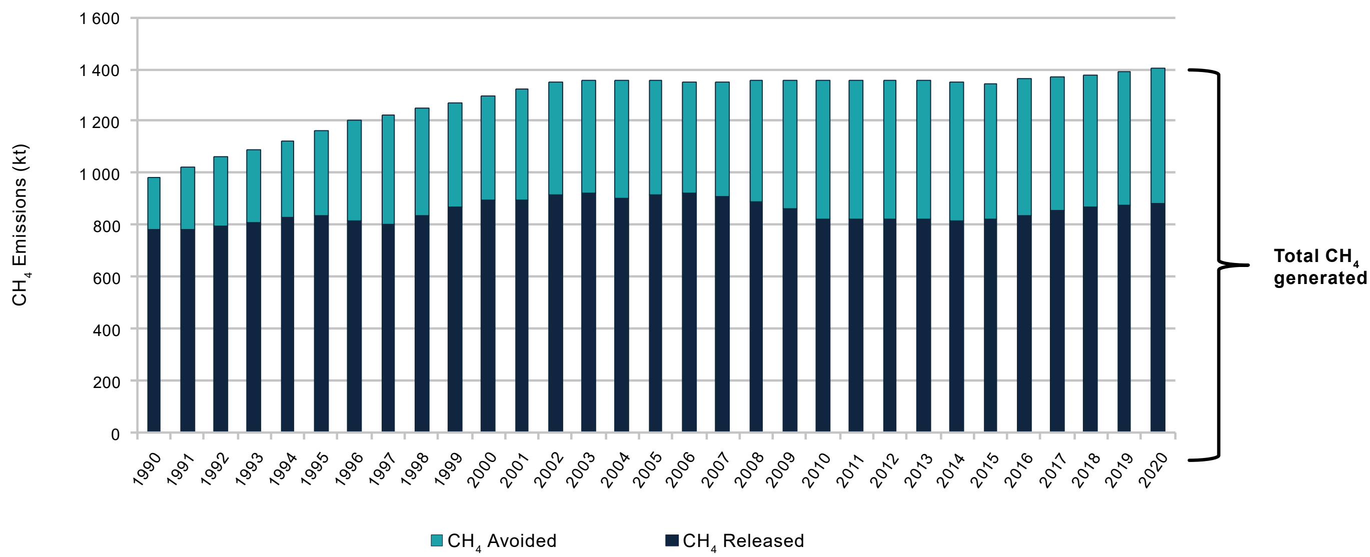
2.3.5.1. Solid Waste Disposal and Industrial Wood Waste Landfills (2020 GHG Emissions, 24 Mt)

The Solid Waste Disposal category reports CH_4 emissions from municipal solid waste (MSW) landfills, and the Industrial Wood Waste Landfill category reports CH_4 emissions from wood waste landfills.

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

In 2020, emissions from MSW landfills were 22 Mt, while emissions from wood waste landfills were 2.2 Mt. Emissions from MSW landfills increased by 13% from 1990 to 2020, and have decreased by 5% from 2005 to 2020. Emissions from wood waste landfills increased by 56% from 1990 to 2020 and by 32% from 2005 to 2020. The amount of CH_4 generated by MSW landfills has steadily increased since 1990, primarily as a result of a growing population producing more waste. This increase has been offset by an increase in the capture of LFG at landfills. In 2020, 37% of the LFG generated in landfills was recovered through LFG capture technologies or oxidized through cover material, compared with 20% in 1990 (Figure 2–25). In contrast, LFG capture is believed not to occur at industrial wood waste landfills. The decreasing emission trend is directly related to the decreasing amount of wood waste sent to dedicated landfills due to the repurposing of residual wood waste.

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



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

2.3.5.2. Other Waste Sources (2020 GHG Emissions, 3.0 Mt)

Over the 1990–2020 time series, emissions from the Biological Treatment of Solid Waste (anaerobic digestion and composting), Wastewater Treatment and Discharge (municipal and industrial wastewater treatment), and Incineration and Open Burning subcategories collectively increased by 55% (Figure 2–23 and Table 2–11).

An increase in Wastewater Treatment and Discharge emissions reflects the increase in the Canadian population. A decrease in total incineration emissions (MSW, sewage sludge, hazardous and clinical waste) was due mainly to declines in emissions from the closure of aging MSW incinerators. Since 1990, many municipalities in Canada have opened centralized composting facilities to reduce the quantity of organics sent to landfills. These practices have contributed to an increase in emissions from the Biological Treatment of Solid Waste category.

2.4. Emissions by Canadian Economic Sector

In this report, emissions estimates are primarily grouped into the activity sectors defined by the IPCC: Energy, IPPU, Agriculture, LULUCF and Waste. While this categorization is consistent with the UNFCCC reporting guidelines, reallocating emissions into economic sectors is more suitable for the purposes 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,[11] Buildings, Agriculture, and Waste and other.

This reallocation simply recategorizes emissions under different headings but does not change the overall magnitude of Canadian emissions estimates. It takes the relevant proportion of emissions from various IPCC subcategories to create a comprehensive emissions profile for a specific economic sector. This is the approach that has been taken for reporting emissions projections and progress towards Canada's GHG reduction targets in *Canada's 2020 Greenhouse Gas and Air Pollutant Emissions Projections* report, past *Canada's Emissions Trends* reports, in Canada's national communications and in biennial reports to the UNFCCC. Examining the historical path of Canadian GHG emissions by economic sector results in a better understanding of the connection between economic activities and emissions for the purposes of analyzing trends and for policy and public analysis. This approach is also more closely aligned with the sectoral categories of the Pan-Canadian Framework on Clean Growth and Climate Change, allowing Canada to track progress of its key policies and measures to reduce emissions.

For example, the Transport sector represents emissions arising from the cars, trucks, trains, aircraft and ships fulfilling mobility requirements of people, as well as mobility service emissions from heavy-duty trucks and other commercial vehicles. However, unlike the IPCC categorization, the Transport sector does not contain off-road transportation emissions related to farming, mining, construction, forestry, pipelines or other industrial activities. These off-road emissions related to industrial activities are allocated to their corresponding economic sectors. For example, if there were any upward trend in farming or mining activity, emissions arising from the increased use of mobile farming machinery or mining trucks would be reflected in the economic sector estimates for Agriculture or Heavy Industry (mining).

Annex 10 (available at open.canada.ca) contains a series of tables which show the distribution of national emissions allocated on the basis of the Canadian economic sector from which they originate for all years in the time series (1990–2020) and the relationship between economic and IPCC categories or sectors. Each Canadian economic sector includes all applicable emissions from energy-related and non-energy-related processes. Specifically, the Oil and Gas sector represents all emissions that are created in the extraction, distribution, refining and upgrading of oil and gas products; the Electricity sector represents all emissions from electric utility generation and transmission for residential, industrial and commercial users; the Transport sector represents all emissions arising from the tailpipes of domestic passenger and freight transport; the Heavy Industry sector represents emissions arising from metal and non-metal mining activities, smelting and refining, and the production and processing of industrial goods such as paper or cement; the Buildings sector represents emissions arising directly from residential homes and commercial buildings; the Waste and other sector represents emissions that arise from solid and liquid waste, waste incineration, and coal production, light manufacturing, construction and forestry activities; and finally, the Agriculture sector represents all emissions arising from farming activities, including those related to energy combustion for farming equipment as well as those related to crop and animal production. Similar tables for provinces and territories can be found in Annex 12 (available at open.canada.ca).

11 The Heavy Industry sector represents emissions arising from metal and non-metal mining activities, as well as smelting and refining, pulp and paper, iron and steel, cement, lime and gypsum, and chemicals and fertilizers.

2.4.1. Emissions Trends by Canadian Economic Sector

Emissions trends since 2005 have remained consistent with those described for IPCC sectors, with emissions increases in the Oil and Gas and Building economic sectors (7.5 Mt or 4.4%, and 4.1 Mt or 4.9%, respectively) being offset by decreases in other sectors, notably Electricity (-61 Mt or -52%), Heavy Industry (-15 Mt or -18%); and Waste and others (-5.0 Mt or -9.0%).

Oil and Gas

In 2020, the Oil and Gas sector produced the largest share of GHG emissions in Canada (27%) (Figure 2–26). Between 1990 and 2020, emissions from this sector increased by 76 Mt. While fluctuations due to economic conditions (e.g., crude oil and natural gas prices) caused short-term increases and decreases in emissions between 1990 and 2020, emissions from this sector have generally increased steadily from 103 Mt in 1990 to 205 Mt in 2014. From 2014 to 2019, emissions were relatively stable, followed by a significant decrease of 25 Mt (-12%) between 2019 and 2020. The majority of the increase (68 Mt) between 1990 and 2014 is due to massive expansion in Canada's oil sands. Since 1990, oil sands production has increased by over 725% and emissions have increased by over 430% (see 'Trends in the Oil and Gas Sector' text box). The decrease between 2019 and 2020 coincides with federal regulations to reduce methane emissions from the upstream oil and gas industry which came into effect January 1, 2020, and equivalent provincial regulations in Saskatchewan, Alberta and British Columbia, as well as a sharp decrease in the price of crude oil in the early days of the COVID-19 pandemic.

Transport

Canada's Transport sector is the second-largest contributor to Canada's GHG emissions, accounting for 24% of total emissions in 2020 (Figure 2–26). Between 1990 and 2020, emissions rose by 39 Mt (32%). Since then, emissions from this sector have continued to increase gradually, with the exception of the decrease between 2019 and 2020 largely due to fewer kilometers driven. Transport emissions in 2020 are comparable to 2005 levels (-0.93 Mt or -0.6% since 2005). Section 2.3 discusses the main drivers of historical emissions trends associated with passenger and freight transport.

Electricity

In 2020, the Electricity sector (excluding industrial and commercial cogeneration) contributed 8.4% to total Canadian emissions (Figure 2–26). Between 1990 and 2020, emissions decreased by 39 Mt (41%). 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 61 Mt or 52% since 2005. Section 2.3 discusses the main historical drivers of emissions trends associated with electricity generation.

Heavy Industry

The Heavy Industry sector experienced some fluctuation in emissions over the reporting period. In 2020, the Heavy Industry sector contributed 11% to Canada's total emissions (Figure 2–26). Emissions from this sector were responsible for 16% of total Canadian emissions in 1990, falling to 12% in 2005. In more recent years, emissions have fallen further as a result of reduced economic activity and the continued evolution of Canadian production towards other sectors and services, representing a decrease of 15 Mt (18%) between 2005 and 2020.

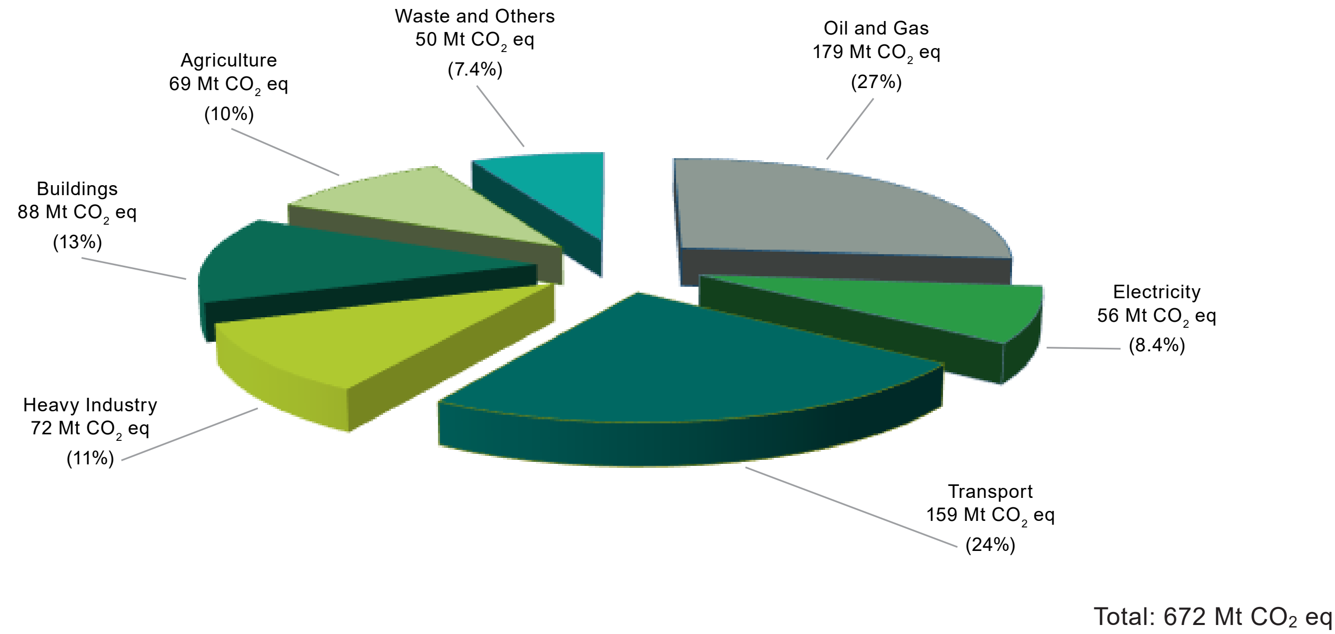
Buildings

In 2020, the Buildings sector contributed 13% to total Canadian emissions (Figure 2–26). While residential fuel use has remained relatively steady since 1990, increases in the service industry have resulted in an increase in emissions of 17 Mt (23%) between 1990 and 2020. Since 2005, emissions increased by 4.1 Mt or 4.9%. GHG emissions from the Buildings sector have increased with population growth and commercial development but, like all sectors of the economy, decreased in the 2008–2009 recessionary period and have remained relatively steady since then.

Agriculture and Waste and Others

Emissions from the Agriculture sector continued a slow upward trend throughout the reporting period, rising from 52 Mt in 1990 to 69 Mt in 2020 (Figure 2–26). This rise in emissions is due primarily to increases in livestock and crop production. Emissions from the Waste and others sector remained relatively stable. Overall, emissions increased over the time series, from 24 Mt in 1990 to 27 Mt in 2020. 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 (2020)**



Note: Totals may not add up due to rounding.

TRENDS IN THE OIL AND GAS SECTOR

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

In 2020, the largest contributor to O&G emissions was the Oil Sands category (81 Mt, or 45%), followed by Natural Gas Production and Processing (44 Mt, or 25%), Conventional Oil Production (25 Mt, or 14%) and Petroleum Refining (17 Mt, or 10%). The primary drivers of emissions within the O&G sector are production growth and emissions intensity (defined as the average amount of GHG emissions generated per barrel of oil equivalent).

Production Growth

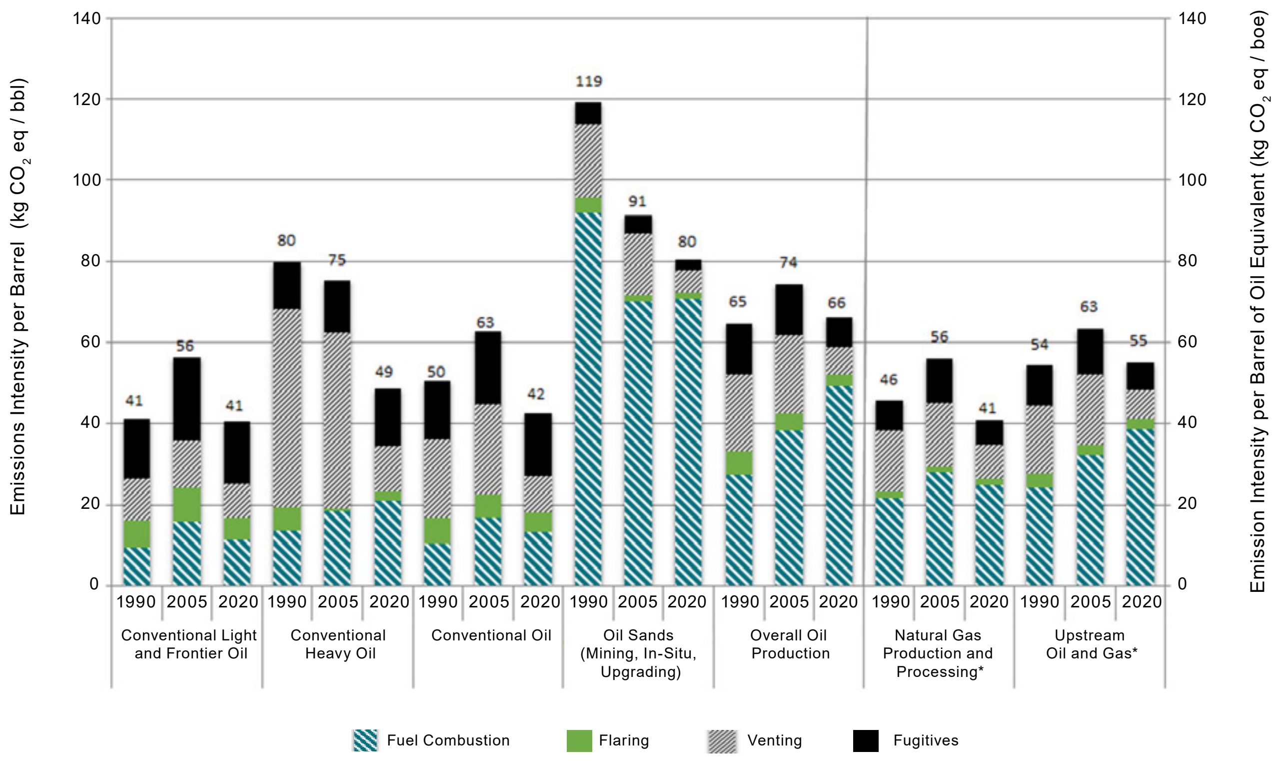
From 1990 to 2020, the production of total crude oil increased by 161% (StatCan, n.d.[c], n.d.[d]). The increase was driven almost entirely by Canada's oil sands operations, which accounted for 100% of total production growth as conventional oil production volumes in 2020 were roughly equivalent to 1990 production volumes. Total oil sands output (non-upgraded bitumen and synthetic crude oil production) has increased by over 725% since 1990. Consistent with the production increases, emissions from total crude oil production increased by 67 Mt (about 170%), with emissions from oil sands alone increasing by 66 Mt (437%).

Emissions Intensity

The emissions intensity of overall oil production in Canada has increased by about 2% between 1990 and 2020, from 65 to 66 kg CO_2 eq per barrel (Figure 2–27). However, the overall emission intensity increased to a peak in 2010 at around 81 kg CO_2-eq per barrel and has decreased since that time. Contributors to this trend in emissions intensity include decreasing reserves of easily removable crude oil, along with increasing reliance on reserves requiring more energy- and GHG-intensive extraction methods. These include crude bitumen and reserves of heavier or more difficult-to-obtain conventional oils, such as those from offshore sources or 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 approximately 80% per barrel of oil extracted (27 kg CO_2-eq per bbl in 1990 to 49 kg CO_2-eq per bbl in 2020), which is indicative of increased oil sands production which requires large quantities of steam, generally produced from combusting natural gas. In contrast, venting, flaring and fugitive emissions per barrel of oil extracted have decreased by 65%, 53% and 42%, respectively. These reductions are due to increased oil sands production, which produces much fewer fugitive emissions per barrel than conventional oil production, and initiatives such as Alberta's *Directive 60* (AER, 2014), British Columbia's *Flaring and Venting Reduction Guideline* (BCOGC, 2015), Saskatchewan's *Directive S-10*, the Canadian Association of Petroleum Producers (CAPP) *Best Management Practice for Fugitive Emissions* (CAPP, 2007) and, 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), all of which came into effect January 1, 2020.

The rising quantity of petroleum extracted from Canada's oil sands has had the largest impact on increasing the emissions intensity of overall oil production. However, the intensity of oil sands operations themselves has declined steadily from 119 kg CO_2 eq per barrel in 1990 to 80 kg CO_2 eq per barrel in 2020. The emissions 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, over time, more crude bitumen has been produced without the additional processing step of upgrading to synthetic crude oil (SCO), which has also contributed to decreasing the overall emissions intensity. This was particularly evident between 2010 and 2020, when non-upgraded bitumen production increased by over 130% while SCO production increased by only 41%. The additional energy required to process the crude bitumen (and resulting emissions) is therefore transferred downstream, mainly to export markets where the bitumen is processed at petroleum refineries. Since 2015, CO_2 emissions from the hydrogen plant at the Scotford Upgrader have been captured and transported to an underground storage site. In 2020, 0.94 Mt of CO_2 was captured at Scotford, reducing the emissions intensity of overall oil sands operations by approximately 1.1%.

Figure 2–27 **Emissions Intensity by Source Type for Oil and Gas (1990, 2005 and 2020)**



Notes:

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

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

Production data source = StatCan (1990–, n.d.[c], n.d.[d]) and AER 2021.

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

	1990	2005	2015	2016	2017	2018	2019	2020
	Mt CO_2 eq							
NATIONAL GHG TOTAL	**595**	**741**	**733**	**715**	**725**	**740**	**738**	**672**
Oil and Gas	**103**	**171**	**205**	**194**	**196**	**205**	**203**	**179**
Upstream Oil and Gas	83	148	184	173	177	186	183	160
Natural Gas Production and Processing	31	66	61	57	54	56	55	44
Conventional Oil Production	24	35	40	37	37	37	35	25
Conventional Light Oil Production	15	19	25	24	24	25	24	17
Conventional Heavy Oil Production	9.1	14	13	11	10	9.5	8.7	6.5
Frontier Oil Production	0.26	1.7	1.5	1.7	1.8	1.9	1.9	1.8
Oil Sands (Mining, In-situ, Upgrading)	15	35	73	70	77	82	83	81
Mining and Extraction	2.2	5.6	11	11	13	15	15	15
In-situ	4.5	12	38	38	42	44	43	41
Upgrading	8.4	17	24	21	22	24	25	25
Oil, Natural Gas and CO_2 Transmission	12	12	10	9.9	9.8	11	11	10
Downstream Oil and Gas	20	23	21	21	19	19	20	18
Petroleum Refining	18	22	20	20	18	18	19	17
Natural Gas Distribution	1.6	1.3	1.2	1.2	1.2	1.1	1.2	1.1
Electricity	**95**	**118**	**80**	**74**	**73**	**63**	**62**	**56**
Transport	**120**	**160**	**172**	**173**	**179**	**184**	**185**	**159**
Passenger Transport	71	90	92	95	96	97	99	80
Cars, Trucks and Motorcycles	64	82	83	86	86	88	89	73
Bus, Rail and Aviation	7.1	8.2	8.8	8.7	9.1	9.8	9.7	6.2
Freight Transport	31	60	72	70	74	77	78	70
Heavy-Duty Trucks, Rail	26	54	67	66	70	72	72	66
Aviation and Marine	4.6	5.3	4.5	4.6	4.8	5.1	5.6	4.9
Other: Recreational, Commercial and Residential	18	10	8.7	8.6	9.1	9.3	9.2	9.0
Heavy Industry	**97**	**87**	**78**	**76**	**76**	**77**	**77**	**72**
Mining	6.7	6.7	7.7	7.1	7.8	9.2	8.8	9.2
Smelting and Refining (Non-Ferrous Metals)	17	14	10	11	11	9.8	11	10
Pulp and Paper	15	9.0	6.4	6.6	6.9	7.8	8.2	7.2
Iron and Steel	16	16	15	15	15	16	15	12
Cement	10	13	10	10	11	11	11	9.9
Lime and Gypsum	2.9	3.5	2.5	2.5	2.6	2.4	2.3	2.1
Chemicals and Fertilizers	29	24	26	24	22	21	22	21
Buildings	**71**	**84**	**84**	**82**	**87**	**93**	**92**	**88**
Service Industry	27	40	42	43	45	47	49	48
Residential	44	44	42	39	42	46	43	40
Agriculture	**52**	**66**	**65**	**65**	**64**	**66**	**67**	**69**
On-Farm Fuel Use	11	12	12	12	12	13	13	13
Crop Production	10	12	18	18	17	18	19	21
Animal Production	31	42	34	35	35	35	35	34
Waste and Others	**57**	**55**	**50**	**50**	**50**	**51**	**52**	**50**
Waste	24	29	26	26	27	27	27	27
Coal Production	4.0	2.3	2.3	2.4	2.2	2.5	2.5	2.3
Light Manufacturing, Construction and Forest Resources	28	24	21	21	22	22	22	20

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/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 (CRF SECTOR 1)

3.1. Overview

In 2020, the Energy sector accounted for 540 Mt (80%) of Canada's total greenhouse gas (GHG) emissions (Table 3–1). The Energy sector includes all activities associated with energy production and its use. Total GHG emissions for this sector includes, with exceptions, all carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from fuel combustion, fugitive sources, and carbon capture, transport and storage activities.[1]

Emissions resulting from stationary fuel combustion include the use of fossil and biomass (excluding peat) fuels by the electricity generating industry, the oil and gas industry, the manufacturing and construction industry, and the residential and commercial sectors. Canada does not use peat as a combustion fuel. Data from the non-energy use of peat appears in the Land Use, Land-use Change, and Forestry (LULUCF) sector (Chapter 6.1) and the fuel used to harvest and produce peat is included in the Agriculture/Forestry/Fishing subcategory within Other Sectors (1.A.4). Only the CH_4 and N_2O emissions from the combustion of biomass fuels, such as biodiesel, residential fuel wood and spent pulping liquor, are included in the Energy sector, while CO_2 emissions appear as a memo item in the Common Reporting Format (CRF) tables.

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

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

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

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

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

Overall, recalculations resulted in an increase of 15.1 Mt compared to the 2021 UNFCCC submitted value for 2019. Recalculations occurred for the following reasons.

Activity data: Revisions to activity data are a result of QA/QC checks, revised data or new information, and are as follows:

- Revisions to fuel data in the Report on Energy Supply and Demand (RESD) generally result in a recalculation of most combustion sources. Revisions to the 2019 RESD data have been incorporated (as per standard practice) as an update to the 2019 preliminary data[2] along with corrections to some historical data utilized in last year's national inventory submission to the UNFCCC. Revisions to the RESD consist of:
    - revised natural gas data, between 2005 and 2019;
    - revised heavy fuel oil data, between 2007 and 2019;
    - revised diesel fuel oil data, between 2005 and 2019; and,
    - revised motor gasoline data, between 2005 and 2019.

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

GHG Source Category	GHG Emissions (kt CO_2 eq)														
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Energy Sector	**472 000**	**512 000**	**594 000**	**602 000**	**583 000**	**591 000**	**590 000**	**597 000**	**598 000**	**600 000**	**581 000**	**594 000**	**606 000**	**604 000**	**540 000**
Fuel Combustion Activities (1.A)	**423 000**	**449 000**	**522 000**	**529 000**	**512 000**	**519 000**	**515 000**	**521 000**	**521 000**	**526 000**	**513 000**	**526 000**	**538 000**	**538 000**	**490 000**
Energy Industries (1.A.1)	143 000	152,000	203 000	208 000	199 000	196 000	197 000	195 000	195 000	202 000	193 000	192 000	190 000	190 000	177 000
Manufacturing Industries and Construction (1.A.2)	71 400	74 000	72 400	63 400	60 200	63 700	62 700	63 400	63 100	62 300	59 700	61 900	64 300	64 500	59 700
Transport (1.A.3)	124 000	130 000	151 000	163 000	165 000	166 000	168 000	173 000	172 000	173 000	174 000	179 000	185 000	186 000	160 000
Other Sectors (1.A.4)	84 100	92 700	95 900	93 800	87 500	93 100	86 800	89 600	90 700	88 800	86 600	92 100	98 100	97 200	93 300
Other (Not Specified Elsewhere) (1.A.5)	262	259	293	286	284	271	302	288	296	342	335	290	287	317	295
Fugitive Emissions from Fuels (1.B)	**50 000**	**63 000**	**72 000**	**73 000**	**72 000**	**73 000**	**75 000**	**76 000**	**78 000**	**74 000**	**68 000**	**68 000**	**68 000**	**66 000**	**50 000**
CO_2 Transport and Storage (1.C)	**NO**	**NO**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.10**	**0.22**	**0.27**	**0.27**	**0.28**	**0.28**	**0.49**

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

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

IPCC Categories	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1 Energy Sector	**GHG Emissions (Mt CO_2 eq)**													
2021 submission	472	513	592	591	569	577	575	583	584	585	566	578	588	589
2022 submission	472	512	594	602	583	591	590	597	598	600	581	594	606	604
Total change due to recalculations	**0.6**	**-0.4**	**1.9**	**10.4**	**14.0**	**13.9**	**15.2**	**14.1**	**14.0**	**15.8**	**14.8**	**15.8**	**18.4**	**15.1**
1.A – Fuel Combustion	0.0	0.0	-0.4	-1.4	-2.6	-3.0	-1.4	-1.4	-1.0	1.1	1.0	2.6	5.0	2.7
1.B – Fugitive and 1.C – CO_2 Transport & Storage	0.6	-0.4	2.3	11.9	16.6	16.9	16.6	15.5	15.1	14.6	13.8	13.2	13.4	12.4

Note: Totals may not add up due to rounding.

2 Statistics Canada annually publishes a revised, final version of the previous year's (preliminary) energy data. Currently, energy data for 2020 is preliminary and is subject to revision in late 2022.

- Revisions to the volumes of flared gas subtracted from stationary combustion to avoid double counting between 1990 and 2019.
- Revisions to the quantity of residential firewood combusted between 2018 and 2019.
- Revisions to the quantity of landfill gas combusted between 1990 and 2019.
- Revisions to the quantity of municipal solid waste combusted between 1990 and 2019.
- Revisions to the provincial activity data of rail transport combusted between 1990 and 2019.

Methodology: Improvements to the following methods resulted in recalculations:

- A revised method for estimating emissions from pneumatics, compressor seals and fugitive equipment leaks (refer to Annex 3, section A3.2.2.1.3 for more details).
- A revised method for estimating emissions from surface casing vent flows in Alberta and British Columbia (refer to Annex 3, section A3.2.2.1.4 for a detailed description of the method).
- An updated method for estimating emissions from reported venting and flaring in Saskatchewan using detailed gas composition data and facility reported volumes of vented and flared gas (refer to Annex 3, section A3.2.2.1.2 for a detailed description of the method).
- An updated method for estimating provincial emissions from rail transport based on fuel consumed within a province instead of fuel supplied to the province.

Emission Factors: Implementation of improved emission factors, based on new information, resulted in recalculations. Revisions include:

- CO_2 emission factor for sub-bituminous coal stationary fuel combustion in New Brunswick (see Annex 6, section A6.1, for more details).
- CO_2 emission factors for marketable natural gas in all provinces, and all years from 1999 to 2019, developed using detailed gas composition data, and volumes, supplied by industry (see Annex 6, section A6.1.1 for more details).

3

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

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

In 2020, about 490 Mt (73 %) of Canada's GHG emissions were from the combustion of fossil and biomass fuels (Table 3–1). Overall, GHG emissions from Fuel Combustion Activities have increased by 15.9% since 1990. Between 1990 and 2020, emissions from the Energy Industries (1.A.1), Manufacturing Industries and Construction (1.A.2) and Other Sectors (1.A.4) categories increased by 10.5% (31.5 Mt), and emissions from the Transport (1.A.3) category increased by 28.9% (35.8 Mt) (see Figure 3–1).

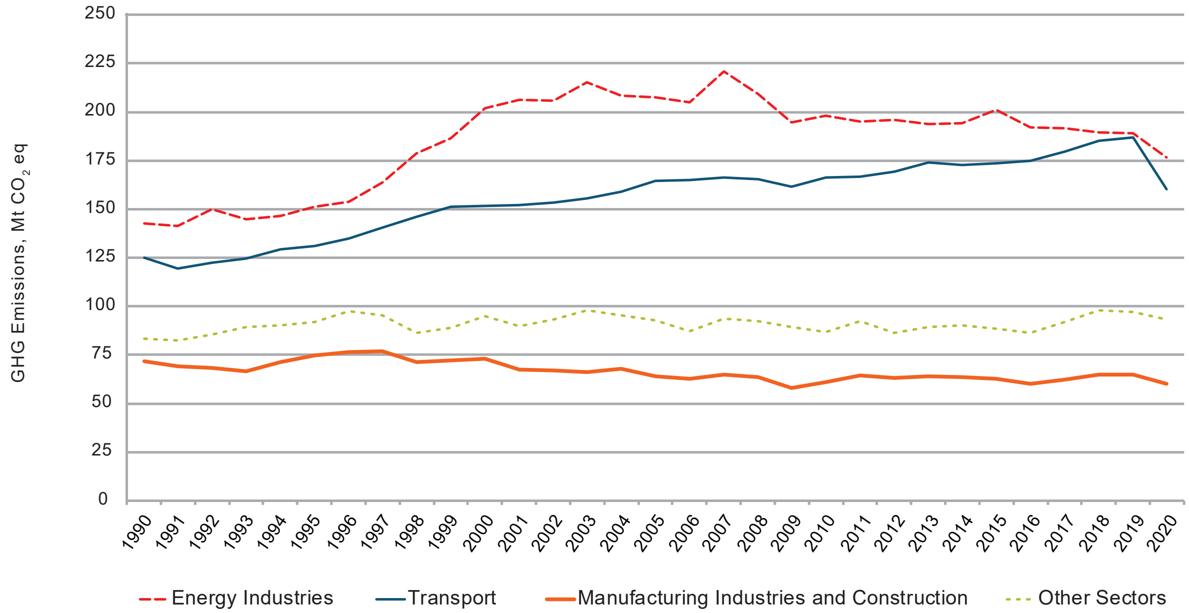
3.2.1. Comparison of the Sectoral Approach with the Reference Approach

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

3.2.2. International Bunker Fuels

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

Figure 3–1 **GHG Emissions from Fuel Combustion**



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

Emissions (Table 3–3) were calculated using the same methods listed in the Domestic Aviation section (see section 3.2.6.2). Fuel-use data are reported in the RESD (Statistics Canada, 1990–) as being sold to domestic and foreign airlines. However, with the Aviation Greenhouse Gas Emission Model (AGEM), flight-by-flight aircraft movements are used to determine whether a flight stage is domestic or international. This method greatly improves the allocation between domestic and international flights.

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

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

Emissions (Table 3–4) were calculated using the same methods listed in the Domestic Navigation section (see section 3.2.6.2). Fuel-use data are reported in the RESD (Statistics Canada, 1990–) as being sold to domestic or foreign flag vessels. However, with the Marine Emission Inventory Tool (MEIT), vessel movements determine whether a voyage is domestic or international, as defined by the 2006 IPCC Guidelines. This method greatly improves the allocation between domestic and international movements.

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

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

GHG Source Category	GHG Emissions (kt CO_2 eq)									
	1990	2005	2013	2014	2015	2016	2017	2018	2019	2020
International Aviation	5 800	10 100	11 100	11 000	11 400	12 000	13 200	15 000	15 200	6 670
Domestic & Military Aviation	7 510	7 720	7 880	7 590	7 590	7 520	7 940	8 660	8 590	4 810
Total	**13 300**	**17 800**	**19 000**	**18 600**	**19 000**	**19 500**	**21 100**	**23 700**	**23 800**	**11 500**

Note: Totals may not add up due to rounding.

Table 3–4 **GHG Emissions from Domestic and International Navigation**										
GHG Source Category	GHG Emissions (kt CO_2 eq)									
	1990	2005	2013	2014	2015	2016	2017	2018	2019	2020
International Navigation	7 250	9 540	8 680	8 680	8 430	7 480	7 630	7 820	8 780	7 430
Domestic, Fishing & Military Navigation	3 070	3 980	3 530	3 480	3 430	3 510	3 650	3 830	4 360	4 190
Total	**10 300**	**13 500**	**12 200**	**12 200**	**11 900**	**11 000**	**11 300**	**11 600**	**13 100**	**11 600**
Note: Totals may not add up due to rounding.										

consumption values reported to the IEA by Canada are based on vessel flag (domestic or foreign). Furthermore, due to design and operating procedures of marine vessels, it is common for vessels to store significant amounts of fuel onboard. This means that it is possible for vessels to navigate in Canadian waters without purchasing fuel from a Canadian supplier. Since the RESD contains only domestic fuel transactions, it is possible to have more fuel consumed in the marine sector than the amounts reported for Canada.

3.2.3. Feedstocks and Non-Energy Use of Fuels

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

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

3.2.4.1. Source Category Description

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

In 2020, the Energy Industries category accounted for 177 Mt (26.3%) of Canada's total GHG emissions, with a 23.7% increase in total GHG emissions since 1990. The Public Electricity and Heat Generation subcategory accounted for 35.1% (62.1 Mt) of the GHG emissions from Energy Industries, while the Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries subcategories contributed 8.2% (14.4 Mt) and 56.7% (100 Mt), respectively (Table 3–5). Chapter 2, Emissions Trends has further discussion of trends in emissions from the Energy Industries category.

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

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

Table 3–5 **Energy Industries GHG Contribution**															
GHG Source Category	GHG Emissions (kt CO_2 eq)														
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Energy Industries TOTAL (1.A.1)	**143 000**	**152 000**	**203 000**	**208 000**	**199 000**	**196 000**	**197 000**	**195 000**	**195 000**	**202 000**	**193 000**	**192 000**	**190 000**	**190 000**	**177 000**
Public Electricity and Heat Generation	94 500	98 800	132 000	125 000	102 000	94 100	91 200	87 300	84 300	87 700	81 400	79 200	70 800	69 600	62 100
Petroleum Refining	17 400	16 300	17 300	20 100	19 000	18 300	17 500	16 600	16 000	16 000	16 300	14 500	14 700	15 800	14 400
Manufacture of Solid Fuels and Other Energy Industries[a]	31 200	36 900	53 300	63 300	77 600	83 600	87 900	90 700	94 400	98 100	95 000	98 000	105 000	104 000	100 000

Notes:

Totals may not add up due to rounding.

a. In accordance with the UNFCCC Common Reporting Format tables, Manufacture of Solid Fuels and Other Energy Industries includes stationary combustion emissions from coal mines. However, in Annexes 9 and 11, these emissions are included in the Mining category.

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

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

The electricity supply grid in Canada includes combustion-derived electricity as well as hydro, nuclear and other renewables (wind, solar and tidal power). Total power generated by wind, tidal and solar resources is small relative to that generated by Canada's significant hydro and nuclear installations. Nuclear, hydro, wind, solar and tidal electricity generators only emit small quantities of GHGs[3], generally from diesel generators used as a backup power supply. In the case of nuclear facilities, uranium fuel production and processing occurs at separate facilities, so any GHG emissions associated with these facilities appear under Manufacturing Industries and Construction. Emissions from the mining of uranium are reported under Mining. The GHG estimates in the Public Electricity and Heat Generation category therefore only reflect emissions from combustion-derived electricity. Steam generation and internal combustion engines are the primary systems used to generate electricity through thermal processes. Steam turbine boilers burn coal, petroleum coke, refined petroleum products (RPPs), natural gas or biomass, while gas turbines use natural gas or RPPs. Reciprocating engines can use natural gas and/or a combination of RPPs.

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

The Petroleum Refining subcategory includes emissions from the production of petroleum products from a raw feedstock. Conventional or synthetic crude oil is refined into petroleum products such as heavy fuel oil, residential fuel oil, aircraft fuel, gasoline and diesel by distillation and other processes. These processes use heat from combusting either internally generated fuels (such as still gas and petroleum coke) or purchased fuels (such as natural gas). The Fugitive Emissions from Fuels category (section 3.3) includes CO_2 generated as a by-product during the production of hydrogen in the steam reforming of natural gas, as well as other fugitive emissions from refinery operations.

3

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

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

Upgrading facilities are responsible for producing synthetic crude oil from a feedstock of bitumen produced by oil sands mining, extraction and *in-situ* recovery activities (e.g. thermal extraction). The synthetic (or upgraded) crude oil has a hydrocarbon composition similar to that of conventional crude oil, which can be refined to produce RPPs such as gasoline and diesel. Upgrading facilities also rely on natural gas as well as internally generated fuels such as still gas and petroleum coke for their operation, which result in both combustion- and fugitive-related emissions.

3.2.4.2. Methodological Issues

The methodology described in Annex 3.1 calculates emissions for all source categories, using primarily fuel consumption data reported in the RESD (Statistics Canada, 1990–). The method is consistent with the IPCC Tier 2 approach, with country-specific emission factors.

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

Statistic Canada (StatCan) fuel-use data in the RESD differentiates industrial electricity generation from utility generation, but aggregates industrial generation data into one category titled Transformed to Electricity by Industry. Reallocating GHG emissions from industrial electricity generation to their respective industrial subcategories uses the detailed industry information that feeds the RESD. See Annex 3.1 for methodological details.

The 2006 IPCC Guidelines divide the Public Electricity and Heat Generation subcategory into three additional subcategories: Electricity Generation (1.A.1.a.i), Combined Heat and Power Generation (1.A.1.a.ii), and Heat Plants (1.A.1.a.iii). StatCan does not differentiate fuel-use data in the RESD using these subcategories; rather, they aggregate data into one category

3 In the case of hydroelectric generation facilities, emissions from their associated hydro reservoirs (due to the flooding of land) are reported in the Land Use, Land Use Change and Forestry Sector.

titled Transformed to Electricity by Utilities. Disaggregating GHG emissions from the RESD Transformed to Electricity by Utilities category into the Electricity Generation and Combined Heat and Power Generation CRF subcategories uses the RESD input data.[4] See Annex 3.1 for methodological details.

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

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

The calculation of emissions for this subcategory uses all fuel use attributed to the petroleum refining industry and includes all petroleum products reported as producer-consumed/own consumption as well as purchases of natural gas for fuel use by refineries. The fuel-use data in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the Fugitive Emissions from Fuels category. Subtracting fuel-use and emission data associated with flaring avoids double counting. See Annex 3.2, section A3.2.2.7, for more details.

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

Emissions for this subcategory are calculated using all fuel use attributed to fossil fuel producers. The fuel-use data in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the Fugitive Emissions from Fuels category. To avoid double counting, Stationary Combustion Sources do not include fuel-use and emission data associated with flaring. See Annex 3.2, section A3.2.2.7, for more details.

Fossil fuel producers often combust unprocessed, non-marketable natural gas. This has a higher CO_2 emission factor than marketable natural gas (see Annex 6), since it contains a larger percentage of complex hydrocarbons, resulting in higher carbon content. Likewise, the energy content of non-marketable natural gas is higher than that of marketable natural gas.

3

3.2.4.3. Uncertainties and Time-Series Consistency

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

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

The estimated uncertainty for CH_4 (±112%) and N_2O (±261%) emissions for the Energy Industries category is influenced by the uncertainty associated with the emission factors (ICF Consulting 2004). Additional expert elicitation is required to improve the CH_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by ICF Consulting. The estimates for the Energy Industries category are consistent over time and calculated using the same methodology. Section 3.2.4.5, Recalculations, includes a discussion of RESD activity data.

Approximately 35% of the emissions from the Manufacture of Solid Fuels and Other Energy Industries subcategory are associated with the consumption of non-marketable natural gas for natural gas production and processing, conventional crude oil production, and in-situ bitumen extraction. The uncertainty estimates for emissions from the combustion of this fuel is influenced by the CO_2 (-1.4 to +2.0% for Alberta; ±6% for all other provinces) and CH_4 (0% to +240%) emission factor uncertainties for the consumption of unprocessed natural gas. Emissions estimates for the natural gas industry used provincially weighted natural gas emission factors since plant-level information on the composition of consumed unprocessed natural gas (which will vary from plant to plant) is unavailable.

3.2.4.4. QA/QC and Verification

The completed quality control (QC) 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.

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

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

3.2.4.5. Recalculations

Several improvements and activity data revisions have contributed to increased data accuracy and better comparability, as well as consistency with the 2006 IPCC Guidelines and UNFCCC reporting guidelines. There were revisions, for all years, to emission estimates for the Energy Industries category, with estimates for 2019 increasing by 0.9 Mt CO_2 eq compared to the previous submission.

Revisions to the CO_2 emission factors for marketable natural gas caused recalculations for all source categories in the Energy Sector that consume natural gas between 1999 and 2019 across all regions. Updated natural gas CO_2 emission factors incorporated new detailed information on gas composition data, and volumes as supplied by industry (see Annex 6, section A6.1.1 for more details) from domestic and imported sources.

Recalculations ranging from -8.0 Mt in 1998 to -4.8 Mt in 2009, for the category Manufacture of Solid Fuels and Other Energy Industries, and -182.4 kt in 2006, to 512.1 kt CO_2 in 2019, for the category Public Electricity and Heat Production resulted from revised CO_2 emission factors for natural gas. The natural gas emission factor revision also caused smaller changes to the Petroleum Refinery category that ranged from -22.2 kt in 2006 to 79.6 kt CO_2 in 2019.

Revisions to the CO_2 emission factors for coal in New Brunswick resulted in recalculations between 2010 and 2019. The updated CO_2 emission factors incorporated detailed coal composition data, resulting in recalculations ranging from -312 kt in 2011 to 535 kt in 2018, for the category Public Electricity and Heat Production category.

3.2.4.6. Planned Improvements

Environment and Climate Change Canada (ECCC), Natural Resources Canada (NRCan), and Statistics Canada (StatCan) continue to collaborate on improvements to the quality of the national energy balance and the disaggregation of fuel-use data via a Trilateral Energy Working Group. Shared quality control responsibilities across working group members (for the RESD and some feeder surveys[5]) also contributes to annual improvements in the national energy balance and, in turn, the National Inventory. StatCan is responsible for implementing improvements, conducting feasibility assessments of projects and recommending approaches to collect new data. Discussions of recalculations resulting from improvements to the energy balance are found in their respective sections or in the general overview section of this chapter.

StatCan has assessed and modernized some surveys to better capture supply and demand of fossil and renewable fuels. These updates will improve the quality and enhance the transparency of RESD data. Examples of refinements include: 1) integration of data collected from an expanded pool of respondents from the monthly refined petroleum production survey, 2) collection of monthly renewable fuels survey, on types of biodiesel and ethanol produced in Canada and 3) improvement to data collection methods regarding the movement of fossil, and renewable, fuels via rail and marine vessels.

Canada is focused on developing country specific emission factors with improvements that prioritize fuels with the largest GHG contribution, such as coal, gasoline, diesel and natural gas. In recent years, new test results and studies have provided the basis for updates to the CO_2 emission factors and heating values for coal, gasoline, diesel, and marketable and non-marketable natural gas. Annex 6 of this report presents the results of these improvement activities. Canada will continue to assess and identify additional fuels for improvement.

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

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

3.2.5.1. Source Category Description

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

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

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

GHG Source Category	GHG Emissions (kt CO_2 eq)														
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Manufacturing Industries and Construction TOTAL (1.A.2)	**71 400**	**74 000**	**72 400**	**63 400**	**60 200**	**63 700**	**62 700**	**63 400**	**63 100**	**62 300**	**59 700**	**61 900**	**64 300**	**64 500**	**59 700**
Iron and Steel	4 950	5 780	6 200	5 510	4 950	5 260	5 500	5 600	6 050	5 750	5 620	6 000	6 380	6 070	4 680
Non-ferrous Metals	3 310	3 220	3 570	3 640	3 060	3 410	2 970	3 100	2 910	3 130	3 210	3 250	2 820	3 270	3 050
Chemicals	8 260	10 300	10 600	8 260	9 870	11 100	11 000	11 600	12 400	12 100	10 800	9 800	9 500	9 600	9 400
Pulp, Paper and Print	14 500	12 800	12 500	8 600	5 920	6 180	5 970	6 220	6 090	6 000	6 010	6 400	7 090	7 190	6 480
Food Processing, Beverages and Tobacco[a]	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Non-metallic Minerals	3 970	4 160	4 640	5 400	4 080	4 310	4 030	3 850	4 000	3 910	3 930	4 160	4 170	4 010	3 130
Other	36 400	37 700	34 800	32 000	32 300	33 400	33 200	33 000	31 600	31 500	30 100	32 400	34 400	34 300	33 000
Mining (excluding fuels) and Quarrying[b]	4 170	4 400	4 300	3 980	5 090	5 180	5 650	4 860	4 570	4 170	3 880	4 510	5 940	5 840	5 610
Construction	1 880	1 180	1 080	1 440	1 520	1 360	1 390	1 290	1 300	1 310	1 300	1 300	1 380	1 440	1 430
Off-road Manufacturing, Mining and Construction	9 160	12 400	11 300	10 400	12 600	13 200	12 000	12 400	12 200	13 100	12 200	13 500	14 400	14 200	14 100
Other Manufacturing	21 200	19 700	18 200	16 200	13 100	13 700	14 200	14 500	13 600	12 900	12 800	13 000	12 700	12 900	11 800

Notes:

IE = Included elsewhere

Totals may not add up due to rounding.

a. Food Processing, Beverages and Tobacco emissions are included under Other Manufacturing.

b. In accordance with UNFCCC Common Reporting Format tables, combustion emissions from coal mines are excluded from Mining (excluding fuels) and Quarrying. However, in Annexes 9 and 11, these emissions are included in the Mining category.

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In 2020, the Manufacturing Industries and Construction category accounted for 59.7 Mt (8.9%) of Canada's total GHG emissions, with a 16.3% (11.7 Mt) decrease in overall emissions since 1990 (refer to Table 3–6 for more details). Within the Manufacturing Industries and Construction category, 33.0 Mt (55.3%) of the GHG emissions are from the Other subcategory, which is made up of mining, construction, off-road (associated with the manufacturing, mining and construction) along with other manufacturing activities. This subcategory is followed by, in order of decreasing contributions, the Chemicals (9.4 Mt, 15.7%), Pulp, Paper and Print (6.48 Mt, 10.8%), Iron and Steel (4.68 Mt, 7.8%), Non-metallic Minerals (3.13 Mt, 5.2%); and Non-ferrous Metals (3.05 Mt, 5.1%) 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 Annex 3.1). The Industrial Processes and Product Use sector reports GHG emissions from the non-energy use of fossil fuels, such as metallurgical coke for iron ore reduction, other fuels for feedstocks and chemical reagents.

3.2.5.2. Methodological Issues

Calculation of GHG emissions from fuel combustion for each subcategory within the Manufacturing Industries and Construction category uses the methodology described in Annex 3.1, including the off-road method, which is consistent with an IPCC Tier 2 approach. GHG emissions generated from the use of transportation fuels (e.g. diesel and gasoline) appear under Off-road Vehicles and Other Machinery (1.A.2.g.vii) of the Manufacturing Industries and Construction category. CH_4 and N_2O emissions from the combustion of biomass were also included in the relevant subcategory of Manufacturing Industries and Construction. CO_2 emissions from biomass combustion are not included in totals but appear separately in the UNFCCC CRF tables as a memo item.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3.2.5.3. Uncertainties and Time-Series Consistency

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

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

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

The estimates for the Manufacturing Industries and Construction category have been prepared in a consistent manner over time using the same methodology. Section 3.2.4.5, Recalculations, presents a discussion on updated RESD fuel-use data.

3.2.5.4. QA/QC and Verification

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

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

3.2.5.5. Recalculations

There are revised emissions estimates for all years, with estimates for 2019 increasing by 0.7 Mt CO_2 eq over the previous submission, because of the following changes:

- revised RESD data
- revised municipal solid waste data
- revised CO_2 emission factors for marketable natural gas in all provinces, and all years from 1999 to 2019, developed using detailed gas composition data, and volumes, supplied by industry (see Annex 6, section A6.1.1 for more details).

Revisions to the Manufacturing Industries and Construction category occurred back to 1990. Changes to CO_2 emission factors for marketable natural gas affect the time series from 1999 onward, and resulted in changes to emissions ranging from -0.43 Mt to 0.80 Mt between 1999 and 2018, and a 0.67 Mt increase in emissions in 2019. Changes to the activity data, in the form of updates in the RESD, affects 2019 and resulted in a 0.03 Mt increase in emissions. Updates to municipal solid waste activity data affects 1990 to 1994 and resulted in a decrease in emissions ranging from -0.4 kt in 1990 to -0.2 kt in 1994.

3.2.5.6. Planned Improvements

ECCC, NRCan, and StatCan continue to collaborate on improvements to the quality of the national energy balance and to the disaggregation of fuel-use data via a Trilateral Energy Working Group. Refer to 3.2.4.6, Planned Improvements for a bit more detail on StatCan and the Trilateral Energy Working Group's activities.

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

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

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

In 2020, transport-related GHG emissions total 160 Mt, accounting for about 24% 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), light-duty diesel trucks (LDDTs) and heavy-duty diesel vehicles (HDDVs), with growth of 124% (25 Mt) for LDGTs, 547% (0.8 Mt) for LDDTs and 240% (33 Mt) 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 18 Mt since 1990. Emissions from the Transport category have increased 31% and have contributed the equivalent of 58% of the total overall growth in emissions observed in Canada.

Table 3–7 **Transport GHG Emissions**

GHG Source Category	GHG Emissions (kt CO_2 eq)												
	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020
Transport	**124 000**	**130 000**	**151 000**	**163 000**	**165 000**	**173 000**	**172 000**	**173 000**	**174 000**	**179 000**	**185 000**	**186 000**	**160 000**
Domestic Aviation[a]	7 280	6 470	7 530	7 460	6 430	7 670	7 380	7 350	7 270	7 710	8 420	8 340	4 620
Road Transportation	83 800	86 600	111 000	130 000	137 000	144 000	142 000	142 000	145 000	148 000	152 000	153 000	131 000
Light-Duty Gasoline Vehicles	41 600	40 400	40 400	41 400	37 800	35 700	34 200	34 500	34 600	33 700	33 000	32 400	25 000
Light-Duty Gasoline Trucks	20 300	23 900	31 800	38 100	41 300	43 300	43 400	45 300	48 100	49 200	51 100	53 100	45 500
Heavy-Duty Gasoline Vehicles	6 320	7 170	10 500	11 700	12 500	13 400	12 400	12 300	13 000	13 300	13 400	13 500	12 600
Motorcycles	90	78	123	204	248	262	260	271	287	296	296	298	243
Light-Duty Diesel Vehicles	467	400	600	605	663	856	857	901	842	842	810	777	492
Light-Duty Diesel Trucks	153	156	338	345	422	535	642	809	900	1 080	1 180	1 200	991
Heavy-Duty Diesel Vehicles	13 600	13 600	26 500	36 900	44 300	50 100	49 800	48 400	46 800	49 400	51 700	51 500	46 400
Propane and Natural Gas Vehicles	1 160	903	522	381	38	18	9	8	9	10	10	10	5
Railways	6 920	6 260	6 530	6 580	6 530	7 280	7 450	7 100	6 530	7 470	7 630	7 690	7 170
Domestic Navigation[a, b]	2 170	2 430	2 700	3 080	2 820	2 990	3 050	3 100	3 200	3 380	3 600	4 070	3 850
Other Transportation[c]	23 600	28 300	23 000	16 500	12 000	11 100	12 500	13 100	12 600	12 700	13 600	13 500	12 700
Off-Road	16 700	16 300	11 700	6 400	6 300	4 300	4 540	4 820	4 920	5 120	5 260	5 050	4 980
Pipeline Transport	6 900	12 000	11 300	10 100	5 720	6 770	7 960	8 270	7 720	7 550	8 380	8 480	7 730

Notes:

Totals may not add up due to rounding.

a. Excludes emissions from military equipment, reported in the Other (Not Specified Elsewhere) (CRF Category 1.A.5) categories.

b. Excludes emissionsfrom fishing vessel which are reported in the Agriculture/Forestry/Fishing categories.

c. Excludes off-road emissions reported in the Manufacturing Industries and Construction and Other Sectors categories.

3.2.6.1. Source Category Description

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

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

3.2.6.2. Methodological Issues

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

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

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

The methodology for the Domestic Aviation subcategory follows a modified IPCC Tier 3 approach. Emissions estimates employ a mix of country-specific, aircraft-specific and IPCC default emission factors. The estimates are generated using AGEM and are calculated using the reported quantities of aviation gasoline and turbo fuel consumed that are published in the RESD (Statistics Canada, 1990–). The majority of aircraft fuel sales reported in the RESD represents aircraft fuels sold to Canadian airlines, foreign airlines, and public administration and commercial/institutional sectors.

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

The methodology used to estimate road transportation GHG emissions is a detailed IPCC Tier 3 method, as outlined in IPCC (2006). MOVES calculates energy consumption by a range of vehicle classifications based on country-specific fleet information and driving rates, which are then applied to country-specific emission factors.

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

The procedure used to estimate GHG emissions from the Railways subcategory adheres to an IPCC Tier 2 methodology for CO_2 emissions and an IPCC Tier 1 methodology for CH_4 and N_2O emissions (IPCC, 2006). Fuel sales data from the RESD (Statistics Canada, 1990–) reported under railways are multiplied by country-specific emission factors.

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

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

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

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

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

Pipeline[6] represent the only non-vehicular transport in this sector. They use fossil-fuelled combustion engines to power motive compressors that propel hydrocarbon-based products. In the case of natural gas pipelines, the fuel used is primarily natural gas. While oil pipelines tend to use electric motors to operate pumping stations, some consumption of refined petroleum, such as diesel fuel, occurs as a backup during power failures.

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

Other Transportation (Off-road) (CRF Category 1.A.3.e.ii)

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

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

Non-road or off-road transport[7] (ground, non-rail vehicles and equipment) includes GHG emissions resulting from fuel combustion. Vehicles in this subcategory include airport ground support equipment, railway maintenance equipment, and off-road recreational vehicles.

Off-road emissions are calculated using an IPCC Tier 3 approach. Emissions are based on country-specific emission factors, equipment populations and usage factors.

3.2.6.3. Uncertainties and Time-Series Consistency

Transport

The overall uncertainty of the 2020 estimates for the Transport category (not including pipelines) was estimated to be ±1.3% for CO_2, CH_4 and N_2O combined.

Emissions from Domestic Aviation

The uncertainty associated with overall emissions from domestic aviation was estimated to be ±5.8%. The Domestic Aviation subcategory only contributed approximately 3% to total Transport GHG emissions and therefore did not significantly influence overall uncertainty levels.

Emissions from Road Transportation

The uncertainty related to the overall emissions from on-road vehicles was estimated to be within the range of ±1.4%, driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO_2 emissions. Conversely, the high uncertainties associated with CH_4 and N_2O emissions, as well as biofuel activity data, did not significantly influence the analysis because of their comparatively minor contributions to the inventory.

Emissions from Railways

The uncertainty associated with emissions from rail transport was estimated to be ±21%. The greatest influence was exerted by the high N_2O emission factor uncertainty (-50% to +200%), whereas the relatively low uncertainties in diesel fuel activity data and CO_2 emission factors contributed very little. It is important to note that railway emissions only accounted for approximately 4% of the Transport category GHG inventory and therefore did not significantly influence the overall uncertainty results.

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

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

Emissions from Domestic Navigation

The uncertainty associated with emissions from the Domestic Navigation category was estimated to be ±2.9%. The high N_2O emission factor uncertainty (-40% to +140%) represented the largest contribution to uncertainty, while CO_2 emission factor uncertainties were insignificant. Since domestic navigation emissions only made up 2% of the Transport category GHG inventory, they did not substantially alter the overall uncertainty results.

Emissions from Pipeline Transport

In general, the CH_4 emission uncertainty for pipeline transport ranges from ±15%. Table A2-1 and Table A2-2 show specific uncertainties from pipelines, by GHGs.

Emissions from Off-road

The Off-road subcategory includes equipment consuming gasoline, diesel, propane and natural gas. The uncertainty associated with the off-road transport sources was estimated to be ±1.4%, driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO_2 emissions.

3.2.6.4. QA/QC and Verification

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

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

3.2.6.5. Recalculations

Transportation estimates were revised for the 1990–2019 period as follows.

- RESD fuel: Notable revisions include updating preliminary 2019 RESD data for all fuels as well as updating motor gasoline and diesel fuel volumes associated with the Northwest Territories for the 2005–2018 period.
- Rail activity data update: The provincial rail activity data was updated to reflect the amount of fuel consumed within a geographical region whereas the previous model was based on fuel supplied to a geographical region. This update did not affect the amount of diesel fuel oil consumed nationally; however, it had minor impacts on the amount of biodiesel consumed nationally.
- Emission Factors: Revised CO_2 emission factors for marketable natural gas in all provinces, and all years from 1999 to 2019, developed using detailed gas composition data, and volumes, supplied by industry (see Annex 6, section A6.1.1 for more details).

The revised natural gas emission factors resulted in changes to pipeline transportation emissions ranging from -83.6 kt CO_2 in 2006 to 185.0 kt in 2019.

Table 3–2 summarizes the net impact of all recalculations.

3.2.6.6. Planned Improvements

Planned improvements have been identified for the Transport category. Current high priorities include implementing several updates to both off-road and on-road emissions modelling inputs. For off-road, these updates include revising vehicle and equipment population data, modifying how these vehicles and equipment are regionally distributed and revising annual hours of use rates for select vehicles and equipment. These improvements will not be exclusive to off-road vehicles and equipment assigned to the Transport category. Off-road vehicles and equipment assigned to Other Sectors (CRF Category 1.A.4) and Manufacturing Industries and Construction (CRF Category 1.A.2) will also be improved upon. For on-road, these updates include revising on-road vehicle population data, updating KARs for recent years and potentially adopting the latest version of MOVES.

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

3.2.7.1. Source Category Description

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

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

In 2020, the Other Sectors category contributed 93.3 Mt (13.9%) of Canada's total GHG emissions, with an overall growth of about 11.0% (9.27 Mt) since 1990. Within the Other Sectors category, the Residential subcategory contributed emissions of about 39.3 Mt (42.1%), followed by the Commercial/Institutional subcategory with emissions of 39.1 Mt (41.9%) and the Agriculture/Forestry/Fishing subcategory with 15.0 Mt (16.0%). Since 1990, GHG emissions have grown by 41.1% (11.4 Mt) in the Commercial/Institutional subcategory and 21.3% (2.6 Mt) in the Agriculture/Forestry/Fishing subcategory, while GHG emissions in the Residential subcategory have declined by about 10.8% (4.8 Mt). Refer to Table 3–8 for additional details. Chapter 2 has further discussion of trends for the Other Sectors category.

3.2.7.2. Methodological Issues

Emission calculations for these source categories use the methodology described in Annex 3.1, which is an IPCC Tier 2 approach, with country-specific emission factors. See below for methodological issues specific to each category. Emissions from the combustion of transportation fuels (e.g. diesel and gasoline) are estimated using methods described in the Transport category.

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

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

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

GHG Source Category	GHG Emissions (kt CO_2 eq)														
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Other Sectors TOTAL (1.A.4)	**84 100**	**92 700**	**95 900**	**93 800**	**87 500**	**93 100**	**86 800**	**89 600**	**90 700**	**88 800**	**86 600**	**92 100**	**98 100**	**97 200**	**93 300**
Commercial/Institutional	27 700	31 400	35 400	34 800	31 200	33 300	31 200	32 400	34 200	33 100	34 500	37 000	38 500	40 500	39 100
Commercial and Other Institutional	26 200	29 400	33 300	32 400	28 600	30 500	28 700	29 700	31 400	30 400	31 900	34 200	35 600	37 500	36 200
Off-Road Commercial & Institutional	1 520	1 990	2 080	2 400	2 680	2 730	2 520	2 720	2 760	2 720	2 550	2 820	2 900	2 950	2 880
Residential	44 000	45 300	45 400	44 600	41 800	44 900	41 400	43 100	42 700	42 100	39 000	41 500	45 100	41 900	39 300
Stationary Combustion	43 800	44 900	44 700	43 300	40 600	43 600	40 200	41 900	41 500	40 900	37 900	40 300	43 900	40 700	38 000
Off-Road Residential	241	380	775	1 250	1 170	1 300	1 220	1 180	1 210	1 220	1 170	1 190	1 230	1 240	1 230
Agriculture/Forestry/Fishing	12 300	16 100	15 100	14 400	14 500	14 900	14 200	14 100	13 800	13 600	13 100	13 600	14 500	14 800	15 000
Agriculture and Forestry	2 410	2 770	2 570	2 180	2 660	3 160	3 260	3 150	3 000	2 960	3 180	3 080	3 180	3 490	3 100
Off-Road Agriculture/Forestry/Fishing	9 920	13 310	12 520	12 260	11 880	11 750	10 960	10 960	10 780	10 650	9 890	10 570	11 350	11 340	11 860

Note: Totals may not add up due to rounding.

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

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

Emissions estimates in this category use RESD residential fuel-use data, with the exception of biomass data which StatCan, ECCC and NRCan collects using a periodic stand-alone survey. Annex 3.1 details the methodology for biomass combustion from residential firewood. The CH_4 and N_2O emissions from firewood combustion are reported here, and CO_2 emissions, while not accounted for in the national residential GHG total, are reported as a memo item.

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

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

This subcategory includes emissions from fuel combustion in the agriculture, forestry and fishing industries. Emissions estimated for this category are from fishing boats, on-site machinery operation and heating, and use RESD marine, agriculture and forestry fuel-use data. While emissions associated with fishing vessels are included here, emissions from land-based fish processing activities are currently included under the Other Manufacturing (i.e. food processing) subcategory. Annex 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 CRF categorization.

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3.2.7.3. Uncertainties and Time-Series Consistency

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

The underlying fossil fuel quantities and non-biomass CO_2 emission factors have low uncertainties, since they are predominantly commercial fuels that have consistent properties and accurately tracked quantities, as compared to residential biomass data. The overall non-CO_2 emissions uncertainty is 5% for the Residential subcategory, compared to 2% for the Commercial subcategory; this is due to the higher uncertainty associated with residential firewood emission factors (CH_4 with -90% to +1500% and N_2O with -65% to +1000%) than with fossil-fuel-based CH_4 and N_2O emission factors (ICF Consulting 2004). As stated with respect to the Energy Industries category, for some of the emission factor uncertainty ranges and probability density functions, additional expert elicitation will improve the associated CH_4 and N_2O uncertainty estimates.

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

3.2.7.4. QA/QC and Verification

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

3.2.7.5. Recalculations

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

- revised RESD data
- revised residential firewood data
- revised municipal solid waste data
- revised landfill gas data
- revised CO_2 emission factors for marketable natural gas in all provinces, and all years from 1999 to 2019, developed using detailed gas composition data, and volumes, supplied by industry (see Annex 6, section A6.1.1.1 for more details).

Revisions to the Other Sectors category occurred back to 1990. Changes to the activity data, in the form of updates to the RESD, affected 2007 to 2019. The revised RESD data resulted in a 0.1 Mt increase in emissions for 2019.

The revised residential firewood data resulted in a decrease in emissions ranging from -57.4 to 2.7 kt between 1990 and 2019. Refer to the recalculations discussion in the overview, section 3.1, for additional details.

The revised municipal solid waste data ranged from -17.7 to 14.6 kt over the entire time series.

The revised landfill gas data ranged from -0.15 to 0.33 kt over the entire time series.

The revised emission factors for all fuels resulted in changes to emissions ranging from -0.75 Mt to 1.3 Mt between 1990 and 2019, with new natural gas CO_2 emissions factors causing the largest proportion of change between 1999 and 2019. The changes due to natural gas emission factors ranged from -0.75 Mt in 2006 to 1.3 Mt in 2019.

3.2.7.6. Planned Improvements

Although improvements were implemented to the RESD (as presented in the recalculation discussion in the overview section of 3.1), ECCC, NRCan, and StatCan continue to work jointly to improve the underlying quality of the national energy balance and to further disaggregate fuel-use information. Refer to 3.2.4.6, Planned Improvements for a bit more detail on the StatCan and the Trilateral Energy Working Group's activities.

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

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

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

The UNFCCC reporting guidelines assign military fuel combustion to this CRF category. Emissions generated by military aviation are estimated by AGEM and are included under this category (1.A.5.b). Emissions generated by military water-borne navigation are estimated by MEIT and are included under this category (1.A.5.b). As in previous submissions, emissions related to military vehicles have been included in the Transport category, whereas stationary military fuel use has been included in the Commercial/Institutional subcategory (section 3.2.7) in accordance with the RESD fuel data (Statistics Canada, 1990–). See Table 3–9 for additional data.

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

GHG Source Category	GHG Emissions (kt CO_2 eq)														
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Other (Not Specified Elsewhere) TOTAL (1.A.5)	**262**	**259**	**293**	**286**	**284**	**271**	**302**	**288**	**296**	**342**	**335**	**290**	**287**	**317**	**295**

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

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

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

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

In 2020, the Fugitive Emissions from Fuels category accounted for 50 Mt (7.4%) of Canada's total GHG emissions, with a 0.2% (115 kt) growth in emissions since 1990. Fugitive emissions from oil and natural gas increased by 4.0% to 48.6 Mt, and those from coal decreased by 62% (-1.8 Mt) since 1990. The oil and gas production, processing, transmission and distribution activities contributed 97% of the fugitive emissions. Refer to Table 3–10 for more details.

Table 3–10 **Fugitive GHG Contribution**

GHG Source Category	GHG Emissions (kt CO_2 eq)														
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Fugitive Emissions from Fuels (1.B)	**50 000**	**63 000**	**72 000**	**73 000**	**72 000**	**73 000**	**75 000**	**76 000**	**78 000**	**74 000**	**68 000**	**68 000**	**68 000**	**66 000**	**50 000**
Solid Fuels – Coal Mining (1.B.1)	**2 800**	**2 300**	**1 700**	**1 400**	**1 400**	**1 400**	**1 400**	**1 500**	**1 300**	**1 100**	**1 300**	**1 200**	**1 300**	**1 400**	**1 100**
a. Underground – Mining activities	1 500	700	100	90	90	90	70	90	50	30	NO	60	100	160	0
b. Abandoned Underground Mines	190	400	550	170	150	140	140	140	60	60	70	80	70	60	60
c. Surface – Mining activities	1 100	1 200	1 100	1 100	1 100	1 100	1 200	1 300	1 200	1 100	1 200	1 100	1 200	1 200	1 000
Oil and Natural Gas (1.B.2)	**47 000**	**61 000**	**70 000**	**71 000**	**70 000**	**71 000**	**74 000**	**74 000**	**76 000**	**73 000**	**67 000**	**67 000**	**67 000**	**65 000**	**49 000**
a. Oil[a]	7 700	9 300	10 900	11 900	13 300	13 600	14 600	14 700	14 600	13 600	14 100	14 300	14 600	14 500	11 700
b. Natural Gas[a]	11 000	13 000	14 000	15 000	14 000	14 000	14 000	14 000	13 000	13 000	12 000	11 000	11 000	11 000	9 000
c. Venting and Flaring[b]	28 000	38 000	45 000	44 000	42 000	43 000	46 000	46 000	48 000	47 000	41 000	41 000	41 000	39 000	28 000
i. Venting	23 000	32 000	39 000	39 000	37 000	38 000	39 000	39 000	41 000	40 000	35 000	35 000	35 000	33 000	22 000
ii. Flaring	5 050	5 910	6 360	5 490	4 990	5 220	6 120	7 130	7 430	6 890	5 710	6 030	6 320	6 090	6 410

Notes:

NO = Not occurring

Totals may not add up due to rounding.

a. All other fugitives except venting and flaring.

b. Both oil and gas activities.

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

3.3.1.1. Source Category Description

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

Coal Mining and Handling

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

Abandoned Underground Mines

Abandoned underground coal mines are sites where active mining and ventilation management have ceased but fugitive methane emissions continue to occur. In 2020, emissions from abandoned mines were approximately 60 kt CO_2 eq. The decrease in emissions between 2013 and 2014 reflected a return to production of a mine in Nova Scotia. The increase from about 50 kt CO_2 eq in 2015 to 70 kt CO_2 eq in 2016 resulted from two previously active underground mines that ceased operations at the beginning of 2016. See Table 3–10 for additional data.

Solid Fuel Transformation

Solid fuel transformations include activities such as the production of charcoal briquettes, or activated carbon, from coal. There is currently only one facility in Canada engaged in this activity and reliable data was only available for a year when the plants peak production of 100 kt occurred. Using the default IPCC EF values of 1 570 g CO_2/kg and 40.3 g CH_4/kg from the 2019 Refinement to the 2006 IPCC Guidelines (vol. 4, chap. 4.3.2.1, p.4.103), this source would produce approximately 260 kt CO_2 eq. This is below the reporting threshold of 0.05 per cent of Canada's national total emissions and below 500 kt CO_2 eq in accordance with UNFCCC Conference of the Party, Decision 24/CP19, Annex 1, paragraph 37.b., as such NE notation key is reported in the CRF table for this source.

3.3.1.2. Methodological Issues

Coal Mining and Handling

King (1994) developed an inventory of fugitive emissions from coal mining operations and this provides the bases for some of the coal mining fugitive emissions estimates. Dividing the emission estimates from King (1994) by the known coal production values provided appropriate emission factors. These factors are available in Annex 3.2.

King (1994) estimated emission rates from coal mining using a modified procedure from the Coal Industry Advisory Board. It is a hybrid IPCC Tier 2 and Tier 3 methodology, depending on the availability of mine-specific data. The separate estimates of underground and surface mining activity emissions both include post-mining activity emissions. Annex 3.2, Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution, provides a more detailed description of the methodology.

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

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

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

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

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Abandoned Underground Mines

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

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

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

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

3.3.1.3. Uncertainties and Time-Series Consistency

Coal Mining and Handling

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

Abandoned Underground Mines

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

3.3.1.4. QA/QC and Verification

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

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

3.3.1.5. Recalculations

Coal Mining and Handling

This category required no recalculations.

Abandoned Underground Mines

This category required no recalculations.

3.3.1.6. Planned Improvements

Coal Mining and Handling

There are currently no planned improvements.

Abandoned Underground Mines

There are currently no planned improvements.

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

3.3.2.1. Source Category Description

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

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

Upstream Oil and Gas

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

The emission sources fall into these major groups.

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

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

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

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

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

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

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

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

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

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

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

Abandoned Oil and Gas Wells

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

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

GHG Source Category	GHG Emissions (kt CO_2 eq)														
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Abandoned Oil and Gas Wells	**40**	**50**	**60**	**70**	**120**	**130**	**140**	**160**	**170**	**190**	**210**	**230**	**240**	**260**	**270**
Abandoned Oil Wells[a]	30	30	40	50	70	70	80	90	100	110	130	130	140	150	160
Abandoned Gas Wells[b]	20	20	20	30	50	50	60	70	70	80	80	90	100	110	110

Notes:

Totals may not add up due to rounding.

a. Included in CRF category 1.B.2.a – Fugitive emissions from fuels – Oil and natural gas – Oil

b. Included in CRF category 1.B.2.b – Fugitive emissions from fuels – Oil and natural gas – Natural Gas

Oil Sands / Bitumen

This component includes emissions from oil sand open pit mining operations and heavy oil/bitumen upgrading to produce synthetic crude oil and other derived products for sale. Fugitive emissions are primarily from hydrogen production, flue gas desulphurization (FGD), venting and flaring activities, storage and handling losses, fugitive equipment leaks, and CH_4 from the open mine surfaces and from methanogenic bacteria in the mine tailings settling ponds.

Downstream Oil and Gas

Downstream oil and gas includes all fugitive emissions from the production of refined petroleum products and the distribution of natural gas to end consumers. Reported emissions fall into the two major groups described below.

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

Natural Gas Distribution: The natural gas distribution system receives high-pressure gas from the gate of the transmission system and distributes this through local pipelines to the end user. The major emission sources are fugitive emissions from main and service pipelines and meter/regulator stations.

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, emissions estimates used facility reported volumetric data and detailed gas composition data. This applies to Alberta and Saskatchewan reported venting and flaring emissions (see Annex 3 section A3.2.2.1.2) and Alberta and British Columbia surface casing vent flow emissions (see Annex 3 section A3.2.2.1.4).

Modelling: when facility reported data is not available, emissions estimates used 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 can also be reflected annually. For a full description of modelled UOG fugitive emissions, see Annex 3 section A3.2.2.1.3.

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

Interpolated or extrapolated fugitive emission estimates for the UOG industry use information in two separate studies that follow the same methodology. The Canadian Association of Petroleum Producers' (CAPP) study titled *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emissions by the Upstream Oil and Gas Industry* (CAPP, 2005) and referred to as the CAPP study, and an update of this inventory completed in 2014 for Environment Canada by Clearstone Engineering Ltd., referred to as the UOG study (EC, 2014).

The CAPP study provides a detailed emission inventory for the UOG industry for the year 2000. Similarly, the UOG study estimates emissions for the years 2005 and 2011. For both studies, the respective emission inventories used an IPCC Tier 3 bottom-up assessment, beginning at the individual facility and process unit level and aggregating the results to provide emission estimates by facility and geographic area. The Canadian UOG sector assets and operations are vast. As such, the inventory of 2011 emissions included over 300 000 capable oil and gas wells, 14 100 batteries producing gas into more than 5000 gathering systems delivering to almost 750 gas plants, and 24 000 oil batteries delivering to 150 tank terminals, all interconnected by tens of thousands of kilometres of pipeline carrying hydrocarbons from wells to batteries to plants and ultimately markets. The inventory includes emission estimates from flaring, venting, equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses and accidental releases.

Both studies collected, and used, significant amounts of data, including the number and type of active facilities and facility-level activity data such as volumes of gas produced, vented and flared. An inventory of equipment was derived based on typical facility layouts and average number of pieces of equipment by facility type. Emission factors came from a variety of sources, including published reports, equipment manufacturers' data, observed industry values, measured vent rates, simulation programs and other industry studies. Volume 5 of the CAPP study (CAPP, 2005) and Volume 4 of the UOG study (EC 2014) lists data and emission factors.

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The 1990–1999 fugitive emissions estimates used annual industry activity data and the 2000 emission results. Volume 1 of the CAPP study presents the 1990–1999 estimates and method. The 2001–2004 fugitive emissions were estimated using the 2000 (CAPP, 2005) and 2005 (EC, 2014) emission results along with annual industry activity data and interpolation techniques. Similarly, the 2006–2010 emissions were estimated using the 2005 and 2011 (EC, 2014) emission results with annual industry activity data and interpolation techniques. From 2012 on, the 2011 (EC, 2014) emission results are used in conjunction with annual activity data to estimate emissions. Annex 3 section A3.2.2.1.1 provides a more detailed description of the interpolation and extrapolation methodologies.

Abandoned Oil and Gas Wells

Emissions estimates for abandoned wells use an IPCC Tier 1 approach. The CH_4 emission factors are the default EFs provided in the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019). Annual counts of abandoned wells are determined from provincial databases. See Annex 3.2, section A3.2.2.6, for more details.

Natural Gas Transmission and Storage

Fugitive emissions from natural gas transmission for 1990–1996 are from the study titled *CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP, 1999). This study follows a rigorous IPCC Tier 3 approach in estimating GHG emissions. Fugitive emission estimates for 1997–1999 were derived based on length of natural gas pipeline and leakage rates developed using results from the original study. For the year 2000 onwards, emissions are based on data from the UOG study (EC, 2014), following an IPCC Tier 3 approach that rolled up the reported GHG emissions from individual natural gas companies. ORTECH Consulting Inc. (2013) compiled emissions data for the natural gas transmission and storage industry for the Canadian Energy Partnership for Environmental Innovation (CEPEI). CEPEI provided the data for the years 2000–2004, 2006–2010 and 2012–2014 following an IPCC Tier 3 approach. Emission estimates for 2015–2020 are derived using length of natural gas transmission pipeline and the amount of gas deposited into and withdrawn from storage. Annex 3.2 details the complete methodology.

Oil Sands/Bitumen

Fugitive GHG emissions from oil sands mining, bitumen extraction and heavy oil/bitumen upgraders are from two separate reports: *An Inventory of GHGs, CACs and H_2S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP, 2006), prepared by Clearstone Engineering Ltd. (referred to here as the bitumen study) and an update to the study that was completed in 2017 by Clearstone Engineering Ltd. for ECCC titled *An Inventory of GHGs, CACs and Other Priority Emissions by the Canadian Oil Sands Industry: 2003 to 2015* (ECCC, 2017) (referred to here as the oil sands study).

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

The bitumen study (CAPP, 2006) is the basis for the 1990–2003 fugitive emissions estimates, and the oil sands study (ECCC, 2017) is the basis for the 2004–2020 fugitive emission estimates. An oil sands estimation model (referred to here as the oil sands model) allows annual updating of fugitive emissions from oil sands mining and bitumen/heavy oil upgrading activities from 2003 onwards. The oil sands model was developed using relevant parameters and results from the oil sands study, along with annual activity data. The activity data required by the model comes from the following sources: *Alberta Mineable Oil Sands Plant Statistics* by the Alberta Energy Regulator (AER, 2020) and annual reports for the Lloydminster Upgrader (Cenovus, 2021; Husky, 1998–2019). Annex 3 also presents a summary of the estimation method of the oil sands model.

Emissions for oil sands facilities not included in the oil sands study, such as the Horizon Liquid Extraction Plant and the Fort Hills Mine, were estimated using emission factors from similar facilities or emission data reported to the Greenhouse Gas Reporting Program (GHGRP). See Annex 3 for more details.

The Scotford upgrader operated by Shell Canada Energy began capturing CO_2 emissions from its hydrogen production plant in 2015. The CO_2 venting emission estimates for this facility does not include the captured CO_2 transported and injected into storage.

Downstream Oil and Gas Production

Calculating fugitive emissions from refineries uses information contained in the Canadian Petroleum Products Institute (CPPI) study, *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI, 2004). Refer to the CPPI report for full details on the study. The CEEDC and Canadian refineries provided historical fuel, energy and emission data, for the years 1990 and 1994–2002. Fugitive, venting and flaring emissions for the years 1991–1993 and 2003 onward were extrapolated, using data in the CPPI report and the petroleum refinery energy consumption and production data from the RESD (Statistics Canada, 1990–). Annex 3 provides a detailed description of the methodology used to estimate emissions from 1991 to 1993 and 2003 onward.

Natural Gas Distribution

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

For the year 2000 onwards, emissions 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 distribution industry for CEPEI. CEPEI provided emissions data for the years 2000–2004, 2006–2010 and 2012–2014 following an IPCC Tier 3 approach. Emissions for 2015–2020 are estimated using length of natural gas distribution pipeline. Annex 3.2 presents more details on the methodology used to estimate fugitive emissions from natural gas distribution systems.

3.3.2.3. Uncertainties and Time-Series Consistency

Upstream Oil and Gas

The overall uncertainty for the 2020 upstream oil and gas fugitive emissions is -4.3% to +7.8%. Table 3–12 lists the uncertainties for specific UOG categories. Note that the gas transportation industry includes natural gas transmission, storage and distribution. Accidents and equipment failures, and abandoned oil and gas wells, have the highest uncertainty, while oil production and transport have the lowest uncertainty.

Table 3–12 **Uncertainty in Upstream Oil and Gas Fugitive Emissions**

GHG Source Category	Uncertainty (%)					
	Oil Production and Transport	Gas Production / Processing	Gas Transportation	Accidents and Equipment Failures	Well Drilling, Servicing and Testing	Abandoned Oil and Gas Wells
Flaring	± 9.8	-4.2 to +4.3	-16.3 to +21.1	—	-18.9 to +16.3	—
Fugitive	-4.6 to +6.3	-2.6 to +5.2	-26.8 to +28.2	± 59.9	-23.8 to +26.5	-48.0 to +71.5
Venting	± 6.7	-9.9 to +29.9	-20.4 to +22.9	—	-19.8 to +40.6	—
Total	**-3.7 to +4.2**	**-5.4 to +16.2**	**-19.7 to +20.9**	**± 59.9**	**-16.7 to +14.8**	**-48.0 to +71.5**

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Table 3–13 **Uncertainty in Oil Sands/Bitumen Fugitive Emissions**

GHG Source Category	Uncertainty (%)
	Oil Sands/Bitumen
Flaring	-24.2 to +24.3
Fugitive	-29.3 to +33.5
Venting	-28.9 to +29.5
Overall	**-19.0 to +19.7**

Table 3–14 **Uncertainty in Oil Refining Fugitive Emissions**

	Uncertainty (%)			
	Overall	Excluding Refinery Fuel Gas	Excluding Flare Gas	Excluding Refinery Fuel and Flare Gas
Tier 1	± 8.3	± 4.3	± 8.3	± 8.3
Tier 2	± 14	± 5	± 14	± 14

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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 2020 oil sands/bitumen fugitive emissions is -19.0% to +19.7%. An IPCC Good Practice Guidance Tier 1 uncertainty assessment was conducted for each oil sands mining and upgrading facility, with full details of the assessment contained in both the bitumen study (CAPP, 2006) and the oil sands study (ECCC, 2017). Table 3–13 shows the aggregation of facility-level uncertainties by emission source.

Downstream Oil and Gas

The CPPI (2004) study provides the data used in the inventory for fugitive emissions from refineries for 1990 and for 1994–2002. There is greater uncertainty for the 1991–1993 and 2003–2012 periods because of the available level of disaggregation of the activity data. For comparison purposes, a Tier 1 and Tier 2 uncertainty analysis provided overall CO_2 uncertainty values for the 2002 emission factors and activity data (CPPI, 2004).

For the Tier 1 analysis, the overall uncertainty was ±8.3%. The Tier 2 analysis determined that the overall uncertainty was ±14%. The difference between the Tier 1 and Tier 2 uncertainties may be due to the high level of variability in some of the emission factors. Table Table 3–14 presents these uncertainty results.

3.3.2.4. QA/QC and Verification

The completed QC checks for all methods used to estimate fugitive oil and gas emissions were consistent with the 2006 IPCC Guidelines. Elements of the QC checks included a review of the estimation models, activity data, emission factors, time-series consistency, transcription accuracy, reference material, conversion factors and unit labelling, and sample emission calculations.

To ensure that the results were correct, the CAPP and UOG studies (CAPP, 2005; EC, 2014) were subject to the following QA/QC procedures. First, all results were reviewed internally by senior personnel to ensure that there were no errors, omissions or double counting. In addition, individual companies reviewed and commented on the report. The project steering committee and nominated experts performed a second level of review. Where possible, results were compared with previous baseline data and other corporate, industrial and national inventories. Any anomalies were verified through examination of activity levels, changes in regulations, and voluntary industry initiatives.

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

3.3.2.5. Recalculations

Fugitive emissions from oil and natural gas were revised for the 1990–2019 period because of changes to activity data and methodology. See Table 3–2 for a summary of recalculations.

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

- **Oil**: the following describes the various changes to fugitive emissions (excluding venting and flaring) from crude oil systems. Fugitive emissions increased from 1990 to 2019, with changes ranging from +2.5 Mt CO_2-eq in 1992 to +9.1 Mt CO_2-eq in 2017.
  - a) **Fugitive equipment leaks**: Implementation of the new Fugitive Emissions Model (FEM) for equipment leaks resulted in increases in all years from 1990 to 2019, ranging from +1.0 Mt CO_2-eq in 1992 to +5.9 Mt CO_2-eq in 2013.

    Surface casing vents: New method to estimate surface casing vent flow (SCVF) emissions in British Columbia and Alberta and improved allocation of SCVF emissions resulted in increases from 1990 to 2019, ranging from +1.3 Mt CO_2-eq in 1990 to +3.4 Mt CO_2-eq in 2018. Note that the new SCVF method results in overall decreases in SCVF emissions from 1994 to 2019 (largest decrease: -3.3 Mt CO_2-eq in 2014) and overall increases in 1990 to 1993 (largest increase: +324 kt CO_2-eq in 1990), however all SCVF emissions were previously allocated to 'Natural Gas'. Improved method allows for better allocation of emissions to proper sector with significant emissions now allocated to 'Oil'.
  - b) **Abandoned oil wells**: Updated provincial datasets from Alberta and British Columbia resulted in changes to abandoned well counts from 1990 to 2019, and corrected emission factors now align with the default values from the IPCC 2019 Refinement (IPCC, 2019). These changes resulted in decreases in emissions from abandoned oil wells in each year of the time series, ranging from -0.3 kt CO_2-eq in 1990 to -7.1 kt CO_2-eq in 2019.
- **Natural Gas**: the following describes recalculations to fugitive emissions (excluding venting and flaring) from natural gas systems. Fugitive emissions decreased from 1990 to 2003 and 2016 to 2019, and increased from 2004 to 2015. Changes range from -4.3 Mt CO_2-eq in 1999 to +2.5 Mt CO_2-eq in 2006.
  - a) **Fugitive equipment leaks**: Implementation of new Fugitive Emissions Model (FEM) for equipment leaks resulted in decreases from 1990 to 2000 and increases from 2001 to 2019. Decreases range from -809 kt CO_2-eq in 2000 to -1.8 Mt CO_2-eq in 1996, and increases range from +296 kt CO_2-eq in 2001 to +7.6 Mt CO_2-eq in 2011.
  - b) **Surface casing vents**: New method to estimate surface casing vent flow (SCVF) emissions in British Columbia and Alberta and improved allocation of SCVF emissions resulted in decreases from 1990 to 2019, ranging from -1.0 Mt CO_2-eq in 1990 to -6.4 Mt CO_2-eq in 2014. Note that the new SCVF method results in overall decreases in SCVF emissions from 1994 to 2019 (largest decrease: -3.3 Mt CO_2-eq in 2014) and overall increases in 1990 to 1993 (largest increase: +324 kt CO_2-eq in 1990), however all SCVF emissions were previously allocated to 'Natural Gas.' Improved method allows for better allocation of emissions to proper sector with significant emissions now allocated to 'Oil'.
  - c) **Abandoned gas wells**: updated provincial datasets from Alberta and British Columbia resulted in changes to abandoned well counts from 1990 to 2019, and corrected emission factors now align with the default values from the IPCC 2019 Refinement (IPCC, 2019). These changes resulted in decreases in emissions from abandoned gas wells in each year of the time series, ranging from -0.04 kt CO_2-eq in 1990 to -11 kt CO_2-eq in 2019.
  - d) **Transmission, Distribution and Storage**: minor revisions to pipeline lengths resulted in an increase of +20 kt CO_2-eq in 2019.

- **Flaring**: the following describes a number of changes to flaring emission estimates. Flaring emissions increased in the years 1990 to 2015 and decreased from 2016 to 2019, with changes ranging from -530 kt CO_2-eq in 2017 to +800 kt CO_2-eq in 1998.
  - **a) Alberta**: the methodology for estimating flaring emissions from Alberta now incorporates an additional data source, as described in section A3.2.2.1.2 of Annex 3. This change resulted in recalculations for UOG flaring from 2010 to 2019, with increases in each year ranging from +0.2 kt CO_2-eq in 2016 to +50 kt CO_2-eq in 2014.
  - **b) Saskatchewan**: the methodology for estimating flaring emissions from Saskatchewan now incorporates new data sources, as described in section A3.2.2.1.2 of Annex 3. This change resulted in recalculations for oil and natural gas flaring from 1990 to 2019. Recalculations resulted in increases in 1990 to 2014 and decreases from 2015 to 2019, which range from -524 kt CO_2-eq in 2017 to +801 kt CO_2-eq in 1998.
  - **c) Correction**: the Sturgeon refinery in Alberta started operations in 2017 and was initially classified as an upgrader in the oil sands emissions model. However, the province of Alberta, Statistics Canada and the operator classify the facility as a refinery. Flaring emission estimates for refineries are derived using data from Statistics Canada, which includes the Sturgeon refinery. Therefore, the Sturgeon refinery was removed from the Oil Sands upgrading estimates to ensure no double counting. This resulted in a downward revision of emissions between 2017 and 2019 ranging from -13 kt CO_2-eq in 2017 to -198 kt CO_2-eq in 2018.
- **Venting**:
  - **a) Pneumatics and Compressor Seals**: Implementation of the new Fugitive Emissions Model (FEM) for compressor seals and pneumatic devices resulted in recalculations from 1990 to 2019. Compressor seal emissions estimates increased in all years, with changes ranging from +192 kt CO_2-eq in 1990 to +3.6 Mt CO_2-eq in 2011. Emissions from pneumatic devices (instruments and pumps) decreased from 1990 to 2001 and in 2019, and increased from 2002 to 2018, with changes ranging from -1.8 Mt CO_2-eq in 1996 to +3.0 Mt CO_2-eq in 2006.
  - **b) Reported venting**: Improved method for estimating emissions from reported venting in Saskatchewan resulted in recalculations from 1990 to 2019. The methodology now incorporates new data sources, as described in section A3.2.2.1.2 of Annex 3. This change resulted in increases in venting emissions for the time series, ranging from +992 kt CO_2-eq in 2010 to +2.6 Mt CO_2-eq in 2018.
  - **c) Formation CO_2**: updated acid gas shrinkage volumes for natural gas processing facilities in British Columbia resulted in recalculations for 2018 and 2019. These recalculations resulted in increases to emissions estimates of +157 kt CO_2-eq in 2018 and +124 kt CO_2-eq in 2019.

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3.3.2.6. Planned Improvements

Upstream Oil and Gas

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

- Analyze and incorporate raw gas composition data collected by the British Columbia Oil and Gas Commission (BCOGC) into fugitive emission estimates from oil and gas facilities in British Columbia.
- Further incorporate gas composition data provided by the Saskatchewan Ministry of Energy and Resources into fugitive emission estimates from oil and gas facilities in Saskatchewan. Currently, this data is only used to estimate reported venting and flaring emissions in Saskatchewan, but could be used for other fugitive sources.
- Develop and incorporate Canadian-specific emission factors from measurement data to improve estimates for abandoned oil and gas wells.
- Incorporate storage tank emission estimates into the Fugitive Emissions Model (FEM) previously developed to estimate emissions for pneumatics, compressor seals and equipment leaks in the oil and gas industry.
- Inclusion of fugitive estimates for post-meter emissions of natural gas fueled appliances (e.g. home heating, water heating, stoves, and barbecues) and vehicles.

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

Carbon dioxide transport and storage involves the capture of anthropogenic CO_2 and its transport to a storage facility or enhanced oil recovery (EOR) operation. Table 3–15 summarizes the three sources of CO_2 transported in Canada: CO_2 imported from the Dakota Gasification Company in North Dakota, United States, and domestically captured CO_2 from SaskPower's Boundary Dam power station, in Saskatchewan, Shell's Scotford bitumen upgrader, in Alberta and Agrium's fertilizer plant, in Alberta. Table 3–15 also summarizes the final disposition of CO_2 imported into, or captured in, Canada: whether used for EOR or injected into long-term storage. In 2020, CO_2 emissions from the three active pipelines were approximately 0.5 kt, an increase of about 0.4 kt since 2000, as shown in Table 3–16.

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

Captured CO_2 Usage for Enhanced Oil Recovery

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

CO_2 flooding started in 2000 at the Weyburn site and in 2005 at the Midale site in order to extend the life of these mature reservoirs by another 30 years. Carbon dioxide, purchased from the Dakota Gasification Company located in North Dakota and SaskPower's Boundary Dam coal-fired power station, arrives via pipeline. By the end of 2020, the Boundary Dam facility had captured approximately 3.8 Mt of CO_2 for shipment to the Weyburn site (SaskPower, 2021). Injections at this reservoir include this fresh supply of CO_2 and the recovered CO_2 from previous flooding cycles. Currently, the CO_2 injection rate at the Weyburn-Midale operations is about two Mt[8] per year. From 2000 to 2020, the Weyburn and Midale sites have injected over 40 Mt of new CO_2 purchased from the Dakota gasification plant and Sask Power Boundary Dam power plant.

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Table 3–15 CO_2 Import, Capture and Final Disposition

	CO_2 Quantity (kt)														
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
CO_2 Capture Source															
Imported	NO	NO	1800	2000	2000	2000	2000	2000	2700	2200	1600	1700	1600	1800	1600
Domestic Capture	NO	NO	NO	NO	NO	NO	NO	NO	100	800	1900	1600	1700	1700	1800
CO_2 Final Disposition															
Long-term Geologic Storage	NO	NO	NO	NO	NO	NO	NO	NO	NO	400	1200	1200	1100	1200	1000
Enhanced Oil Recovery	NO	NO	1800	2000	2000	2000	2000	2000	2800	2600	2300	2200	2100	2300	2400

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

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

GHG Source Category	GHG Emissions (kt CO_2)														
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
CO_2 Transport and Storage (1.C)	NO	NO	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.22	0.27	0.27	0.28	0.28	0.49

Note:
NO = Not occurring

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

In addition to being a CO_2 EOR operation, Weyburn is also the site of a full-scale geological CO_2 storage research program led by the International Energy Agency's (IEA) Greenhouse Gas Research and Development Programme (IEAGHG) with the support of various industries, research organizations and governments. Modelling and simulation results from the first phase (2000 to 2004) of the IEAGHG's CO_2 monitoring and storage project, managed by the Petroleum Technology Research Centre (PTRC), indicate that after EOR operations are completed, over 98% of CO_2 will remain trapped in the Weyburn reservoir after 5000 years, with only 0.14% of the remainder released to the atmosphere (Mourits, 2008). Additional details on the findings of the research project are available on the PTRC website.

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

Some of the data associated with carbon capture cannot be disaggregated and fully reported under category 1.C. These emissions, including fugitive emissions from projects that use CO_2 injection to enhance oil production, appear in subcategories 1.B.2.a.2 oil – production, 1.B.2.c.1.i venting – oil and 1.B.2.c.2.i flaring – oil in the CRF table. The net impact of GHG emissions from all capture activities is included in Canada's inventory as part of the Energy Industries (1.A.1), Oil and Natural Gas (1.B.2) categories and CO_2 Transport and Storage (1.C).

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

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

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

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

3.4.1.1. Source Category Description

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

3.4.1.2. Methodological Issues

The 2006 IPCC Guidelines provide a Tier 1 methodology for emissions from pipeline transport of CO_2. Pipeline length from both the Canada/United States border to the Whitecap Resources EOR facilities at Weyburn and from Boundary Dam to Weyburn are approximately 60 km. The pipeline length between the Scotford refinery and the associated long-term geological storage site is about 80 km. The pipeline length between the Agrium facility and the associated EOR site is approximately 80 km. Emission calculations use the IPCC default medium emission factor of 0.0014 kt CO_2/km pipeline length/year.

3.4.1.3. Uncertainties and Time-Series Consistency

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

3.4.1.4. QA/QC and Verification

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

3.4.1.5. Recalculations

No recalculations were undertaken.

3.4.1.6. Planned Improvements

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

3.5. Other Issues

3.5.1. CO_2 Emissions from Biofuels: Biodiesel and Ethanol

As per UNFCCC reporting guidelines, a memo item reports CO_2 from sustainably produced biomass fuels combusted to produce energy, and the energy sector totals do not include these emissions. The Land Use, Land-use Change and Forestry (LULUCF) sector tracks the CO_2 as a loss of biomass (forest) stocks. The energy sector reports the CH_4 and N_2O emissions from biomass fuels in the appropriate categories.

3.5.1.1. Fuel Ethanol

Table 3–17 presents the quantities of fuel ethanol used in transportation. Analysis of the chemical properties of ethanol resulted in a higher heating value (HHV)[9] of 29.67 kJ/g, a carbon content of 52.14% and a density of 789.3 kg/m^3 (ECCC, 2017b).

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

3.5.1.2. Fuel Biodiesel

Table 3–18 presents the quantities of biodiesel used in transportation. A study conducted between 2004 and 2005 (BioMer, 2005) provided the properties used for biodiesel. Those properties include a HHV of 35.18 TJ/ML, with a carbon content of 76.5% and a density of 882 kg/m^3.

A portion of the total biodiesel is included in diesel fuel statistics provided by StatCan, but the extent of that coverage is uncertain. Therefore, the volumes of biodiesel consumed are in addition to the volumes of diesel fuel reported in the RESD to ensure that we have full coverage. To address the uncertainty around the coverage of biodiesel, StatCan has introduced a Monthly Renewable Fuels Survey (refer to section 3.2.4.6 for more information). Biodiesel was introduced and modelled as if it were mixed into the total fossil fuel-based diesel for the region(s). Total fuel available per province was allocated to each mode (on-road, by vehicle technology class, and off-road, railways and domestic marine as a whole) as per the percentage of total fossil fuel-based diesel fuel. In lieu of developing specific emission factors for CH_4 and N_2O for biodiesel, the representative fossil fuel-based diesel emission factor was applied as per mode and technology class. CO_2 emission factors used are those based on true chemical characteristics mentioned previously and a 100% oxidation rate.

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

Year	1990	2005	2013	2014	2015	2016	2017	2018	2019	2020
Ethanol Consumed (ML)	7	253	2 441	2 392	2 432	2 516	2 517	2 561	2 594	2 189

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

Year	1990	2005	2013	2014	2015	2016	2017	2018	2019	2020
Biodiesel Consumed (ML)	NO	NO	782	771	778	749	810	858	856	801

Note:
NO = Not occurring

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

INDUSTRIAL PROCESSES AND PRODUCT USE (CRF SECTOR 2)

4.1. Overview

This chapter covers greenhouse gas (GHG) emissions produced by various industrial processes that chemically or physically transform materials. These processes include the production and use of mineral products, metal production, chemical production, consumption of sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3), halocarbon production and use as substitutes to ozone-depleting substances (ODS), and non-energy products from fuels and solvent use.

GHG emissions from fuel combustion supplying energy to industrial activities are reported in the Energy sector (Chapter 3). In some cases, it is difficult to differentiate between emissions associated with energy and those produced by industrial process use of fuel. In such cases, and where industrial process use of fuel is predominant, the emissions are allocated to the Industrial Processes and Product Use (IPPU) sector. Emissions from the use of natural gas for hydrogen production in the upstream and downstream oil industries are accounted for in the Energy sector.

Greenhouse gas emissions from the IPPU sector contributed 50.3 Mt to the 2020 national GHG inventory (Table 4–1), compared with 56.6 Mt in 2005. IPPU emissions represented 7.5% of total Canadian GHG emissions in 2020. The contributing factors of the long-term and short-term trends in this sector are discussed in Chapter 2.

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

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

Greenhouse Gas Category	GHG Emissions (kt CO_2 eq)										
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
INDUSTRIAL PROCESSES AND PRODUCT USE	**57 000**	**58 400**	**54 100**	**56 600**	**50 700**	**53 500**	**54 500**	**52 700**	**53 900**	**53 500**	**50 300**
Mineral Products	**8 490**	**9 190**	**10 060**	**10 280**	**7 830**	**8 010**	**7 880**	**8 580**	**8 630**	**8 780**	**8 120**
Cement Production	5 820	6 530	7 230	7 610	6 010	6 180	6 110	6 830	6 910	7 130	6 620
Lime Production	1 810	1 900	1 920	1 750	1 420	1 410	1 380	1 420	1 390	1 340	1 190
Mineral Product Use	860	750	910	910	410	410	390	330	320	310	300
Chemical Industry	**17 550**	**18 510**	**8 790**	**10 430**	**5 820**	**6 800**	**7 020**	**6 420**	**6 810**	**6 710**	**6 590**
Ammonia Production	2 750	2 940	2 970	2 730	2 490	2 940	2 870	2 650	2 420	2 510	2 470
Nitric Acid Production	970	960	1 180	1 200	480	230	260	250	270	250	190
Adipic Acid Production	10 300	10 310	870	2 550	-	-	-	-	-	-	-
Petrochemical and Carbon Black Production (includes Carbide Production)	3 520	4 300	3 770	3 950	2 850	3 630	3 880	3 520	4 110	3 950	3 930
Metal Production	**23 770**	**23 490**	**23 370**	**20 230**	**16 030**	**14 430**	**15 350**	**14 600**	**14 540**	**13 870**	**12 990**
Iron and Steel Production	10 480	11 470	11 820	10 310	8 980	8 470	9 220	8 450	8 880	8 280	6 990
Aluminium Production	10 330	10 010	8 890	8 680	6 870	5 720	5 990	6 010	5 510	5 290	5 900
SF_6 Used in Magnesium Smelters and Casters	2 960	2 010	2 660	1 230	180	240	140	140	150	300	100
Production and Consumption of Halocarbons, SF_6 and NF_3	**980**	**500**	**2 790**	**5 120**	**7 740**	**11 100**	**11 360**	**11 150**	**12 210**	**12 170**	**12 000**
Non-Energy Products from Fuels and Solvent Use	**5 800**	**6 320**	**8 460**	**9 990**	**12 800**	**12 660**	**12 310**	**11 300**	**11 010**	**11 280**	**9 910**
Other Product Manufacture and Use	**370**	**390**	**610**	**540**	**430**	**540**	**600**	**630**	**700**	**660**	**730**

Note: Totals may not add up due to rounding.

Table 4–2 Impact of Recalculations from Revisions and Improvements

Greenhouse Gas Categories	GHG Emissions or Change in Emissions (Mt CO_2 eq), Selected Years									
	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
INDUSTRIAL PROCESSES AND PRODUCT USE										
Current (2022) submission	57.0	58.4	54.1	56.6	50.7	53.5	54.5	52.7	53.9	53.5
Previous (2021) submission	57.0	58.4	54.1	56.6	50.7	53.5	54.5	53.0	54.3	54.3
Net change in emissions	-0.1	-0.0	-0.0	-0.0	-0.0	+0.0	+0.0	-0.4	-0.4	-0.8
Mineral Products										
Current (2022) submission	8.5	9.2	10.1	10.3	7.8	8.0	7.9	8.6	8.6	8.8
Previous (2021) submission	8.5	9.2	10.1	10.3	7.8	8.0	7.9	8.6	8.7	8.8
Net change in emissions	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1
Chemical Industry										
Current (2022) submission	17.5	18.5	8.8	10.4	5.8	6.8	7.0	6.4	6.8	6.7
Previous (2021) submission	17.6	18.5	8.8	10.4	5.9	6.7	7.0	6.4	6.8	6.8
Net change in emissions	-0.1	-0.0	-0.0	-0.0	-0.0	+0.1	+0.1	+0.1	-0.0	-0.1
Metal Production										
Current (2022) submission	23.8	23.5	23.4	20.2	16.0	14.4	15.3	14.6	14.5	13.9
Previous (2021) submission	23.8	23.5	23.4	20.2	16.0	14.4	15.3	14.6	14.5	13.8
Net change in emissions	+0.0	+0.0	+0.0	+0.0	-0.0	-0.0	-0.0	-0.0	+0.0	+0.0
Production and Consumption of Halocarbons, SF_6 and NF_3										
Current (2022) submission	1.0	0.5	2.8	5.1	7.7	11.1	11.4	11.2	12.2	12.2
Previous (2021) submission	1.0	0.5	2.8	5.1	7.7	11.1	11.3	11.5	12.6	12.4
Net change in emissions	+0.0	+0.0	+0.0	-0.0	+0.0	+0.0	+0.0	-0.4	-0.3	-0.3
Non-Energy Products from Fuels and Solvent Use										
Current (2022) submission	5.8	6.3	8.5	10.0	12.8	12.7	12.3	11.3	11.0	11.3
Previous (2021) submission	5.8	6.3	8.5	10.0	12.8	12.6	12.3	11.3	11.0	11.6
Net change in emissions	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	-0.3
Other Product Manufacture and Use										
Current (2022) submission	0.4	0.4	0.6	0.5	0.4	0.5	0.6	0.6	0.7	0.7
Previous (2021) submission	0.4	0.4	0.6	0.5	0.4	0.6	0.6	0.7	0.7	0.8
Net change in emissions	+0.0	+0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1

Note: Totals may not add up due to rounding.

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

4.2.1. Category Description

Portland cement accounts for more than 90% of all cement produced in Canada, while the rest is masonry and other cement (Statistics Canada, n.d.[b]). The Cement Production category considers carbon dioxide (CO_2) emissions associated with the production of clinker, the precursor of Portland cement, and excludes other cement production (IPCC, 2006). There are 15 separate facilities that produce clinker in Canada, all of which use dry kilns. These facilities are located in Nova Scotia, Quebec, Ontario, Alberta and British Columbia.[1] Total clinker production capacity in Canada is approximately 18 Mt/year.

The Cement Production category accounted for 6620 kt (or 1.0%) of Canada's total emissions in 2020, a 13% decrease from 2005.

Emissions resulting from the combustion of fossil fuels to generate heat to drive the reaction in the kiln fall under the Energy sector and are not considered in this category.

4.2.2. Methodological Issues

CO_2 emissions from Cement Production were estimated for 1990–2016 using a modified Tier 2 method (Equation 4–1) that incorporates country-specific emission factors and emissions from carbon-bearing non-fuel materials (IPCC, 2006). For 2017–2020, CO_2 emission estimates came directly from the CO_2 emissions reported by Canadian cement production facilities to the Greenhouse Gas Reporting Program (GHGRP) (ECCC, 2021). The CO_2 emissions reported by cement production facilities to the GHGRP were calculated using a modified Tier 3 method (IPCC, 2006).

Equation 4–1

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

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

Disaggregated data on the composition of raw materials and clinker, the calcination degree of cement kiln dust (CKD), and the amount of bypass dust and CKD are not publicly available for 1990–2016. However, national aggregated data expressed as an annual calcination emission factor (EF_{cl}) and annual amounts of bypass dust and CKD are available from the Cement Association of Canada (CAC) for 1990, 2000 and 2002–2014 (CAC, 2014) and from the GHGRP for 2017–2020 (ECCC, 2021). These same quantities have been estimated for the remaining reporting years (1991–1999, 2001, 2015–2016). The CAC receives plant-based data from its member companies in accordance with the quantification method published under the umbrella of the Cement Sustainability Initiative of the World Business Council for Sustainable Development (WBCSD), CO_2 Emissions Inventory Protocol, Version 3.0. The protocol provides for two pathways for estimating process-related CO_2 emissions from the calcination of raw materials. The first is based on the amount and chemical composition of the products (clinker plus dust leaving the kiln system). The second is based on the amount and composition of the raw materials entering the kiln. Canadian cement production facilities report plant-based data to the GHGRP in accordance with section 4 of Canada's Greenhouse Gas Quantification Requirements.[2]

The CO_2 calcination emission factor, organic carbon emission factor, and CKD/bypass dust correction factor vary from year to year and is based on the available data from the CAC for 1990, 2000 and 2002–2014 and from the GHGRP facility-reported data for 2017–2020. 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]).

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

2 [ECCC] Environment and Climate Change Canada. Canada's greenhouse gas quantification requirements / Greenhouse Gas Reporting Program. 2021. [accessed 2022 Feb 04]. Available online at: http://publications.gc.ca/site/eng/9.866467/publication.html

Provincial/territorial emission estimates are apportioned from national emission estimates on the basis of the clinker production capacity of each province/territory for 1990–2016. The source of 1990–2006 data was the *Canadian Minerals Yearbook* (NRCan, 1990–2006). For 2007–2013, Natural Resources Canada provided capacity information directly via personal communication.[3] For 2014–2016, the Mining and Processing Division of ECCC provided clinker production capacity via personal communication.[4] For 2017–2020, provincial/territorial emission estimates are based on the emissions reported to the GHGRP by cement production facilities in each province/territory.

4.2.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty estimate has been developed on the basis of the default uncertainty values set out in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) for the parameters in the modified Tier 2 method and modified Tier 3 method. The error associated with the non-response rate of the Statistics Canada survey for clinker production data has also been considered in the uncertainty estimate. The Tier 1 uncertainty associated with the CO_2 emission estimates for clinker production has been calculated to be ±13.8% for 1990–2016 and ±8.5% for 2017–2020. Equation 3.1 from Volume 1, Chapter 3 (IPCC, 2006) has been applied over the time series. The activity data sources have changed over the time series from CIEEDAC publications to data collected by Statistics Canada, as described in section 4.2.2.

To address time-series consistency between the Tier 2 method applied for 1990–2016 and Tier 3 method applied for 2017–2020, splicing techniques were assessed from Volume 1, Chapter 5, Section 5.3.3 (IPCC, 2006) and a modified average splicing technique was chosen as being the most suitable. With this approach, the annual EF_{cl}, EF_{toc}, and CF_{ckd} for 2015–2016 were averages calculated based on the 2014 values provided by the CAC and the 2017 values calculated from the GHGRP facility-reported data. This modified average splicing technique was chosen because the country-specific EF_{cl}, EF_{toc}, and CF_{ckd} were last updated in 2014 by the CAC and the EF_{cl}, EF_{toc}, and CF_{ckd} calculated from the 2017 GHGRP facility-reported data were comparable with the EF_{cl}, EF_{toc}, and CF_{ckd} updated by the CAC in 2014. A similar approach was applied for 1990–2014 to ensure time-series consistency for the EF_{cl}, EF_{toc}, and CF_{ckd}. The CAC provided national cement production data for the calculation of EF_{cl}, EF_{toc}, and CF_{ckd} for years 1990, 2000 and 2002–2014 (CAC, 2014). The EF_{cl}, EF_{toc}, and CF_{ckd} for 1991–1999 were taken to be an average of the 1990 and 2000 EF_{cl}, EF_{toc}, and CF_{ckd}, while the EF_{cl}, EF_{toc}, and CF_{ckd} for 2002 was taken to be an average of the 2000 and 2002 EF_{cl}, EF_{toc}, and CF_{ckd}.

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

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

4.2.5. Category-Specific Recalculations

Recalculations for this category include updated GHGRP facility-reported data from the GHGRP for 2017–2019, updates to the CO_2 calcination emission factor, organic carbon emission factor and CKD/bypass dust correction factor for 2015–2016, and the Tier 3 calculation methodology corrected to subtract CO_2 emissions from CKD not recycled to the kiln in the calculation of the total CO_2 emissions from Cement Production. The magnitude of the 2015–2019 recalculations ranged from -65 kt CO_2 to -26 kt CO_2.

4.2.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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

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

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

4.3.1. Category Description

Dolomitic lime and high-calcium lime are both produced in Canada, and emissions from their production are accounted for in this inventory submission. Table 4–3 indicates the proportion of dolomitic and high-calcium lime in Canada. Information on hydraulic lime production in Canada is unavailable, and as a result its proportion of total lime production is assumed to be zero. There are 11 separate lime production facilities in Canada. These facilities are located in New Brunswick, Quebec, Ontario, Manitoba, Alberta and British Columbia. Total lime calcining capacity in Canada is approximately 3.1 Mt/year.

The Lime Production category contributed 1190 kt (0.2%) to Canada's total emissions in 2020, 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_2 emissions associated with the use of natural limestone for lime production in the pulp and paper industry are accounted for in the Other Limestone and Dolomite Use category (section 4.4).

4.3.2. Methodological Issues

A Tier 2 methodology (Equation 4–2) was used to estimate the CO_2 emissions from Lime Production for 1990–2016, where country-specific emission factors were applied to national activity data (IPCC, 2006). The country-specific emission factors for dolomitic lime and high-calcium lime were developed using information on Canadian lime compositions collected from the Canadian Lime Institute[5] and from annual averages of all lime production facilities in Canada that reported to the GHGRP for 2017–2020, which are provided in Annex 6. Data on total national lime production, hydrated lime production and lime plant calcining capacities were obtained from the *Canadian Minerals Yearbook* (NRCan, 1990–2006)[6] for the period up to and including 2006. In subsequent years, information was provided directly by Natural Resources Canada via personal communication.[7] For 2017–2020, CO_2 emissions came directly from the CO_2 emissions reported by lime production facilities in Canada to the GHGRP (ECCC, 2020). The CO_2 emissions reported by lime production facilities to the GHGRP were calculated using a modified Tier 3 method (IPCC, 2006) in accordance with section 3 of Canada's Greenhouse Gas Quantification Requirements.[8]

Equation 4–2

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

Q_i	=	production data of lime i, kt of lime i
EF_i	=	emission factor for lime type i produced in Canada, kt of lime i/kt CO_2
CF_{LKD}	=	correction factor that corrects for the loss of lime kiln dust, fraction
$CF_{hydrated}$	=	correction factor that corrects for hydrated lime, fraction

Canadian lime plants are classified into three types based on their final products: dolomitic lime only, high-calcium lime only, and both dolomitic lime and high-calcium. In the absence of disaggregated data on the breakdown of lime types for 1990–2016, a 15/85 value for dolomitic lime/high-calcium lime was assumed for lime plants that produced both high-calcium lime and dolomitic lime. Table 4–3 provides the breakdown between dolomitic lime and high-calcium Lime Production in Canada. National CO_2 emissions for 1990–2016 were calculated by applying the Canadian emission factors to the estimated annual national lime production data, by lime type.

The water content of Canadian hydrated lime is estimated to be 28.25%.[9] The water content of hydrated lime is deducted from national lime production to calculate the amount of "dry" lime production, which is broken down into dolomitic lime and high-calcium lime. Corresponding emission factors are subsequently applied.

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

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

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

8 [ECCC] Environment and Climate Change Canada. Canada's greenhouse gas quantification requirements / Greenhouse Gas Reporting Program. 2020. [accessed 2021 Feb 24]. Available online at: http://publications.gc.ca/site/eng/9.866467/publication.html

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

Table 4–3 **Split between Dolomitic and High-Calcium Lime Production in Canada (1990–2016)**

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

The lime kiln dust (LKD) correction factor was developed from annual averages of all lime production facilities in Canada as reported to the GHGRP for 2017–2020 and is applied for 1990–2016.

Provincial CO_2 emission estimates are apportioned from national emission estimates on the basis of the calcining capacity of each province/territory for 1990–2016. *The Canadian Minerals Yearbook* (NRCan, 1990–2006) provided data on calcining capacity for 1990–2006. For 2007–2013, Natural Resources Canada provided capacity information directly via personal communication.[10] For 2014–2016, the Mining and Processing Division of ECCC provided calcining capacity via personal communication.[11] For 2017–2020, provincial/territorial emission estimates are based on the emissions reported to the GHGRP by lime production facilities in each province/territory.

The decline in the share of dolomitic lime between 1999 and 2000 is the result of operational changes at two Ontario plants in that period. First, Guelph DoLime Limited, which produced only dolomitic lime up to 1999, ceased operations in 2000. Second, the Lafarge Canada quarry in Dundas switched from producing only dolomitic lime to both high-calcium lime and dolomitic lime in 1999–2000.[12] The slight decrease in the share of dolomitic lime in 2008–2009 is attributed to the closure of the Timminco Limited plant in Haley Station, Ontario that produced only dolomitic lime.

4.3.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty estimate has been developed on the basis of the default uncertainty values set out in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) for the parameters in the modified Tier 2 method and modified Tier 3 method. The Tier 1 uncertainty associated with the CO_2 emission estimates for Lime Production has been calculated to be ±33.2% for 1990–2016 and ±6.7% for 2017–2020. 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 2017–2020, splicing techniques were assessed from Volume 1, Chapter 5, Section 5.3.3 (IPCC, 2006) and a modified average splicing technique was chosen as being the most suitable. With this approach, the annual EF for dolomitic lime production (EF_{dol}) and the annual EF for high-calcium lime production ($EF_{h\text{-}c}$) for 2009–2016 are averages calculated based on the 2008 values provided by the Canadian Lime Institute and the 2017–2020 values calculated from the GHGRP facility-reported data. This modified average splicing technique was chosen because the country-specific EF_{dol} and $EF_{h\text{-}c}$ were last provided in 2008 by the Canadian Lime Institute, and the EF_{dol} and $EF_{h\text{-}c}$ calculated from the 2017–2020 GHGRP facility-reported data were comparable with the EF_{dol} and $EF_{h\text{-}c}$ provided by the Canadian Lime Institute in 2008. The 1990–2007 EF_{dol} and $EF_{h\text{-}c}$ were assumed to be the same as the 2008 EF_{dol} and $EF_{h\text{-}c}$ provided from the Canadian Lime Institute because no other national EFs were available from Canadian Lime Institute and were considered the most representative EFs for that time period. The source of activity data has changed over the time series from the Canadian Lime Institute to Natural Resources Canada, as described in section 4.3.2.

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

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

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

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

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

4.3.5. Category-Specific Recalculations

Recalculations for this category include updates to the LKD correction factor for 1990–2016. The magnitude of the recalculations ranged from -8 kt CO_2 to -4 kt CO_2 for 1990–2016.

4.3.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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

4.4.1. Category Description

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

In 2020, the aggregate category accounted for 300 kt (or 0.05%) of Canada’s total GHG emissions, with a decrease of approximately 67% in total emissions since 2005. Non-metallurgical Magnesia Production accounted for 38.5% of Mineral Product Use emissions, whereas Other Limestone and Dolomite Use, Other Uses of Soda Ash, and Glass Production contributed 32%, 15.5% and 14% of emissions, respectively.

Glass Production (CRF Category 2.A.3)

CO_2 emissions associated with soda ash and limestone consumed in Canadian glass production are included in this category. Soda ash has been the predominant source of CO_2 emissions from Glass Production throughout the entire time series.

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

The production of bricks, roof tiles, vitrified clay pipes, refractory products, expanded clay products, wall and floor tiles, table and ornamental ware, sanitary ware, technical ceramics, and inorganic bonded abrasives are included in the Ceramics Production category. Calcination of carbonates in the clay results in process emissions of CO_2.

To assess the significance of CO_2 emissions from Ceramics Production, emissions were estimated for 2005 to 2007 and for 2011 to 2020. For 2005 to 2007, national total annual amounts of clay used for ceramics were obtained from the *Canadian Minerals Yearbook* (NRCan, 1990–2008). Equation 2.14 of Volume 3, Chapter 2, Section 2.5.1.1 (IPCC, 2006), which is a Tier 1 method, was used to assess the emissions for these years. A default carbon content of 10% was applied to the annual amount of clay used to determine the mass of carbonate consumed (M_c). The M_c for each year from 2005 to 2007 was then multiplied by 85% of the default emission factor for limestone calcination and by 15% of the default emission factor for dolomite calcination to estimate the CO_2 emissions per year. For 2011 to 2020, industrial process emission estimates were obtained from major Canadian manufacturers of structural clay products via the Greenhouse Gas Reporting Program. The emission estimates for 2005 to 2007 ranged from 45 kt CO_2 in 2006 to 54 kt CO_2 in 2007 and for 2011 to 2020 ranged from 23 kt CO_2 in 2014 to 52 kt CO_2 in 2017, which were below 0.05% of Canada’s national total GHG emissions and did not exceed 500 kt CO_2 eq. Subsequently, CO_2 emissions from Ceramic Production are considered “insignificant” under paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. As of the 2020 inventory submission, they are reported in the CRF Reporter as “NE” (“not estimated”) with an explanation provided, in accordance with the ERT’s recommendation.

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

Soda ash is used in the production of chemicals, soaps and detergents, pulp and paper, flue gas desulphurization (FGD), and water treatment.

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

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

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

Limestone and dolomite are used in a number of industrial applications in Canada, including the production of cement, lime, glass, and iron and steel. The emissions associated with these industrial applications are reported within their respective categories.

The emissions included in the Other Limestone and Dolomite Use category are associated with other applications, such as its use in pulp and paper mills as makeup lime, and other chemical uses, including FGD and wastewater treatment.

4.4.2. Methodological Issues

Glass Production (CRF Category 2.A.3)

National CO_2 emissions from Glass Production are calculated using a Tier 1 method that applies the stoichiometric carbon emission factors to the estimated quantities of soda ash and limestone consumed in the production of glass.

The fraction of total soda ash use that goes to glass production in the United States is applied to the total Canadian soda ash consumption to obtain the quantity of soda ash used for glass production in Canada. The quantity of limestone consumed in glass production is based on limestone production statistics collected by Natural Resources Canada.[13]

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

CO_2 process emissions from Ceramics Production was determined to be insignificant under paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines, as described in section 4.4.1.

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

National CO_2 emissions are calculated using a Tier 1 method that applies the stoichiometry-based emission factor of 415 g CO_2/kg soda ash to the national consumption data, assuming 100% purity of soda ash used in Canada.

Soda ash consumption data has been estimated on the basis of soda ash production, import and export data.

Import and export data have been obtained from Global Trade Information Services (GTIS, 1995–2006, 2007–2009) and Statistics Canada's Canadian International Merchandise Trade Database (Statistics Canada, 2010–2020). The trade data for the years 1990–1994 was assumed to be the average of the 1995–2000 trade data, as GTIS commenced reporting trade data in 1995. The total quantities of soda ash used have been distributed by application type, on the basis of the U.S. pattern of soda ash consumption: glass, chemical, soaps and detergents, pulp and paper, FGD and other. Likewise, provincial emissions have been estimated by apportioning the national emissions according to the respective provincial gross output values of the same sectors.

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

A Tier 1 method is used to estimate CO_2 process emissions from the use of magnesite in magnesia production. The method applies an emission factor of 522 g CO_2/kg magnesite, on the basis of the stoichiometric quantity of carbon available in the magnesite and assumes the purity of magnesite to be 97% (AMEC, 2006). The emission factor is multiplied by facility-specific activity data to estimate CO_2 emissions at provincial and national levels.

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

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

The third plant has been operational for the full reporting period (1990–2020) and its annual activity data is sourced from British Columbia's Ministry of Energy and Mines (British Columbia Geological Survey, 2020).

13 Data for 1990–2006 is available in the Canadian Minerals Yearbook (NRCan, 1990–2006). Subsequent data has been provided by Natural Resources Canada via personal communication.

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

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

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

The emission factor used for Canadian limestone use is derived from the process stoichiometric ratio of 440 g of CO_2 per kilogram of pure limestone used, and is adjusted to consider a purity fraction of 95% (Derry Michener Booth and Wahl and Ontario Geological Survey, 1989). The Canadian emission factor is therefore 418 g CO_2/kg of limestone used (AMEC, 2006).

An overall emission factor of 468 g CO_2/kg of dolomite used was derived on the basis of the emission factors for pure limestone (440 kg CO_2/tonne) and magnesite (522 kg CO_2/tonne) and on the assumption that dolomite is composed of approximately 58% $CaCO_3$ and 41% $MgCO_3$ (AMEC, 2006).

For the years 1990 through 2006, data on raw stone use in iron and steel furnaces, non-ferrous smelters, glass factories, pulp and paper mills, and other chemical uses was gathered from the *Canadian Minerals Yearbook* (NRCan, 1990–2006). For subsequent years, information has been provided directly by Natural Resources Canada via personal communication. Moreover, data for stone used as flux in iron and steel furnaces for all years is disaggregated into limestone and dolomite on the basis of a 70/30 split (AMEC, 2006). Table 4–4 exhibits the split between consumption of high-calcium limestone and dolomite in the iron and steel sector, glass production, and other process uses of carbonates. National

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

CO_2 emissions are estimated by multiplying the quantities of limestone and dolomite consumed by the corresponding emission factors. The emissions are subsequently allocated to the respective reporting categories of Glass Production (CRF category 2.A.3), Iron and Steel Production (CRF category 2.C.1, refer to section 4.10), and Other Limestone and Dolomite Use (CRF category 2.A.4.d).

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

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

Provincial emission estimates have been obtained by apportioning the national emissions according to the sum of the provincial gross output values for the major sectors in which limestone and dolomite have been used (i.e., pulp and paper, non-ferrous metal, glass, and chemical sectors).

4.4.3. Uncertainties and Time-Series Consistency

Glass Production (CRF Category 2.A.3)

The Tier 1 uncertainty assessment of the Glass Production category considers uncertainties associated with the consumption data, emission factors, and assumptions for soda ash and limestone used in glass production. The overall uncertainty associated with the 2020 estimate is ±10.2%.

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

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

No uncertainty assessment was performed for this category because this category was determined to be insignificant under paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines, as described in section 4.4.1.

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

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

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

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

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

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

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

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

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

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

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

Categories under Mineral Product Use have undergone informal quality control checks throughout the emission estimation process.

4.4.5. Category-Specific Recalculations

For the Other Limestone and Dolomite Use category, updates to the activity data for 2019 resulted in a decrease of less than 1 kt CO_2.

4.4.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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

4.5.1. Category Description

The Ammonia Production category accounted for 2500 kt (0.3%) of Canada's emissions in 2020.

There are currently nine ammonia production plants[16] operating in Canada, located in Alberta, Saskatchewan, Manitoba and Ontario. Eight of these plants use steam-methane reformers to produce ammonia; most of which also recover CO_2 emissions to produce urea. The ninth plant uses by-product hydrogen (purchased from a neighbouring chemical plant) to feed into the Haber-Bosch reaction and is therefore assumed to have negligible process-related CO_2 emissions.

Urea production is a downstream process associated with ammonia production plants. The process recovers and uses the by-product CO_2 stream from the ammonia synthesis process. To avoid over-estimation of CO_2 emissions, the use of recovered CO_2 in urea production is accounted for as part of estimations for this category (see Equation 4–3). The use of urea as a fertilizer and its associated emissions are reported in the AFOLU sector, as per 2006 IPCC Guidelines (box 3.2 on page 3.16). Emissions from use of urea-based additives in catalytic converters are discussed in section 4.13 and reported in CRF category 2.D.3. Other uses of urea (e.g., its use as an ingredient in manufacturing of resins, plastics or coatings) were determined to be a significant source of emissions and are reported in CRF category 2.B.10.

4.5.2. Methodological Issues

The Ammonia Production category includes CO_2 emissions resulting from the feedstock use of natural gas and takes into account emissions that are recovered for use in urea production. A Tier 3 country-specific method is applied in accordance with the 2006 IPCC Guidelines (IPCC, 2006) for the years 2018 to 2020, while a Tier 2 country-specific method was applied for years 1990–2017. Collection of facility reported data from the federal Greenhouse Gas Reporting Program (GHGRP) allowed for sufficient information to transition into a Tier 3 approach for years 2018 and after. Since disaggregated activity data (i.e. natural gas used as feedstock and that used for energy purpose) are available, emissions resulting from the energy use of natural gas are accounted for in the Energy sector.

The feedstock use of natural gas is determined by multiplying the annual ammonia production by the calculated ammonia-to-feed fuel conversion factor that is specific to each facility for 1990 to 2017. The annual ammonia production data for 1990–2004 were gathered in a study conducted by Cheminfo Services (2006); that for 2005–2009 was collected by Environment Canada through a voluntary data submission process with the fertilizer industry; and that for 2008–2017 was obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey (Statistics Canada, n.d.[c]). The ammonia-to-feed fuel conversion factors were developed from the data collected between 2005 and 2009 as part of the voluntary data submission. For the 2005–2009 period, there were nine plants in operation (two others stopped operating in 2005). Seven of the nine plants (two of which have 2 units each) provided ammonia-to-feed fuel factors. Two of the nine plants did not provide such factors. Also to note is that one of the two plants did not use steam methane reforming and for the remaining facility with SMR, an average of the reported ammonia-to-feed fuel conversion factors was applied. At the plant level, the variability of the ammonia-to-feed fuel conversion factor is very steady, varying by less than 0.001% from year to year over the five years. Similarly, the average value varied by less than 0.001% from year to year over the five years. For the years 2018 to 2020, the natural gas quantity used as feedstock reported by facilities through the GHGRP was directly used in the CO_2 emission estimation.

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

The amount of natural gas used as feed is multiplied by a facility-specific natural gas carbon content factor (CCi) and default carbon oxidization factor (COF) (IPCC, 2006) to determine the resulting CO_2 emissions generated. All of the eight active facilities that use steam methane reformation have voluntarily confirmed or provided natural gas carbon content values used for estimating 1990 to 2017 emissions. Table 4–5 below shows a summary of description of these natural gas carbon contents.

In general, it is observed that natural gas carbon contents do not vary significantly from year to year and from facility to facility. The range of facility-confirmed natural gas content values is 0.49 to 0.54 kgC/kl feedstock, which is comparable to the values obtained through the GHGRP. For the three facilities that shut down prior to 2018, internally developed year- and province-specific carbon contents were used. Facility-reported carbon content values obtained through the GHGRP were applied for 2018 to 2020.

The amount of CO_2 recovered for urea production is then subtracted from the process-related emissions (Equation 4–3). Over the 1990 to 2017 time series, it is assumed that the urea production process consumes a stoichiometric quantity of CO_2 (i.e., 0.733 kg CO_2/kg urea) and that 5 kg of CO_2 are emitted per tonne of urea produced in accordance to the 2006 IPCC Guidelines. The resulting recovery factor ($RFCO_2$) is therefore 0.728 kg CO_2/kg urea. CO_2 recovered for urea production from 2018 to 2020 was directly reported by facilities through the GHGRP. For 1990–2007, urea production was estimated on the basis of actual ammonia production and the respective average ratio of ammonia- to-urea production for each plant. Urea production data for 2008–2017 was retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

Equation 4–3 **CO_2 Emissions from Ammonia Production**

$$E_{CO2} = \sum_i \frac{44}{12} \times NG_i \times CC_i \times COF - E_{CO2Urea\,i}$$

E_{CO_2}	=	national emissions of CO_2, kt
NG_i	=	natural gas used as feed of facility i, m^3
CC_i	=	carbon content factor of facility i, kt carbon/m^3 of natural gas
$44/12$	=	ratio of molecular weights, CO_2 to carbon
COF	=	carbon oxidation factor = 1 (unitless)
$E_{CO_2Urea\,i}$	=	CO_2 recovered for urea production of facility i, kt

Finally, the quantity of natural gas used to produce hydrogen for ammonia production was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double counting, the natural gas amounts allocated by Statistics Canada for hydrogen production are systematically removed from the non-energy use of natural gas reported under the Non-Energy Products from Fuels and Solvent Use category.

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

Table 4–5 **Description of 1990–2017 Natural Gas Carbon Content Values used in Ammonia Production Emission Estimation**

Active Facility	Time Period	Natural Gas Carbon Content Description
A	1990 to 2017	Facility confirmed the use of the average of 2018 to 2020 carbon contents reported to the GHGRP to be suitable.
B	1990 to 2017	Facility provided facility-specific average carbon content value (based 1998 to 2017 values).
C	1990 to 2017	Facility provided facility-specific average carbon content value (based on 2003 to 2017 values).
D	1990 to 2017	Facility provided facility-specific average carbon content value (based on 2004 to 2017 values).
E*	1990 to 2009	Facility confirmed the use of the average of 2018 to 2020 carbon contents reported to the GHGRP to be suitable.
	2010 to 2017	Facility provided facility- and year-specific carbon content values.
F	1990 to 2007	Facility provided facility-specific average carbon content value (based on 2008 to 2012 values).
	2008 to 2018	Facility provided facility- and year-specific carbon content values
G	1990 to 2017	Facility confirmed the use of the average of 2018 to 2020 carbon contents reported to the GHGRP to be suitable.
H	1990 to 2017	Facility suggested the use of annual provincial carbon content values. Internally developed annual and province-specific carbon content values found in Table A6.1-1 were used.

Note:

*Facility E provided carbon content values in KgC/KgFeedstock from 2010 to 2017. These values were converted to KgC/KlFeedstock based on the average of 2018-2020 reference temperature, the average of 2018-2020 pressure reported to the GHGRP and facility-specific molecular mass of natural gas provided by the facility from 2010 to 2017. The use of 2018-2020 average temperature and pressure have been confirmed to be suitable by the facility.

4

4.5.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Ammonia Production. The assessment took into account the uncertainties associated with the ammonia and urea production data, ammonia-to-feed fuel conversion factor and carbon content of natural gas. The uncertainty values associated with CO_2 emissions from the category as a whole vary over time from 6.4% to 8.6% in accordance with changes in natural gas volumes consumed for ammonia production and with changes in urea production.

To ensure time-series consistency, operating facilities were contacted and requested to confirm on a voluntary basis the suitability of the use of 2018 to 2020 facility-specific natural gas carbon content values for emission estimations of 1990 to 2017. As a result of this communication, either confirmation or year- and facility-specific values were obtained. Further details are provided in section 4.5.2 above.

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

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

4.5.5. Category-Specific Recalculations

The application of updated facility and/or province specific carbon content values for natural gas over the entire time series; and the transition from Tier 2 to Tier 3 methodology for years 2018 and onwards contributed to sector specific recalculations, ranging from -48 to +64 kt.

4.5.6. Category-Specific Planned Improvements

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

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

4.6.1. Category Description

Nitric acid is a chemical intermediate that is commonly used to produce ammonium nitrate fertilizers or explosives. The Nitric Acid Production category accounted for 189 kt of Canada's emissions in 2020, an 84% decrease from 2005. 14 nitric acid production lines (plants) at 9 facilities have been active over the time series (Cheminfo Services, 2006). In 2020, 8 plants were operational at 5 facilities. All operational plants currently have N_2O abatement systems installed.

Nitric acid is produced in two stages. In the first stage, ammonia is catalytically oxidized on a platinum-rhodium catalyst gauze, which produces nitrogen oxides (NO_x), notably, nitrogen dioxide (NO_2). In the second stage, the NO_2 is then absorbed into water in an absorption tower to produce nitric acid (HNO_3). During the oxidation of ammonia, some N_2O is produced as a by-product.

There are two basic types of nitric acid production process types: high pressure and dual pressure. Both technologies can be found in Canadian nitric acid plants. The high-pressure design, commonly used in North America, applies a single pressure throughout the oxidation and absorption stages. 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 4–6, 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 4–6 (Cheminfo Services, 2006).

The most commonly used N_2O abatement technology type at Canadian plants are non-selective catalytic reduction (NSCR) systems. The emission abatement systems are classified as "non-selective" when natural gas is used as a reductant to reduce nitrogen oxides (NO_x) and nitrous oxide (N_2O). In contrast, a selective catalytic reduction (SCR) system uses ammonia, which selectively reacts only with nitrogen oxide (NO) and nitrogen dioxide (NO_2) gases, and not with N_2O, hence a higher N_2O emission factor. NSCR systems are installed downstream of the absorption tower tail-gases. They are a considered a tertiary abatement measure when they are installed between the absorption column and the tail-gas expansion turbine, and a quarternary or end-of-pipe solution when installed downstream of the tail-gas expansion turbine prior to the stack (IPCC, 2006). 6 of the 8 active plants employ NSCR systems (Cheminfo Services, 2006).

Process-gas catalytic decomposition (PGCD) systems are also employed in some Canadian nitric acid production plants. These systems are a secondary abatement measure that consist of catalysts installed underneath the ammonia burner that catalyze the N_2O formed during the ammonia oxidation reaction. PGCD systems were installed retroactively in two operating plants in 2008[17] and 2012[18]. These installations are responsible for the majority of the emissions decrease observed between 2005 and 2020 in this category.

4.6.2. Methodological Issues

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

1. Tier 3 method: use of plant-specific production data and plant-specific emission factors or continuous emissions monitoring system (CEMS) data when these were available from companies; or
2. Tier 2 method: use of facility-specific (combined from multiple nitric acid plants at the same facility) or plant-specific production data and production technology-specific emission factors that are provided by plant technology vendors or national technology-specific average values when plant-specific emission factors were not available; or
3. Tier 1 method: use of estimated production data and either plant-specific or technology-specific emission factors

Table 4–6 **Nitric Acid Production Facilities in Canada**

Company	Location	Production Lines	Years in Operation during Time-Series	Process Type	N_2O Emission Controls	Production Data		Emission Factors		Emission Estimate Quality
						Estimated (allocation of national production)	Facility data	Country-specific (CS) or technology-specific	Facility data	IPCC Tier
Agrium Inc.	Redwater, AB	1	1990–2020	HP	NSCR	1991–1999	1990, 2000–2020	2005–2020	1990–2004	T1 (1991–1999) T2 (2005–2020) T3 (1990, 2000–2004)
Cominco Inc.	Calgary, AB	1	1990–1994	DP (M/H), EA2	None	1990–1994	N/A	1990	N/A	T1 (1990–1994)
Cyanamid Canada	Niagara Falls, ON	1	1990	HP	NSCR	1990	N/A	1990–1994	N/A	T1 (1990)
Dyno Nobel Nitrogen Inc.	Maitland, ON	3	1990–2010	HP	NSCR	N/A	1990–2010	1990–2010	N/A	T2 (1990–2010)
Koch Fertilizer Canada, ULC	Brandon, MB	3	Plant 1: 1990–2020 Plant 2: 1994–2020 Plant 3: 1997–2020	HP	NSCR	1991–1999, 2007	1990, 2000–2006, 2008–2020	1990–2020	N/A	T1 (1991–1999, 2007) T2 (1990, 2000–2006, 2008–2020)
Orica Canada Inc.	Carseland, AB	2	Plant 1: 1990–2020 Plant 2: 1998–2020	Plant 1: DP (M/H), EA1 Plant 2: HP	Plant 1: None (1990–2008), PGCD (2008–2020) Plant 2: None (1998–2012), PGCD (2012–2020)	N/A	1990–2020	Plant 1: 1990–2008 Plant 2: 1990–2012	Plant 1: 2008–2020 Plant 2: 2012–2020	Plant 1: T2 (1990–2008) T3 (2008–2020) Plant 2: T2 (1990–2012) T3 (2012–2020)
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	1990–2020	HP	NSCR	N/A	1990–2020	2005–2020	1990–2004	T2 (2005–2020) T3 (1990–2004)
Yara Belle Plaine Inc.	Belle Plaine, SK	1	2004–2020	HP	NSCR	N/A	2004–2020	2005–2020	2004	T2 (2005–2020) T3 (2004)

Note:

HP = Single high-pressure of 6.5–13 bar, held constant through oxidation and absorption stages

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

EA1 = Extended absorption by adding more trays in the absorption tower

EA2 = Extended absoprtion through the use of two absoprtion towers

NSCR = Non-selective catalytic reduction system located downstream of the absorption stage (reducing both NO_X and N_2O emissions)

PGCD = Process-gas catalytic decomposition (located beneath the ammonia burner used for the oxidation stage)

17 Orica. CSA Group Registries [last updated 2016 March 3; accessed 2022 February 8]. https://www.csaregistries.ca/files/projects/9238_1983_AEOR_OffsetProjectPlan_20160303_20210516.pdf.

18 Orica. CSA Group Registries [last updated 2014 January 23; accesses 2022 February 8]. https://www.csaregistries.ca/files/projects/7312-5550_GHGReport_20130101_201312312.pdf.

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

For 2005–2009, activity data was reported by companies to Environment and Climate Change Canada on a voluntary basis. Missing data from the voluntary survey was filled in using facility-level ICSR survey data when available. Rarely, when facility-level data was unavailable from voluntary surveys and the ICSR, the sum of known production data was subtracted from the published national total nitric acid production data, and the remainder was allocated to the plants with missing activity data based on their share of the national production capacity.

For 2010–2020, facility-level production data was obtained from Statistics Canada's ICSR survey. One facility reported their aggregated production to the ICSR using a start and end date that did not correspond to a calendar year. Plant-specific calendar year production information was obtained through a separate company data request for these years.

Tier 3 plant-specific emission factors or Continuous Emissions Monitoring Systems (CEMS) data were used to estimate emissions from five plants when available and applicable to the specific years of activity data. Those for years prior to 2005 were collected from facilities during the 2006 Cheminfo study (Cheminfo Services, 2006). CEMS systems were installed during the installation of PGCD emission control systems at two plants in 2008 and 2012. This 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 data, a Tier 2 method was used, using technology-specific emission factors provided by plant equipment vendors or the Canadian Fertilizers Institute. An average emission factor for high-pressure process plants with NSCR emission controls is available in Table A6.2–3. It should be noted that in order to ensure that confidential plant- or facility-specific production data is fully protected, it is not possible for Canada to specifically associate other plant-specific or production-technology specific emission factors with the plants.

4.6.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Nitric Acid Production. It takes into account the uncertainties associated with the national, facility, and plant-specific nitric acid production data and emission factors. The uncertainty values associated with N_2O emissions from the category as a whole vary from 2.0% to 2.5% between 1990–2007, and drops to 0.8% to 1.1% from 2012–2020. This is due to the replacement of the uncertainty of the Tier 2 equipment vendor emission factors with the uncertainty of the more precise Tier 3 continuous emissions monitoring system (CEMS) data. The emission factors are the largest contributors to the uncertainty for this category.

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

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

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

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

- ensure that activity data are for 100% HNO_3 product and are reported on a calendar year basis
- check new or revised activity data and CEMS-implied emission factors for unexplained inter-year differences that are greater than 10%, and contacting data sources for verification and explanation as required
- check that the sum of allocated activity data and the sum of facility-reported activity data sums to the published national activity data total (when applicable)
- check plant-specific emission factors, CEMS-implied emission factors, and technology-specific emission factors against those reported for similar plants and circumstances in other national inventories and the IPCC Emission Factor Database (EFDB)

4.6.5. Category-Specific Recalculations

2019 emissions were recalculated due to a facility identifying and revising an error in their CEMS report. The corrected estimates have decreased by 4.9 kt (1.9%) from the previous submission.

4.6.6. Category-Specific Planned Improvements

There are no planned improvements for this category.

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

4.7.1. Category Description

Invista Canada, formerly Dupont Canada, located in Maitland, Ontario, operated the only adipic acid production facility in Canada. A catalytic N_2O abatement system with an emission monitoring system was started up in 1997. However, the plant has not produced adipic acid since the spring of 2009; hence for years after 2009, both N_2O and CO_2 are indicated as "NO" in the CRF.

4.7.2. Methodological Issues

Emission estimates for adipic acid production were provided by the facility. For the 1990–1996 period, when no emission controls were in place, the reported emission estimates were calculated by multiplying the annual adipic acid production by the IPCC default generation factor of 0.3 kg N_2O/kg adipic acid.

Since 1997, the estimation method calculated emissions that occur when the abator is operating (Equation 4–5) separately from emissions that occur when the abator is not operating (Equation 4–6) due to maintenance or technical problems. The total emissions for the category are the sum of both operational modes, as shown in Equation 4–4.

Equation 4–4

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

N_2O Emissions with Abator:

Equation 4–5

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

Destruction Efficiency	=	determined on the basis of the difference between the amount of N_2O entering the abatement unit and that leaving the unit. It is a monthly average calculated using values recorded by analyzers located at the inlet and outlet of the abator. The targeted instantaneous destruction efficiency is 97%.
Abatement Utilization Ratio	=	number of hours during which N_2O goes through the abator divided by the total operating time.

N_2O Emissions without Abator:

Equation 4–6

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

Abatement Utilization Ratio	=	number of hours during which N_2O goes through the abator divided by the total operating time.

It is important to note that the in-line continuous emission monitor has never been used to directly monitor net N_2O emissions. This is because the analyzer is limited to accurately measuring relatively low concentrations of N_2O only when the reactor is online and abating N_2O gas. The analyzer is not capable of measuring the full range of N_2O concentrations that could potentially exist in the stack. The N_2O concentration can vary from a low nominal level of 0.3% when the stream leaves the abator to a high nominal level of 35% to 39% N_2O in the unabated stream. When the abatement reactor is bypassed, there is no N_2O abatement occurring and the analyzer will not record N_2O stack emissions (Cheminfo Services, 2006).

The calculation technique used to estimate emissions for the 1990–1997 period is in accordance with the Tier 1 method of the 2006 IPCC Guidelines (IPCC, 2006). For the period between 1998 and 2009, the estimation methods used for emissions with and without the abator aligned with a Tier 3 method when data was provided directly by the facility, otherwise a Tier 2 method was implemented (IPCC, 2006).

4.7.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Adipic Acid Production. It takes into account the uncertainties associated with the adipic acid production data, the emission factor, the destruction efficiency and the abatement utilization factor. The uncertainty associated with the category as a whole is evaluated at ±11%, with the emission factor being the largest contributor. The uncertainty value is applicable to all years of the time series.

As explained in section 4.7.2, two methods are applied in the time series: one for the period during which the plant operated **with** the emission abatement system and another for the period during which the plant operated **without** the emission abatement system.

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

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

4.7.5. Category-Specific Recalculations

There have been no recalculations for this category.

4.7.6. Category-Specific Planned Improvements

There are currently no improvements planned specifically for this category.

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

4.8.1. Category Description

Soda ash can be produced in the Solvay process in which sodium chloride brine, limestone, metallurgical coke and ammonia are used as the raw materials in a series of reactions. Although CO_2 is generated as a by-product during some of these reactions, it is recovered and recycled for use in the carbonation stage, i.e., CO_2 generation equals uptake (IPCC, 2006). Canada had a single operational Solvay -soda ash production facility between 1990 and 2001. There has been no production in Canada since 2001.

4.8.2. Methodological Issues

A Tier 1 method has been applied to estimate the CO_2 emissions potentially generated from the ash production process for the applicable reporting years (1990–2001). However, the net CO_2 emissions are considered negligible because the CO_2 resulting from the Solvay process was recovered for re-use and has been recorded as such in CRF Reporter category 2.B.7 (AMEC, 2006).

4.8.3. Uncertainties and Time Series Consistency

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

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

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

4.8.5. Category-Specific Recalculations

There have been no recalculations for this category.

4.8.6. Category-Specific Planned Improvements

There are currently no improvements planned specifically for this category.

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

4.9.1. Category Description

Carbide Production (CRF Category 2.B.5)

Two kinds of carbide are considered in this section: silicon carbide (SiC) and calcium carbide (CaC_2). SiC and CaC_2 are no longer produced in Canada; the last of two SiC plants closed in 2002 and the only CaC_2 plant closed in 1992.

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

Titanium dioxide (TiO_2) is one of the most commonly used white pigments. Its main use is in paint manufacture followed by paper, plastics, rubber production and other miscellaneous uses. There are two processes for producing TiO_2: the chloride process and the sulphate process. The sulphate process is known to not produce any significant process emissions (IPCC 2006).

According to the 2010 Cheminfo study, there is one TiO_2 producer in Canada. It has been using both the chloride and sulphate processes. During the study, production capacity data for both processes was provided, allowing for the assessment of the significance of emissions from this industry in Canada. Applying the default emission factor of 1.34 tonnes CO_2/tonne of TiO_2 to the 2009 production capacity data (latest available) gave a result that showed that CO_2 emissions from this facility's chloride process represented less than 0.02% of the national level and therefore were considered insignificant (i.e., level for insignificance is below 0.05% of national total and below 500 kt CO_2 eq). In accordance with the ERT's recommendation, as of the 2018 NIR submission, CO_2 emissions from this category are reported in the CRF Reporter as "NE" ("not estimated") and an explanation is provided.

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

There were three methanol production facilities operating in Canada between 1990 and 2006. One was closed in 2001, another in 2005 and the last in 2006. Methanol production in Canada ceased in 2006 but resumed in 2011 at one location.

Process GHG (CO_2, methane [CH_4] and N_2O) emissions result from process off-gas that is separated from methanol and combusted on-site for energy recovery. The process off-gas contains excess CO, CO_2 and light hydrocarbons. Additional CH_4 emissions can occur in venting of process gases containing CH_4 from the methanol distillation train and methanol storage tanks and from fugitive emissions from equipment leaks (Cheminfo Services 2010). N_2O emissions are reported in CRF category 2.B.10 Other (Methanol Production – N_2O Emissions).

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

There were five ethylene facilities in operation in Canada between 1990 and 2020, one of which began operating in 1994 and another of which shut down in 2008. The facilities consume fuels such as ethane and propane in the production of ethylene through steam cracking. Process CO_2 and CH_4 emissions are reported in CRF category 2.B.8.b and N_2O emissions are reported in CRF category 2.B.10 Other (Ethylene Production – N_2O Emission).

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

Three ethylene dichloride production (EDC) facilities operated in Canada for different periods between 1990 and 2006; all plants are currently closed, with the last one closing in 2006.

Two processes had been used for the production of EDC in Canada. The first is the direct chlorination of ethylene in a vapour or liquid phase reaction using ethylene dibromide as catalyst. The second process is called oxychlorination.

In terms of emissions, the process off-gas that contains the chlorinated hydrocarbons is combusted within the plant prior to release, so any carbon in this off-gas is converted to CO_2. The process CO_2 emissions from EDC production come from the side reaction of feedstock oxidation. The process CH_4 emissions would most likely come from light hydrocarbons from distillation operations that are not captured by a flare gas recovery system. These emissions are vented to the atmosphere (Cheminfo Services, 2010).

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

Ethylene Oxide is a chemical intermediate that is used in the manufacture of glycols, including monoethylene glycol. In 1990, there were three plants operating in Canada. One small plant closed in 1993, and two began operation in 1994 and 2000, for a total of four operational plants in 2020. The four plants are owned by three companies, one of which is a 50% joint venture of one of the other two companies. CO_2 emissions are a by-product of the direct oxidation of the ethylene feedstock and are dependent on the selectivity of the process. CH_4 is used to carry all reaction gases through the process. It can be emitted through the ethylene oxide process vent, the purification process exhaust gas stream, and as fugitive.

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

Four facilities produced carbon black in Canada between 1990 and 2020, three of which are currently operating. CO_2, CH_4 and N_2O emissions can arise from carbon black production. It should be noted that N_2O emissions are reported in CRF category 2.B.10 Other (Carbon Black Production – N_2O Emissions), whereas CO_2 emissions are included in CRF category 2.D (Non-Energy Products from Fuels and Solvent Use). Because CRF category 2.D cannot be disaggregated, CO_2 emissions from carbon black production are reported as "IE" ("included elsewhere") in the CRF Reporter.

Styrene Production (CRF Category 2.B.8)

Three styrene facilities produced styrene in Canada between 1990 and 2020, one of which closed in 1998. CO_2 and CH_4 emissions can arise from styrene production. It should be noted that CO_2 emissions are included in CRF category 2.D (Non-Energy Products from Fuels and Solvent Use) and CRF category 2.D cannot be disaggregated. Therefore, CO_2 emissions from styrene production are reported as "IE" in the CRF Reporter.

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

During the manufacture of chlorodifluoromethane (HCFC-22), trifluoromethane (HFC-23 or CHF_3) is generated as a by-product (IPCC, 2006). Two HCFC-22 producers (Dupont Canada and Allied-Signal) operated in Canada in the 1980s and early 1990s, but production ended in 1992. In Canada, there has been no manufacturing or import of equipment containing HCFC-22 as of January 1, 2010 (HRAI, 2008). HFC-23 releases as a by-product of HCFC-22 production were 971 kt, 1,057 kt and 830 kt (in 1990, 1991 and 1992, respectively). There has been no known production of sulphur hexafluoride (SF_6) or perfluorocarbons (PFCs) in Canada throughout the time series.

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

The Other Uses of Urea category takes into account potential emissions from urea used as an ingredient in the manufacturing of resins, plastics, and coatings products. To determine the amount of Other Uses of Urea, the total quantity of urea produced at ammonia plants is balanced with the urea that is imported to and exported from Canada, the quantity used for agriculture, and the estimated amount of urea-based additives required in catalytic converters for vehicles.

4.9.2. Methodological Issues

Carbide Production (CRF Category 2.B.5)

Tier 1 IPCC default emission factors were applied to estimate CH_4 emissions from carbide production. A study was commissioned to identify and establish the production capacities of the three carbide production facilities in Canada. A time series of process CH_4 emissions was estimated for the two silicon carbide facilities from 1990 to 2001 and for one calcium carbide facility from 1990 to 1991 on the basis of assumed capacity utilization and CH_4 emission factors. Only production capacity data (SiC and CaC_2) over the time series was identified in the study. The following equation was used to estimate total CH_4 emissions from carbide production:

Equation 4–7

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

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

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

To assess the emission significance of this category as per the ERT's recommendation, the 2009 (latest available) production capacity data for the chloride process was multiplied by the 2006 IPCC default emission factor of 1.34 tonnes CO_2/TiO_2 produced.

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

When available, facility-reported CO_2, CH_4 and N_2O emissions data was included in this submission. The remaining emissions were estimated using a Tier 2 approach where reported facility production data and emissions were used to derive a country-specific emission factor for CO_2, CH_4 and N_2O. National methanol production values are taken from Camford's CPI Product Profile for 1990–1999 and estimated on the basis of assumed capacity utilization for 2000–2006 (Cheminfo Services 2010). The methanol production data is considered confidential from 1990–2006 and as such has been aggregated for those years under Category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) and Category 2.B.10 Other (Confidential Petrochemicals - N_2O Emissions).

Methanol production restarted in Canada in 2011 in a facility that had previously been included in the inventory. The same country-specific emission factors were applied to the facility's publicly reported production data for 2011 (Cheminfo Services 2015). For 2012–2020, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

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

Two consulting studies were commissioned to evaluate CO_2, CH_4 and N_2O emission sources in Canadian petrochemical production as well as the quantity of fuels consumed as feedstocks. The latter was required to differentiate the emissions associated with petrochemical production (CRF category 2.B.8) from the emissions associated with non-energy uses of fuels (CRF category 2.D).

As part of the first study (Cheminfo Services 2010), a questionnaire was sent on behalf of Environment Canada to the four companies that have had ethylene production operations in Canada. Three of the four operating plants responded to the voluntary questionnaire request, representing 90% of Canadian ethylene production capacity in 2009. The data provided included emissions and production values for the years 2007 to 2009 and was used to develop the facility-level N_2O emission factors. The second study (Cheminfo Services 2015) examined the fuels consumed by Canadian ethylene producers over the 1990–2014 period and derived facility-level emission factors for CO_2 and CH_4 on a year-by-year basis. The two emission factors change over time in step with changes to the feedstocks consumed in Canadian ethylene production.

National ethylene production data is taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. For 2008–2020, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. The facility-specific emission factors applied are treated as confidential since they are derived from business-sensitive data. However, average industry-wide emission factors are recorded in Annex 6.

When process GHGs were reported directly by a facility, the reported data was used in the inventory. When reported emission data is not available, estimated emissions are calculated using the estimated ethylene production (allocated to each non-reporting facility by share of capacity) and the corresponding plant-specific emission factors. N_2O emissions for 2007 and 2008 were reported under Category 2.B.10 Other (Confidential Petrochemicals - N_2O Emissions) due to confidentiality of carbon black production data.

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

CH_4 emissions from ethylene dichloride (EDC) production for 1990–2006 were developed through a consulting study. Since all EDC plants are currently closed and no survey response could be provided for historical data, a Tier 1 calculation approach (i.e., annual production multiplied by the Tier 1 IPCC default emission factor) was taken to develop 1990–2006 process CH_4 emission estimates. The annual EDC production data comes from the Canadian C2+ Petrochemical Report, which was prepared and published by an independent consultant who supplies market intelligence to the Canadian chemical industry. It provides balances of ethylene and its derivatives using total production, dispositions and Canadian trade statistics. The default process CH_4 emission factor for EDC was derived from the integrated EDC/VCM factor in Table 3–19 of the 2006 IPCC Guidelines, using the EDC/VCM process Tier 1 feedstock consumption factor for a balanced process. For the purpose of emission estimation at the provincial level, the annual EDC production was allocated by Cheminfo Services to each plant on the basis of the capacity share (calculated from production capacity data reported by companies during the Cheminfo Services [2010] study). Due to the confidentiality of activity data, CH_4 emissions are reported under CRF Category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions).

Ethylene Oxide (CRF Category 2.B.8)

CO_2 and CH_4 emissions from the production of Ethylene Oxide were estimated using a 2006 IPCC Tier 1 method, which involved multiplication of annual production quantity by the default emission factors. The appropriate Tier 1 CO_2 and CH_4 emission factors used were selected from Tables 3.20 and 3.21 of the 2006 IPCC Guidelines based on consultant knowledge of the industry (Cheminfo, 2010).

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

National production data for the years 1990 to 2009 were obtained through the Canadian C2+ Petrochemical Report, as part of the 2010 Cheminfo Study. National production data was distributed to plants and used for calculating plant-specific emissions based on their share of the national production capacity. For years 2016 onwards, the activity data source was plant- or company-specific production data reported to Statistics Canada's Industrial Chemicals and Synthetic Resins (ICSR) Survey. In 2016, all plants reported their production independently to the ICSR. In 2017 and 2018, one company reported the total combined ethylene oxide production for their two plants. The combined production was distributed based on the 2016 contributions of the respective plants to the company production total. In 2019 and 2020, the same company did not report ethylene oxide production to the ICSR survey and explained that they had stopped tracking production data on ethylene oxide since it is an intermediate product. To fill in the missing production data, Statistics Canada imputed production data by deflating the company's 2019 and 2020 shipment data (monetary) provided to their Annual Survey of Manufacturing and Logging (ASML) to calculate real growth from 2018. The deflated growth rates were applied to the 2018 reported production data to calculate 2019 and 2020 production data, which was then distributed to the two plants based on the 2016 (latest available) contributions of the respective plants to the company total. Production data from 2010 to 2015 were linearly interpolated to complete the time series.

To protect confidential ethylene oxide activity data, CH_4 emissions are reported in Category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) for the entire time series. In addition, 1990–2006 CO_2 emissions are reported in Category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) to protect confidential methanol activity data.

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

CH_4 and N_2O emissions from carbon black production were estimated in 2010 through a consulting study. A survey requesting 1990–2009 data on carbon black capacity and production and on process GHG emissions was sent to the three operating carbon black facilities. All three facilities reported 1990–2009 data for carbon black capacity, but not all facilities reported process emissions.

From the received responses, two facility-level Tier 3 emission factors for CH_4 were derived as weighted averages of the reported 2007–2009 data. Two sector-wide process emission factors, one for each CH_4 and N_2O, were also calculated as weighted averages using the same set of data reported by the two facilities (1.3 kg CH_4/t product and 0.032 kg N_2O/t product).

The sector-wide CH_4 EF value is lower than the IPCC default value of 11 kg CH_4/t product. It is suspected that the IPCC default EF, which is based on only one study, has included CH_4 from the combustion of fuel as well. The Canadian EF only includes the CH_4 that originates directly from the feed.

Sector-wide emission factors are applied when facility-level emission factors cannot be used. When process emissions are reported directly by a facility, the reported data is used in the inventory. However, when reported emission data is 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 is 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 2010–2020 is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

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

Styrene Production (CRF Category 2.B.8)

Process CO_2 emissions can come from the combustion of the process off-gas (fuel gas) as fuel or from flaring of over-pressured process streams. CH_4 could be present along with the process reactants ethylene and benzene and would be emitted if there is any venting of these process or recycle streams. Fugitive emissions from these streams would also contain methane (Cheminfo Services, 2010).

In the absence of data from operating facilities, a Tier 1 approach was taken to develop process CH_4 emission estimates. Annual styrene production data was retrieved from the Canadian C2+ Petrochemical Report. For the purpose of emission estimation at the provincial level, the annual styrene production is allocated to each plant on the basis of capacity share for years 1990–2009. Due to the unavailability of 2010 and 2011 production data, these data years are assumed to be equal to 2009 production. For years 2012–2020, production data is retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

The default process CH_4 emission factor for styrene (4 kg/t) comes from Table 2–10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997). As the 2006 IPCC Guidelines do not cover styrene production under its petrochemicals section, a more recent emission factor cannot be found.

Table 4–7 **Categories Included in Confidential CRF Node**

	1990–2006	2007–2008	2009–2020
Methanol	CO_2, CH_4, N_2O	-	-
Ethylene	-	N_2O	-
Ethylene dichloride and vinyl chloride monomer	CH_4	-	-
Ethylene oxide	CO_2, CH_4	CH_4	CH_4
Carbon black	CH_4, N_2O	CH_4, N_2O	-
Styrene	CH_4	CH_4	CH_4

Note:
- indicates no aggregation is occuring

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CH_4 emission values are reported under 2.B.8.g Other (Confidential Petrochemicals– CO_2 and CH_4 Emissions) for the entire time series to protect confidential styrene activity data.

Activity data for several petrochemical categories contain confidential data that needs to be protected for certain years within the time series. Table 4–7 summarizes, by period of the time series, the categories that need to have their associated GHG emission estimates aggregated in the CRF reporting. CO_2 emissions and CH_4 emissions are aggregated under category 2.B.8.g Other (Confidential Petrochemicals – CO_2 and CH_4 Emissions) and N_2O emissions are aggregated under category 2.B.10 Other (Confidential Petrochemicals – N_2O Emissions).

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

To estimate HFC-23 emissions from HCFC-22 production, the total HCFC-22 production was multiplied by the IPCC Tier 1 default emission factor of 0.04 t HFC-23/t HCFC-22 produced (IPCC, 2006). It was assumed that destruction (through thermal oxidation) or transformation of HFC-23 was not practised in Canada. The 1990–1992 production data was collected by Environment Canada from HCFC producers[19].

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

There is no available methodology in the IPCC 2006 Guidelines for the estimation of emissions coming from other uses of urea. Because it is believed that the Canadian context would be similar to that of the United States for this category, the Canadian methodology (see Equation 4–8) was derived from that described in the U.S. National GHG Inventory[20].

Equation 4–8

Total CO_2 emissions (t) =

$$[U_{production} - U_{fertilizer} + U_{imports} - U_{exports} - (U_{UAN\ fertilizer} - U_{UAN\ imports}) - U_{UAN\ exports} - U_{SCR}] \times EF$$

$U_{production}$	=	Urea produced in Canada (t)
$U_{fertilizer}$, $U_{UAN\ fertilizer}$	=	Urea applied as fertilizer (t) from urea and urea-ammonium-nitrate (UAN)
$U_{imports}$, $U_{UAN\ imports}$	=	Urea imported to Canada (t) as urea or urea-ammonium-nitrate (UAN)
$U_{exports}$, $U_{UAN\ exports}$	=	Urea exported from Canada (t) as urea or urea-ammonium-nitrate (UAN)
U_{SCR}	=	Urea used as an additive in catalytic converters (t)
EF	=	0.733 t CO_2 emitted per t urea

National total urea production data for 2008–2017 was retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. National total urea production data for 2018–2020 was retrieved by summing the facility-reported production to the Greenhouse Gas Reporting Program (ECCC, 2021). For 1990–2007, urea production was estimated on the basis of actual ammonia production and the respective average ratio of ammonia to urea production for each plant. The plant production totals were summed to determine the national total urea production. Emissions (5 kg CO_2 / t) from the production of urea have been accounted for in CRF category 2.B.1, Ammonia Production.

Nationally complete import and export data for urea and urea-ammonium-nitrate from 1990–2020 were obtained from Statistics Canada's Canadian International Merchandise Trade Web Application[21].

Provincial-level data for quantities of urea and urea-ammonium-nitrate used as fertilizer were obtained from the AFOLU sector and summed to determine the national total. Lastly, national totals for urea used as an additive in catalytic converters was calculated based on the estimated emissions, which are discussed in section 4.14 and reported in CRF category 2.D.3.

It is assumed that any urea that is not used as a fertilizer, as an additive for selective catalytic converters, or that is not exported in the same year is used as an ingredient in manufacturing of resins, plastics or coatings. It is also assumed that all the carbon contained in the urea used for other uses is released in the same year as its production or import. A complete urea balance was provided to and reviewed by the ERT to respond to an ERT comment during the inventory review that took place in 2021.

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

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

21 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

To estimate the CO_2 emitted from Other Uses of Urea, an emission factor of 0.733 kg CO_2 emitted/kg of urea used is applied. This factor is the stoichiometric quantity of CO_2 required to produce urea, assuming the complete conversion of ammonia and CO_2 to urea (IPCC, 2006). The same factor is used as the emission factor based on the assumption that all CO_2 contained in the manufactured urea gets emitted upon use.

4.9.3. Uncertainties and Time-Series Consistency

Carbide Production (CRF Category 2.B.5)

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

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

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

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the Titanium Dioxide Production category following the 2006 IPCC Guidelines. The uncertainty estimate for the 2009 estimate was ±15%. However, the uncertainty estimate associated with this category is not taken into account in the overall uncertainty assessment in Annex 2, because this category was determined to be insignificant.

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

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

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

The uncertainty associated with the category as a whole for the time series ranged from ±7% to ±20% for CH_4 emissions, from ±11% to ±30% for N_2O emissions and from ±4% to ±11% for CO_2 emissions.

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

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

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

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

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

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

Ethylene Oxide (CRF Category 2.B.8)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the Ethylene Oxide Production subcategory following the 2006 IPCC Guidelines and all years of the time series have been assessed.

As no plant-specific uncertainty estimates could be collected by Cheminfo Services (2010), uncertainties based on expert knowledge of the industry were used in the analysis. The uncertainty associated with the category range from ±30.5% to ±38.8% for CH_4 emission estimates, and from ±7.5% to ±9.8% for CO_2 emission estimates.

The interpolation method used for the missing data gap (2010 to 2015) is consistent with the 2006 IPCC Guidelines, Volume 1, Chapter 5 (IPCC, 2006).

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

A Tier 1 uncertainty assessment was performed by Cheminfo Services for the Carbon Black Production subcategory following the 2006 IPCC Guidelines. In the Cheminfo Services (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided uncertainty estimates for their data. As a result, uncertainties based on expert knowledge of the industry were used in the analysis.

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

Styrene Production (CRF Category 2.B.8)

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

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

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

Uncertainty in the HFC-23 emission estimates has not been assessed. However, it is believed that the production data reported by HCFC-22 producers was reasonably accurate. A significant source of uncertainty could be attributed to the Tier 1 default emission factor, which does not reflect facility-specific conditions, as the correlation between the quantity of HFC-23 emitted and the HCFC-22 production rate can vary with plant infrastructure and operating conditions (IPCC, 2006). The IPCC 2006 Guidelines state that a 50% uncertainty factor for a Tier 1 HFC production estimate may be appropriate.

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

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

The assessment took into account the uncertainties associated with urea production data, import and export data, urea used in agriculture data, urea used in catalytic converters, and the urea-to-CO_2 conversion factor. In addition, it was assumed that the uncertainty associated with the calculated value of urea available in one year for other uses was high due to the assumption that all the urea is converted to CO_2, regardless of the type of final product. The overall uncertainty associated with CO_2 emission estimates from other uses of urea ranged from ±6.5% to ±10.0%.

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

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

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, 2021) to the published national production totals from Statistic Canada's Industrial Chemicals and Synthetic Resins survey to ensure that activity data is complete

Emission estimates of the other two GHGs (i.e., CH_4 and N_2O) for the same categories and CO_2 emission estimates for the Titanium Dioxide Production category have undergone informal quality control checks.

4.9.5. Category-Specific Recalculations

Ethylene Oxide (CRF Category 2.B.8)

Ethylene Oxide emissions were recalculated for 2019 due to a new Statistics Canada missing data imputation method based on using deflated shipment data as a surrogate instead of using the inter-year production changes of another company. This decreased emissions by 11 kt CO_2 eq (1.7%).

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

Recalculations were performed for 2008–2019 for Other Uses of Urea emissions. These recalculations range from -0.045 Mt (9% in 2019) to 0.00012 Mt (0.02% in 2018) due to revisions of estimates of urea used as fertilizer for 2019, revised urea and urea-ammonium-nitrate fertilizer mix import and export data for 2019, revised urea production data for 2018 and 2019, and revised estimates for urea used as diesel exhaust fluid in selective catalytic reduction (SCR) vehicles for 2008 to 2019.

4.9.6. Category-Specific Planned Improvements

The latest data available for estimating emissions from Titanium Dioxide Production is from 2009. A data collection is being planned to ensure inventory completeness of all related activities in the 2006 IPCC Guidelines (titanium slag, synthetic rutile, and the chloride process), assess recent production information, and gather facility-specific emissions information for a Tier 2 approach (if possible).

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

4.10.1. Category Description

The Iron and Steel Production category contributed 6985 kt (1%) to Canada's total emissions in 2020, a 32% decrease from 2005.

There are four integrated iron and steel mills in Canada, all located in Ontario. One of the mills uses the electric arc furnace (EAF) process to produce a portion of its steel. Annex 3.3 provides additional detail on the technologies employed in Canada to produce iron and steel.

In the production of pig iron, carbon plays the dual role of fuel and reductant. Emissions from the combustion of fuels such as coke oven gas are not reported in this category, but rather under the appropriate industrial category in the Energy sector.

Total emissions in the Iron and Steel Production category is the sum of emissions from the following sources:

- CO_2 emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron
- CO_2 emissions during steel production, which occur to a much lesser extent (these come from the oxidation of carbon in crude iron and electrode consumption)
- CO_2 emissions given off by limestone flux in the blast furnace
- CH_4 emissions from metallurgical coke use (as a reductant)

4.10.2. Methodological Issues

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

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

Equation 4–9

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

E_{CO2_PI}	=	process emissions from pig iron production, kt
EF_{met_coke}	=	year-specific emission factors (t CO_2/ t metallurgical coke used)
M_i	=	mass of i used or produced, kt; where i is metallurgical coke, ore
CC_i	=	carbon content of i, %; where i is metallurgical coke, pig iron;
P_{PI}	=	production of pig iron, kt
$44/12$	=	ratio of the molecular weight of CO_2 to the molecular weight of carbon

For the purposes of calculating emission estimates for this category, it was assumed that the reductant used in the Canadian industry is 100% metallurgical coke (Cheminfo Services, 2010). The GHG emissions associated with the use of reductants other than metallurgical coke are estimated under the appropriate industrial category in the Energy sector.

The data source for the use of metallurgical coke was the *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada, 1990–2020). Data on total pig iron production in Canada came from Statistics Canada for 1990–2003 and 2004–2012 (Cat. No. 41-001 and 41-019, respectively), from the Canadian Steel Producers Association (CSPA) for 2013–2016, and the Greenhouse Gas Reporting Program (GHGRP) for 2017–2020 (ECCC, 2021). The Pig iron CRF category (2.C.1.b) includes iron production from both the blast furnace and the direct reduction process and at this time, cannot be disaggregated due to confidentiality concerns.

The emission factors for coke use (EF_{met_coke}) from 1990–2009 are year-specific and come from the Cheminfo Services (2010) study. In that study, Cheminfo Services surveyed four integrated steel mills in Canada for their coke consumption and emission estimates for the years 1990 to 2009. The emission factors were calculated as ratios of CO_2 emissions to coke consumption. The Canada-specific coke (EF_{met_coke}) emission factors for 2010–2016 was estimated as an average of the 2009 value from Cheminfo Services (2010), and the yearly national average of GHGRP data for the years 2017–2019 (ECCC, 2021). The emissions factor of coke for 2017–2020 was the year-specific national average of facility provided data, as reported to the GHGRP (ECCC, 2021). The coke carbon content was then applied to the coke use data provided by Statistics Canada. With respect to the carbon content of pig iron, CSPA[22] provided an industry-average content value that was used for 1990–2016. The national annual weighted average of facility reported carbon content of pig iron was used for 2017–2020, as per GHGRP (ECCC, 2021).

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

Equation 4–10

$$E_{CO_2\_steel} = [CC_{iron} \times M_{iron} + CC_{scrap\ steel} \times M_{scrap\ steel} - CC_{BOF} \times M_{BOF} - CC_{EAF} \times M_{EAF}] \times 44/12 + EF_{EAF} \times P_{EAF} + EF_{BOF} \times P_{BOF}$$

$E_{CO_2\_steel}$	=	process emissions from steel production, kt
CC_j	=	carbon content of i, %—where j is the pig iron charged, or scrap steel charged in either the electric arc furnace (EAF) or basic oxygen furnace (BOF)
M_j	=	mass of j used, kt
$44/12$	=	ratio of the molecular weight of CO_2 to the molecular weight of carbon
EF_k	=	emission factors (t CO_2/ t steel produced)
P_k	=	steel production by either EAF or BOF, kt

According to Equation 4–10, part of the CO_2 emitted from the steel production process is estimated on the basis of the difference between the amount of carbon in the iron and in scrap steel used to make steel and the amount of carbon in the steel produced in basic oxygen furnaces (BOFs) and electric arc furnaces (EAFs). It should be noted that the amount of pig iron fed to steel furnaces (used in Equation 4–10) is not equal to the amount of total pig iron production (used in Equation 4–9). As part of the steel production process, emissions are also generated by the consumption of electrodes in EAFs and in secondary ladle metallurgy. These are accounted for in the last two terms of the equation.

Data on the total pig iron and scrap steel charged to steel furnaces, and on the amount of steel produced in EAFs and BOFs was obtained from Statistics Canada for 1990–2003 and 2004–2012 (Cat. No. 41-001 and 41-019, respectively), from CSPA for 2013–2017 and from GHGRP for 2018–2020. The facility-specific emission factors from the GHGRP are treated as confidential, since they are derived from business-sensitive data. However, a range of national emission factors and carbon contents are available in Annex 6, based in part, on the CSPA[23], and in part on the annual averages for all facilities in Canada as reported to the GHGRP from 2017–2020 (ECCC, 2021).

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

CH_4 emissions were estimated on the basis of the mass of metallurgical coke used (Statistics Canada 1990–2020) multiplied by an emission factor. The emission factor value for CH_4 emissions from coke use in the iron and steel industry is not presented in this report to protect the confidentiality of the data.

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

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

Data on provincial-level metallurgical coke use from RESD (Statistics Canada, 1990–2020) was used to distribute national-level emissions to the applicable provinces.

It should be noted that RESD data published for any given year is preliminary and subject to revision in subsequent publications. The use of petroleum coke in EAF electrodes is reported by Statistics Canada with all other non-energy uses of petroleum coke. To avoid double counting, the CO_2 emissions from the consumption of electrodes in the steel production process in EAFs are therefore subtracted from the total non-energy emissions. It is assumed that there are no imported electrodes used for steel production in EAFs in Canada. If electrodes are imported, the portion of CO_2 generated by the imported electrodes needs to be subtracted from the emissions from electrode consumption before being subtracted from the total non-energy emissions.

4.10.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Iron and Steel Production. It took into account the uncertainties associated with all the parameters used in estimating emissions of each source in this category, such as data on metallurgical coke use, the emission factor of coke, data on pig iron and steel production, the carbon content of pig iron and steel, limestone data and associated emission factors. The assessment also considered the error associated with the non-response rate of the Statistics Canada surveys. The uncertainties for CO_2 and CH_4 emission estimates associated with this category are ±5.56% and ±405%, respectively.

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

Iron and Steel Production (CO_2) is a key category that has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

4.10.5. Category-Specific Recalculations

CO_2 emissions for this category were recalculated due to a small correction of the emission factor for steel production using a basic oxygen furnace and the carbon content of scrap steel. Additionally, there was a revision to the RESD amount of metallurgical coke used for iron production in 2019. The magnitude of the recalculations ranged from +0.1 to +14 kt CO_2 eq and impacted the time series from 2013–2019.

4.10.6. Category-Specific Planned Improvements

As noted earlier, a smaller part of the process CO_2 emissions associated with iron and steel production originates from the use of reductants other than metallurgical coke, namely natural gas and coal. This fuel data is from the RESD, and owing to its aggregated format, it is currently not possible to allocate the appropriate portion to CRF category 2.C.1, Iron and Steel Production.

Natural gas used as a reductant in the production of direct-reduced iron (DRI) and coal used in pulverized coal injection (PCI) in blast furnaces are currently reported in the Energy sector (as combustion emission sources in Iron and Steel Production). Also, a fraction of coal (aggregated with non-energy fuels in RESD) used in iron and steel making is currently reported under the Non-Energy Products from Fuels and Solvent Use category (section 4.14).

As supporting information (to disaggregate RESD fuel data) becomes available, it is planned to allocate the aforementioned emissions to CRF category 2.C.1, Iron and Steel Production.

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

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

4.11.1. Category Description

The Aluminium Production category accounted for 5901 kt (0.9%) of Canada's emissions in 2020, representing an overall decrease in emissions of 32% since 2005.

Emissions from the combustion of fossil fuels used in the production of baked anodes are covered in the Energy sector, but emissions arising specifically from the combustion of volatile matter released during the baking operation and from the combustion of baking furnace packing material are accounted for under the Aluminium Production category (IPCC 2006).

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In addition to CO_2 emissions, primary aluminium smelting is a source of carbon tetrafluoride (CF_4) and carbon hexafluoride (C_2F_6), both of which are included in this submission. This submission also includes a small amount of SF_6 that is emitted from its use as cover gas as well as a degassing (purifying) agent at some aluminium plants that produce high magnesium-aluminium alloys[24]. The consumption of SF_6 is highly variable depending on whether one or both of these operations (SF_6 use as a cover gas and/or purifying agent) occur within a given year causing significant changes in the trend of SF_6 in this source category.

Aluminium plants are characterized by the type of anode technology employed. In general, older plants using Søderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The last Søderberg aluminium smelter in Canada was closed in 2015[25], and the 10 plants currently in operation have focused on modernizing their facilities and improving production efficiency.

4.11.2. Methodological Issues

As of 2013, Canada's aluminium companies, which operate in Quebec and British Columbia, have developed and reported their GHG emissions under the methodological protocols and reporting rules of the Western Climate Initiative, which are consistent with the methods presented in the 2006 IPCC Guidelines. Under a memorandum of understanding signed in 2006 between Environment Canada and the Aluminium Association of Canada (AAC), Environment Canada receives the same data sets as those provided by AAC member companies in the provinces. As of the data year 2018, aluminium companies have been reporting their emissions directly to ECCC's GHGRP (ECCC 2021), methods of which are also consistent with the 2006 IPCC Guidelines.

The process-related emission estimates for aluminium production are directly obtained from AAC. In addition to the smelter-specific emission estimates, information on the methodologies used by the aluminium producers to calculate CO_2, PFC and SF_6 emissions and plant-specific production data for the time series are also obtained from AAC. According to the methodology documents supplied by the AAC, SF_6 emissions are equal to consumption in the aluminium industry.

Depending on data availability for each year in the time series, the estimation techniques applied vary between Tiers 2 and 3 and depend on the individual facility. To summarize, all facilities in Canada have reported CO_2 emissions at a Tier 3 level since 2017, PFC emissions at a Tier 3 level since 2016 and SF_6 emissions at a Tier 3 level for the entire time series. Table 4–8 presents Canada's individual Aluminium facilities and when facilities were able to transition from a Tier 2 level estimate to a Tier 3 level using plant-specific parameters. When plant-specific data was not available, companies have used Quebec's Framework Agreement or International Aluminium Institute (IAI) EFs as the default (Alcan 2010).

Table 4–8 **Aluminium Facilities in Canada: Method Tier and Emission Factor Information**

Aluminium Facility	Years in Operation	CO_2		PFC		SF_6	
		Method / EF		Method / EF		Method	EF
		T2 / CS	T3 / PS	T2 / CS	T3 / PS		
Rio Tinto							
Usine Isle-Maligne	1990–2000	1990–2000	N/A	1990–2000	N/A	T3	PS
Usine de Bauhamois	1990–2009	1990–2009	N/A	1990–2009	N/A	N/A	N/A
Usine Grande-Baie	1990–2020	1990–2007	2008–2020*	1990–1995	1996–2020	T3	PS
Jonquière	1990–2004	1990–2004	N/A	1990–2004	N/A	N/A	N/A
Usine Arvida	1990–2020	1990–2007	N/A	1990–2006	2007–2020	T3	PS
AP-60	2013–2020	N/A	2013–2020	2013–2015	2016–2020	T3	PS
Usine Laterrière	1990–2020	1990–2007	2008–2020	1990–2013	2014–2020	T3	PS
Usine Shawinigan	1990–2013	1990–2007	2008–2013	1990–2013	N/A	N/A	N/A
Usine Alma	2000–2020	2000–2007	2008–2020*	2000–2007	2008–2020	T3	PS
Kitimat	1990–2020	1990–2007	2008–2020*	1990–2006	2007–2020	T3	PS
Alcoa							
Usine Becancour	1990–2020	1990–2016	2017–2020*	1990–2004	2005–2020	T3	PS
Usine de Baie-Comeau	1990–2020	1990–2016	2017–2020	1990–2003	2004–2020	T3	PS
Deschambault	1993–2020	1993–2016	2017–2020*	1990–2004	2005–2020	T3	PS
Alouette							
Sept-Iles	1992–2020	1992–1994	1995–2020	1990–2004	2005–2020	T3	PS

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

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

25 Banville J. 2020. Personal communication (email from Banville J to Au A, Environment and Climate Change Canada, dated June 15, 2020). Environment and Climate Change Canada, Environmental Protection Branch.

4.11.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the Aluminium Production category (i.e., for the CO_2, PFC and SF_6 emission estimates). It takes into account the uncertainties associated with all the parameters used to calculate the emissions. The *Aluminium Sector Greenhouse Gas Protocol* (IAI, 2006) was the main source of uncertainty values for parameters. The uncertainties for the CO_2, PFC and SF_6 estimates are ±7%, ±9% and ±5%, respectively. For the CO_2 and PFC estimates, it should be noted that the uncertainty assessment is done for only one year of the time series (2006 for CO_2 and 2007 for PFC). It is expected that emission estimates of more recent years would have similar uncertainties, while older estimates would have higher uncertainties. For the SF_6 estimate, it is assumed that the uncertainty is equivalent to the 2006 IPCC default for a Tier 2 method Magnesium Casting category, since the method used to develop SF_6 emission estimates is the same for both Aluminium Production and Magnesium Casting.

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

CO_2 and PFC emissions from Aluminium Production are key categories that have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

4.11.5. Category-Specific Recalculations

There were no recalculations for this category.

4.11.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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

4.12.1. Category Description

SF_6 is emitted during magnesium production and casting, where it is used as a cover gas to prevent oxidation of the molten metals. SF_6 is not manufactured in Canada and is solely imported.

During the 1990–2006 period, there were two major magnesium producers in Canada: Norsk Hydro and Timminco Metals. Norsk Hydro closed in the first quarter of 2007 and Timminco closed in August 2008. Another magnesium producer, Métallurgie Magnola, operated between 2000 and 2003, but closed in April 2003. Between 1990 and 2004, Norsk Hydro had invested in research and development projects designed to find a substitute for SF_6 and eventually eliminate the use of SF_6 as a cover gas at its plant[26]. This research, as well as the use of substitute gas mixtures, produced significant reductions in SF_6 emissions in the mid- to late 1990s. The significant increase in magnesium production across 1999–2000, noted in an ERT's review comment, was the consequence of a new facility beginning operation in 2000 and the other two facilities increasing their SF_6 use by more than 30% between 1999 and 2000. For 2005–2007, Norsk Hydro's SF_6 emissions were significantly reduced as a result of the gradual reduction in production and the plant's closure in 2007.

There were 11 magnesium casting companies in operation during the 1990–2004 period (Cheminfo Services, 2005b). Only a few of them had used SF_6 every year during the entire period. Some casters started using SF_6 towards the mid- or late 1990s, whereas others replaced it with an alternative gas, such as sulphur dioxide (SO_2). During the 2005–2008 period, only seven companies were in operation and had used SF_6. Two companies shut down their magnesium casting operations at different times in 2009 (one in June and one in December), one of which moved its operations to the United States.

It is estimated that the remaining five magnesium casting companies in operation released about 102kt CO_2 eq in 2020 (< 0.1% of Canada's emissions).

Following comments received from the ERT in 2017, emissions from magnesium casting previously reported in CRF category 2.C.7 are reported altogether with SF_6 emissions coming from primary magnesium production in CRF category 2.C.4 since the 2018 inventory submission.

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

4.12.2. Methodological Issues

SF_6 emissions from magnesium production for 1999–2007 were directly reported by the companies (Norsk Hydro, Timminco Metals and Métallurgie Magnola Inc.) to Canada's National Pollutant Release Inventory (NPRI). Emission estimates used in this report are obtained from the NPRI's online database (Environment Canada, 1990–2007). For previous years (i.e., 1990–1998), the data was provided voluntarily by the producers to Environment Canada through personal communication. Since there was no reported 2008 data for Timminco, its 2008 SF_6 value was estimated on the basis of its 2007 data and the number of months of operation in 2008 (i.e., seven months). For 2009 onwards, since there have been no magnesium production plants operating in Canada, there has been no need to perform any data collection.

Norsk Hydro and Timminco were contacted in 2006 regarding the methodology they had applied to estimate SF_6 emissions. Both companies reported that they had estimated emissions based on the assumption that SF_6 emissions are equivalent to SF_6 consumption. However, they used different methods for estimating their SF_6 consumption. Norsk Hydro confirmed the use of the weight difference method[27], which involves measuring the weight of gas cylinders used at the facility at the time of purchase and at the time they are returned to suppliers at the end of their usage. Timminco reported using the accounting method for estimating its SF_6 use[28]. In this method, accounting of delivered purchases and inventory changes of SF_6 used are recorded. The purchases must be the actual volumes received in the calendar period; therefore, beginning-of-year and end-of-year inventories are taken into account.

The technique applied to estimate emissions from magnesium production is considered to be a Tier 2 type method, as it is based on the reporting of facility-specific emission data.

The approach for estimating SF_6 emissions from casting companies assumes all SF_6 used as a cover gas is emitted to the atmosphere. SF_6 use data for the 1990–2020 time series came from a combination of data sources. There were 11 casting companies that operated over 1990–2004. Two companies closed in 2000 and two other companies closed in 2003. The majority of the companies have provided SF_6 consumption data through the Cheminfo Services study (2002) and the Cheminfo Services (2005b) study. Interviews were also conducted with companies that did not complete the Cheminfo studies to collect data.

For 2005–2007, SF_6 consumption data was provided by all seven operating casting companies through a voluntary data submission process. They were used for the calculation of emissions. For 2008, data was made available by six of the seven casting companies through the voluntary data submission process. For the remaining company, it was assumed that its 2008 SF_6 use stayed at the 2007 level. For 2009, communication was established with all seven companies. Two of the companies, for which magnesium casting operations had shut down in 2009, were not able to report their 2009 SF_6 use data, but provided reasonable assumptions that could be used to estimate the 2009 SF_6 use. SF_6 use data for 2009 was provided by the other five companies. For 2014 to 2019, SF_6 use data was provided by four out of five operating magnesium casting companies through a voluntary data collection. For 2020, two out of five companies provided SF_6 data through a voluntary data collection, while two other companies reported their SF_6 emission data through the GHGRP. In the case where SF_6 use data was not available for a company during the years 2010 to 2020, SF_6 emissions were estimated based on provincial gross output data. More specifically, a ratio of "provincial gross output for a year with no facility-specific SF_6 use data" to "provincial gross output for the most recent year for which the facility provided SF_6 use data" was calculated. SF_6 emissions (for the years with no SF_6 use data) were then estimated by multiplying the ratio by the most recent facility-specific SF_6 emission value.

SF_6 consumption was estimated by companies using a variety of methods, with the accounting method being the most common. Other methods include: prorating based on production, inventory weighing, inventory difference and derivation of an annual consumption based on the quantity of bottles of SF_6 consumed over a time period within the year. The technique applied to estimate emissions from magnesium casting for 1990–2004, 2008–2009 and 2010–2020 for facilities where SF_6 use data was estimated based on provincial gross output data or derived from reported magnesium casting production values is considered to be of Tier 2 type (IPCC, 2006). For 2005–2007 and 2010–2020 for facilities that provided SF_6 data directly, the emission estimation method is of Tier 3 type.

4.12.3. Uncertainties and Time-Series Consistency

A combined Tier 1 uncertainty assessment was performed for Magnesium Production and Magnesium Casting. It took into account the uncertainty associated with the SF_6 data reported by each facility. The uncertainty varied from ±2.6% to 20.9% from 1990 to 2020.

The methodology, which equates consumption of SF_6 as a cover gas to emissions of SF_6, is applied over the time series with some assumptions for some historical years, as discussed in the methodology section.

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

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

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

The Magnesium Production category has undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as outlined in Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. There is a step (step 4.4) in Canada's current QC process for detecting large fluctuations (e.g., in production or in implied emission factors).

The Magnesium Casting category has undergone informal quality control checks.

4.12.5. Category-Specific Recalculations

Emission estimates for 2010 to 2019 were recalculated for Magnesium Casting due to updates in gross output data and inclusion of updated SF_6 use data provided by the operating magnesium casting facilities.

The changes were between -3.0 kt to +5.7 kt.

4.12.6. Category-Specific Planned Improvements

There are no planned improvements for magnesium production.

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

4.13.1. Category Description

Emissions from lead and zinc production occur in Canada due to the use of reductants in the sintering or smelting processes. However, CO_2 emissions are not estimated because production data is currently unavailable for the entire time series. Future improvements include identifying production data for the entire time series, along with the type of processes used in Canada and relevant information on source and quantity of reductants for disaggregation from emissions of Category 2.D.3 Other (Other and Undifferentiated).

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

4.14.1. Category Description

Non-Energy Products from Fuels and Solvent Use (CRF Category 2.D.3)

The Non-Energy Products from Fuels and Solvent Use category includes emissions from the non-energy use of fossil fuels that are not accounted for under any of the other categories of the IPPU sector. The following are examples of fuels in non-energy applications: the use of natural gas liquids (NGLs) and refinery output as feedstocks in the chemical industry and the use of lubricants such as engine oil and grease in transportation and industrial applications, with "use" defined as "close-to-production" consumption of fuel, e.g., burning of motor oil in the engine's combustion chamber (excludes waste oil incineration, which is allocated to the Waste sector). All of these activities result in varying degrees of oxidation of the fuel, producing CO_2 emissions. Also included in this category are emissions from the use of hydrocarbons (such as coal) as reductants for base metal smelting as well as petroleum-based solvents, cleaners and paint thinners.

The use of fossil fuels as feedstock or for other non-energy purposes is reported in an aggregated manner by Statistics Canada as "non-energy use" for each individual fuel. In the event that CO_2 emissions resulting from non-energy fuel use are allocated to another category of the IPPU sector (as is the case for Ammonia Production, Petrochemical Production, Iron and Steel Production, and Aluminium Production), those emissions are subtracted from the total emissions from this category to avoid double counting. Additional details on the method used to calculate emissions from this category can be found in Annex 3, section A3.3.3.

The Non-Energy Products from Fuels and Solvent Use category contributed 9909 kt (1.5%) to Canada's total emissions in 2020, a 0.8% increase from 2005.

Efforts have been made to examine the possibility of disaggregating lubricating oils and greases from the Non-Energy Products from Fuels and Solvent Use category and reporting the associated CO_2 emissions under CRF category 2.D.1, instead of CRF category 2.D.3. However, results of the examination show that reporting CO_2 emissions coming from use of lubricating oil and greases as a separate CRF category can lead to disclosure of confidential activity data. Hence, these emissions are kept in CRF category 2.D.3.

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles (CRF Category 2.D.3)

Selective catalytic reduction (SCR) is an emission reduction technology that can use urea as a liquid-reducing agent to help reduce NO_x emissions from vehicle exhaust. CO_2 emissions from the use of urea-based additives in the catalytic converters are considered non-combustive emissions.

4.14.2. Methodological Issues

Non-Energy Products from Fuels and Solvent Use (CRF Category 2.D.3)

Emission factors for non-energy use of fuels were developed on the basis of the total potential CO_2 emission rates and percentages of carbon stored in products. The total potential CO_2 emission factors were derived from the carbon emission factors shown in Jaques (1992), McCann (2000) and CIEEDAC (2006), which are EFs based on natural units of fuel; the IPCC provides energy unit-based EFs. The fractions or percentages of carbon stored used are IPCC default values (IPCC/OECD/IEA, 1997; IPCC, 2006), which are used to determine the “oxidized during use” (ODU) factor (1 minus the percentage of carbon stored).

The types of non-energy fuels that are included in the estimation model for the Non-Energy Products from Fuels and Solvent Use category are outlined in Table 4–9.

Fuel quantity data for non-energy fuel usage was reported by the RESD (Statistics Canada, 1990–2020). It should be noted that RESD data for any given year is preliminary and subject to revisions in subsequent publications. This data was multiplied by the emission factors shown in Annex 6 to estimate CO_2 emissions for this category. For example, to estimate emissions coming from non-energy use or oxidation of petroleum products, such as petroleum used for other products, RESD data was multiplied by the potential CO_2 emission factor and by the ODU factor (which is 1 minus percentage of carbon stored). The percentage of carbon stored in petroleum used as other products, which includes waxes, paraffin and unfinished products, was determined to be equivalent to the default factor from the revised 1996 IPCC Guidelines and not that for paraffin wax as per the 2006 IPCC guidelines, because the disaggregation of paraffin wax use is not possible.

This technique is consistent with the method described in the 2006 IPCC Guidelines and is considered to be a Tier 1 type method as it is based on the use of national consumption data and average national emission factors. Emissions of CH_4 and N_2O for CRF category 2.D.3 are not estimated because there is no methodological guidance provided in the 2006 IPCC Guidelines.

Table 4–9 **Non-Energy Fuel Types Used in the Canadian GHG Inventory**

Gaseous Fuels	Solid Fuels	Liquid Fuels
Natural gas	Canadian bituminous coal	Propane
	Sub-bituminous coal	Butane
	Foreign bituminous coal	Ethane
	Lignite	Petrochemical feedstocks
	Anthracite	Naphthas
	Metallurgical coke	Lubricating oils and greases
	Petroleum coke	Petroleum used for other products[a]

Note:
a. Other products include waxes, paraffin and unfinished products (items that cannot be identified in end-product terms).

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction Vehicles (CRF Category 2.D.3)

The 2006 IPCC Guidelines recommend that Equation 3.2.2 (Volume 2) be used for the estimation of emissions from the use of urea-based additives in catalytic converters.

For estimating emissions from this source, road transportation activity data must be considered. More specifically, vehicle population, fuel consumption ratios and kilometre accumulation rates are used to determine the amount of diesel consumed by these vehicles and consequently the volume of urea-based diesel exhaust fluid (DEF) additive consumed by their SCR catalyst. For more information on the sources of this information, refer to Annex 3.1.

To determine the portion of the fleet employing this technology (technology penetration ratio), vehicle certification and regulatory data is used to identify the vehicles equipped with SCR. The Canadian Vehicles in Operation Census and R.L. Polk & Co.'s database for light-duty and heavy-duty vehicles, respectively, were consulted to calculate the annual technology penetration ratios.

A dosing rate representing 2% of the diesel consumption has been employed as it is the midpoint of the range suggested in the 2006 IPCC Guidelines. Additionally, the default DEF purity of 32.5% was corroborated at Environment Canada's national vehicle emission testing facility, where concentration measurements were taken with a refractometer as part of its testing program[29].

4.14.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Non-Energy Products from Fuels and Solvent Use. The assessment took into account the uncertainties associated with the activity data and emission factors (ICF Consulting, 2004). The uncertainty for the category as a whole was estimated at ±20%. It should be noted that the uncertainty assessment was done for only one year of the time series (2007).

A Tier 1 uncertainty assessment was performed for the category of CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles. The overall uncertainty was found to be ±50%.

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

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

The category of CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles has undergone informal quality control checks throughout the emission estimation process.

4.14.5. Category-Specific Recalculations

For the Non-Energy Products from Fuels and Solvent Use category, CO_2 emissions were recalculated due to a correction in the amount of petroleum coke consumed in the Iron and Steel sector, which contributed to minor recalculations for the time series from 2013 to 2019. There were also recalculations in 2018 and 2019 due to revisions of activity data. The overall impact of all revisions ranges from +0.1 kt to -381 kt.

Revised activity data caused recalculations ranging from -0.003 kt in 2009 to 0.18 kt in 2019, for the category of use of urea in SCR vehicles.

4.14.6. Category-Specific Planned Improvements

Emission factors for various non-energy petroleum products and natural gas were developed based on studies conducted in 1992 and 2005, respectively. There is a plan to evaluate whether these emission factors are still valid and to update them if necessary. In addition, as supporting information becomes available (i.e., information that would allow disaggregation of fuel data and allocation to the appropriate source category) for other (more specific) categories (e.g., iron and steel production), emissions in the Non-Energy Products from Fuels and Solvent Use category will be revised to avoid double counting of emissions and to improve transparency in the inventory.

There is no planned improvement for estimating CO_2 from use of urea in SCR vehicles.

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

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

4.15.1. Category Description

Industrial processes related to the electronics industry in Canada include the use of Perfluorocarbons (PFCs), SF_6 and NF_3 in semiconductor manufacturing and in electronics industry quality control testing. This subsector does not include emissions of SF_6 used in electrical equipment or PFCs used as electrical insulation or as a dielectric coolant, as these are included under Other Product Manufacture and Use (CRF subsector 2.G).

It is estimated that emissions from the electronics industry in Canada accounted for about 47 kt CO_2 eq in 2020, a 443% increase from 2005.

4.15.2. Methodological Issues

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

The activity data for PFC usage in the semiconductor industry was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRF category 2.F; refer to section 4.17. In addition, some users of PFCs for semiconductor manufacturing from the 2014–2020 gas distributor surveys were independently surveyed and provided annual use quantities for processes. There are two main uses of PFCs in the semiconductor manufacturing industry in Canada: plasma etching of silicon wafers and plasma cleaning of chemical vapour deposition (CVD) chambers.

Over the time series, three PFCs have been used for semiconductor manufacturing: perfluoromethane (CF_4), perfluoroethane (C_2F_6), and perfluorocyclobutane (c-C_4F_8). Use of C_2F_6 in semiconductor processes produces emissions of C_2F_6 as well as by-product emissions of CF_4. Use of c-C_4F_8 in semiconductor processes produces emissions of C_4F_8 and by-product emissions of CF_4 and C_2F_6.

The IPCC Tier 2 methodology, as shown in Equation 4–11, was used to estimate PFC emissions from the semiconductor manufacturing industry:

Equation 4–11

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

$E_{SC,PFC}$	=	total PFC emissions from PFC use in semiconductor manufacturing
E_{FC}	=	emissions resulting from the use of PFCs (see IPCC 2006 Volume 3, Equation 6.2)
E_{CF_4}	=	CF_4 emitted as a by-product during the use of PFCs (see IPCC 2006 Volume 3, Equation 6.3)
$E_{C_2F_6}$	=	C_2F_6 emitted as a by-product during the use of PFCs (see IPCC 2006 Volume 3, Equation 6.4)

Process-specific Tier 2b emission factors were used when information on process use was available from semiconductor manufacturing facilities or gas distributors. When the process use of the gas was unknown, Tier 2a emission factors were used. Default Tier 2a and Tier 2b emission factors used in IPCC 2006 equations 6.2, 6.3, and 6.4 are found in Table 6.3 of the 2006 IPCC Guidelines. The subset of emission factors used for estimating Canadian emissions are presented in Table A6.2-10.

The heel (h) value, which is the amount assumed to remain in the purchased canister after use, was assumed to equal 0.1, as suggested in the 2006 IPCC Guidelines. The heel value was not applied when semiconductor users provided data on PFCs fed into processes based on weighing canisters before and after use. As no information on emission control technologies for these processes in Canada was available for 1990–2013 data years, it was assumed that no emission control technologies were used. Two facilities provided annual gas-specific and process-specific values for the fraction of gas volume fed into process types with emission control technology and the fraction of gas destroyed by the emission control technology (respectively a_i and d_i in the IPCC Guidelines) for 2014–2020 data years. These fractions were used to estimate emissions from these facilities and these data years only. For all other 2014–2020 users, since no information on emission control technologies was available, it was assumed that none were used.

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

In 2013, Environment Canada commissioned a study to determine the extent of NF_3 usage in Canada, including a survey of all potential NF_3 gas suppliers as well as seven identified potential users (Cheminfo Services, 2014). In the survey, only one semiconductor manufacturing facility indicated usage of NF_3 in 2013, and a gas distributor identified an additional unidentified purchaser between 2010 and 2013. The results of the study are considered to be complete, as both Canadian fabrication plants in the SEMI World Fab Watch database responded to the survey (Cheminfo Services, 2014). Additionally, previous research conducted by Environment Canada using the Domestic Substances List (Environment Canada, 1986) indicated that between 33 and 199 kg of NF_3 were used in 1986. All NF_3 usage in Canada is believed to occur in the semiconductor manufacturing industry.

The use of NF_3 in the plasma cleaning of CVD chambers can produce by-product emissions of CF_4 (a PFC). The IPCC Tier 2 methodology, as shown in Equation 4–12, was used to estimate NF_3 and by-product CF_4 emissions from the semiconductor manufacturing industry:

Equation 4–12

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

E_{SC,NF_3}	=	total emissions from NF_3 use in semiconductor manufacturing
E_{NF_3}	=	NF_3 emissions resulting from the use of NF_3 (see IPCC 2006 Volume 3, Equation 6.2)
E_{CF_4}	=	CF_4 emitted as a by-product during the use of NF_3 (see IPCC 2006 Volume 3, Equation 6.3)

To determine NF_3 use and emissions throughout the time series, various assumptions needed to be made. For the unidentified 2010–2013 purchaser, the use of the purchased quantity of NF_3 was assumed to be evenly distributed amongst the years since no information on annual use was available. Emissions for this purchaser were estimated using Tier 2a emission factors and the default heel value of 10%. It was assumed that no emission control technologies were employed. The identified 2013 user stated that the NF_3 was used in an etching process and provided a purchase quantity and an amount fed into the process, so the heel value was not applied. Emissions for this facility were estimated using Tier 2b emission factors representative of the etching process. The company indicated that no emission control technologies were employed. It was assumed that 2010–2012 use levels for this company were at 2013 levels, and emissions were calculated using the same method.

To estimate emissions for years 1990–2009, emissions for 1986 were first calculated using the midpoint value of the range from the Domestic Substances List using Tier 2a emission factors and the default heel value, and it was assumed that no emission control technologies were used. Then, the 1990–2009 emissions were calculated by linearly interpolating the 1986 and 2010 NF_3 and by-product CF_4 emissions values. The emissions were interpolated, rather than interpolating the use of NF_3 and calculating emissions independently, because this latter approach would have induced a discontinuity with the by-product emissions of CF_4 from the application of different sets of emission factors (Tier 2a EFs were used for 1986, and a combination of Tier 2a and 2b EFs were used for 2010).

Voluntary surveys were collected from major gas distributors and the identified 2013 user for data years 2014–2020. Other than the identified 2013 user, gas distributors did not sell any NF_3, so the unidentified 2010–2013 user is assumed to have stopped using NF_3 after 2013. Emissions for 2014–2020 are therefore estimated using annual use data for the etching process as collected from the sole facility based on weighing the gas canisters before and after process use along with Tier 2b emission factors. The facility states that they have emission control technology on-site capable of abating NF_3 and CF_4 emissions, but that the process gases from this part of production are not fed into the abatement technology (a_i is equal to 0 for 2014–2020).

For all years where a Tier 2a method is applied (1990–2013), NF_3 usage was assumed, as opposed to NF_3 remote usage, based on the definitions stated in the 2006 IPCC Guidelines. Remote usage only applies to remote plasma cleaning of the reaction (CVD) chamber, which can also be done in-situ. 2014–2020 emissions are estimated using a Tier 2b method for etching processes, where remote NF_3 use is not applicable.

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

The method applied to estimate SF_6 Emissions from Semiconductor Manufacturing was similar to what was used to estimate PFC and NF_3 emissions. However, use of SF_6 as a process gas in etching and CVD processes does not produce any fluorocarbon by-product emissions. A Tier 2a estimate was conducted using IPCC 2006 Volume 3, Equation 6.2.

Quantities of SF_6 sold to semiconductor manufacturers for 1995–2003 were obtained from major Canadian gas suppliers. Since 1990–1994 sales data is unavailable, it was assumed that the quantity sold per year during 1990–1994 was at the 1995 level.

From 2004 onwards, the total amount of SF_6 used in the semiconductor manufacturing industry was estimated by multiplying the total SF_6 imported (from Statistics Canada) by the proportion of gas distributor SF_6 sales data attributed to semiconductor manufacturing (in %) (Cheminfo Services, 2005a and several ECCC surveys). No SF_6 sales data was collected for the years 2010–2013, so the proportions of gas distributor SF_6 sales data attributed to semiconductor manufacturing were linearly interpolated between 2009 and 2014. SF_6 import data was available until 2011 from Statistics Canada. For 2012–2020 data years, the gross output (GO) economic data for NAICS 334 (Computer and Electronic Products Manufacturing) was used as a proxy variable to scale the annual imports of SF_6 to the 2011 import data.

Due to the two different sources of SF_6 data (i.e., Canadian gas suppliers for 1995–2003 and Statistics Canada for 2004–2009), there was a significant difference among these periods. To ensure a consistent trend over the entire time series, an overlap technique (IPCC 2006, Volume 1, Chapter 5) was applied for 1990–2003 (both data sources had SF_6 import data for years 1998–2000).

Emissions were calculated using the heel value (h) of 12% provided and confirmed by two major SF_6 gas distributors, Air Liquide and Praxair.[30] The IPCC 2006 default emission factor (1-U) of 0.2 was used. From 1990 to 2013, it was that assumed no emissions control technologies were used by the industry since no data is available. For 2014 to 2020, some SF_6 users in the semiconductor manufacturing industry provided annual facility-specific values for the fraction of gas volume fed into process types with emission control technology and the fraction of gas destroyed by the emission control technology (respectively, a_i and d_i in the IPCC Guidelines). It was assumed that all other facilities had no emissions control technologies operating from 2014 to 2020. The facility-specific shares (s_f) of the gas distributor SF_6 sales data attributed to semiconductor manufacturing) were used in Equation 4–13 to calculate the total emissions from SF_6 use in semiconductor manufacturing. Equation 4–13 is an expanded country-specific version of IPCC 2006 Volume 3, Equation 6.2:

Equation 4–13

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

E_{SC,SF_6}	=	total emissions from SF_6 use in semiconductor manufacturing
h	=	heel value of 12%, as provided by gas distributors Air Liquide and Praxair
FC	=	total amount of SF_6 used in the semiconductor manufacturing industry (SF_6 imported multiplied by the proportion of gas distributor sales data attributed to semiconductor manufacturing)
U	=	U is the fractional use rate of SF_6 (fraction destroyed or transformed in process), equal to 0.8 (see IPCC 2006 Volume 3, Table 6.3)
s_f	=	facility-specific share of the gas distributor sales data attributed to semiconductor manufacturing
a_f	=	facility-specific fraction of SF_6 volume fed into process types with emission control technology
d_f	=	facility-specific fraction of SF_6 destroyed by the emission control technology

PFC Emissions from Other Emissive Applications (CRF Category 2.E.5)

This category comprises PFCs used for the purposes of electronics industry quality control testing, including electrical environmental testing, gross leak testing, thermal shock testing, and failure analysis and short detection applications. Perfluoromethane (CF_4), perfluoroethane (C_2F_6), perfluorocyclobutane ($c\text{-}C_4F_8$) and perfluorohexane (C_6F_{14}) have been used for these applications during the time series.

The activity data for PFC usage in Other Emissive Applications was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRF category 2.F; refer to section 4.17. Uses for these applications have been intermittently recorded in surveys during the time series.

Emissions from PFCs used in electronics quality control testing applications are assumed to be prompt and to have a similar emissive time profile to the uses of ozone-depleting substance substitutes in aerosols and solvents applications. The Tier 1a methodology from Equation 7.18 of the 2006 IPCC Guidelines was used to estimate emissions at the application

30 Rahal H and Tardif A. 2006. Personal communications (emails from Rahal H and Tardif A to Au A, Environment and Climate Change Canada, dated November 22, 2006, and November 13, 2006, respectively). Praxair and Air Liquide, respectively.

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.

4.15.3. Uncertainties and Time-Series Consistency

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

A Tier 1 uncertainty assessment was performed for the category of PFC Emissions from Semiconductor Manufacturing. PFC emissions in the base year are only from NF_3 usage, so the base year activity data uncertainty was assumed to be the same as NF_3. The base year emission factor uncertainty is from IPCC 2006, Volume 3, Table 6.9. The current year activity data uncertainty is assumed to be the same as other facility and gas distributor data (2%), and the current year emission factor uncertainty is based on an assessment that took into account all of the process-specific emission factors (Japan Ministry of the Environment, 2009). The base year uncertainty is 321%, and the current year uncertainty is 19%.

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

A Tier 1 uncertainty assessment was performed for the category of NF_3 Emissions from Semiconductor Manufacturing. The base year NF_3 activity data uncertainty is based on the 1986 NF_3 use range that was provided by the Domestic Substances List (33-199 kg). The base year activity data uncertainty was calculated by determining the error if the true value was the minimum of the provided range instead of the midpoint that was used for interpolating 1990 activity data. The current year NF_3 activity data uncertainty is assumed the same as other facility data (2%). The NF_3 emission factor uncertainties (Tier 2a for base year, Tier 2b for current year) are from IPCC 2006, Volume 3, Table 6.9. The base year uncertainty is 261%, and the current year uncertainty is 300%.

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

A Tier 1 uncertainty assessment was performed for the category of SF_6 Emissions from Semiconductor Manufacturing that took into account the uncertainty of the SF_6 import data, the total reported SF_6 sales data, the proportion attributed to semiconductors, and the emission factors (±45%). This uncertainty value is assumed to be representative of the entire time series.

PFC Emissions from Other Emissive Applications (CRF Category 2.E.5)

A Tier 1 uncertainty assessment was performed for the category of PFC Emissions from Other Emissive Applications. The base year uncertainty is zero since there are no emissions until 1995. The current year activity data uncertainty from facility and gas-distributor reported data is 2%, and the emission factor uncertainty was assessed to be 50% (Japan Ministry of the Environment, 2009). Therefore, the current year uncertainty is 50%.

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

Categories under the Electronics Industry subsector have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

In addition to the Tier 1 QC Checklist, the following informal checks are conducted for estimating PFCs, NF_3, and SF_6 emissions from semiconductor manufacturing:

- Large inter-year changes in activity data (i.e. the annual number of users and quantities of specific gases sold by each gas distributor) prompt verification and explanation from the data provider
- User-level purchase and use data are compared against the sales reports of gas distributors
- At a facility-level, the specific gas/process combinations are compared between years for consistency
- Facility-provided destruction efficiencies for abatement equipment are compared with those provided by the equipment manufacturers and are cross-checked against the Tier 2a and Tier 2b default efficiency parameters in IPCC 2006, Volume 3, Table 6.6.

4.15.5. Category-Specific Recalculations

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

Emissions were recalculated for years 2010–2019 due to: the receipt of 2019 voluntary survey data from some gas distributors (2019 data for these distributors was formerly calculated to be the average of 2014–2018 survey data); a revised allocation of existing 2014–2019 survey data based on additional company research; and the receipt and incorporation of additional 2014–2019 user-level data on weigh scale measured gas use, gas/process combinations, abatement equipment utilization and destruction efficiencies. 2010–2013 PFC activity data values were affected since they are interpolated between 2009 and the revised 2014 data. The effects of these recalculations range from -1.1 kt CO_2 eq (-8%) in 2018 to +1.9 kt in 2019 (+24%).

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

Emissions were recalculated downwards for years 2014–2019 due to received user survey data on weigh scale measured gas use, with a maximum change of -0.29 kt (-28%).

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

Emissions were recalculated for years 2010–2019 due to: the receipt of 2019 voluntary survey data from some gas distributors (2019 data for these distributors was formerly calculated to be the average of 2014–2018 survey data); a revised allocation of existing 2014–2019 survey data based on additional company research; the receipt and incorporation of additional 2014–2019 user-level abatement equipment utilization and destruction efficiencies; the revision of gross output data; and the fixing of a calculation error used in the extrapolation of 2012–2019 SF_6 imports from 2011 (the latest available year) that uses the gross output data as a proxy. 2010–2013 proportions of gas distributor sales data attributed to semiconductor manufacturing (in %) were re-interpolated from the 2009 survey data to the revised 2014 survey data. The effects of these recalculations range from -1.8 kt CO_2 eq (-5.6%) in 2015 to +3.0 kt (+15%) in 2019.

PFC Emissions from Other Emissive Applications (CRF Category 2.E.5)

PFC Emissions from Other Emissive Applications was recalculated for 2019 due to the receipt of voluntary survey data from a gas distributor that contained nitrogen blend sales data for these applications. The nitrogen blends contained low concentrations (ten parts per million) of PFCs. Formerly, 2019 activity data from this gas distributor was calculated to be the average of their 2014–2018 survey data, which did not contain data on PFCs used in these applications. This increased emissions in 2019 from zero to 0.00000034 kt CO_2 eq (+100%).

4.15.6. Category-Specific Planned Improvements

Additional Canadian electronics manufacturers will be contacted to verify gas distributor purchase data, to provide annual use quantities (if available), to facilitate more accurate and process-specific activity data and to obtain information on implemented emission control technologies. The data obtained from facilities will be assessed for quality for eventual implementation in future inventory submissions.

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

4.16.1. Category Description

In order to provide a clear representation of the Canadian category of Product Uses as Substitutes for Ozone-Depleting Substances, explanations on hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) have been divided into two separate sections in this report (sections 4.16 and 4.17, respectively).

Before the Montreal Protocol ban on the production and use of chlorofluorocarbons (CFCs) came into effect in 1996, very few HFCs were produced and used globally. In Canada, HFC-23 was produced until 1992 as a by-product of HCFC-22 production, which ended in 1992. There has been no other 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 suppression, aerosols, solvent cleaning, and foam blowing agents. All HFCs consumed in Canada are imported in bulk or in manufactured items and products (e.g., refrigerators).

HFC releases contributed 11 940 kt CO_2 eq (1.8%) to Canada's total emissions in 2020, a 134% increase from 2005.

Table 4–10 **HFCs Used in Canada and Years for which Activity Data is Available**

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

4.16.2. Methodological Issues

For this submission, Canada has implemented the IPCC Tier 2a approach to estimating HFC emissions by type of sub-application (IPCC, 2006).

Activity Data

Canadian HFC use data is derived from bulk imports, and imports and exports of manufactured items (MIs). Canada occasionally exports small quantities of HFCs in bulk. Up to the year 2005, activity data was gathered via periodic, mandatory surveys for the data years 1995 through 2004; additional mandatory activity data collection took place in 2014 and 2016, covering activity data of years 2008 through 2015. Activity data for 2017, 2018, 2019, and 2020 was collected in 2018, 2019, 2020 and 2021, respectively, from the *Ozone-depleting Substances and Halocarbon Alternatives Regulations* (ODS Regulations). Note that the 1996 survey did not include information on imports and exports of manufactured items for the 1995 data year, and the activity data was therefore estimated on the basis of the 1996–1998 survey data.

Voluntary surveys for bulk sales and imports and exports of MIs data by market segment were collected from 2006 to 2011 covering activity data of years 2005 through 2010. The surveys were collected by Environment Canada and others (additional information is provided in Annex 3.3) and had varying response rates and aggregation levels of sub-applications.

The 2014, 2016, and 2018–2021 mandatory surveys of HFC bulk imports, exports and sales by HFC type and market segment forms the foundation for the 2008 through 2015 and 2017 through 2020 portion of the HFC inventory. When there were overlaps between the voluntary and the mandatory surveys, the mandatory surveys took precedence. Some additional imports and exports of MIs activity data was reported to the 2014 and 2016 surveys and are included in the inventory. Reporting of HFCs to the 2014 and 2016 mandatory surveys were done on the basis of applications and sub-applications so that the quantities for manufacture and servicing could be broken out.

The full list of HFCs and the years activity data was collected is shown in Table 4–10. No data was collected for 2016.

There are two facilities in Canada that can destroy HFCs and other substances, but no data is publically available on the amount of HFC destroyed.

Emission Factors

Surveys were performed in 2012 to document practices in HFC use and disposal and to support the development of country-specific emission factors that are representative of Canada's circumstances (Environmental Health Strategies Inc. [EHS], 2013; Environment Canada, 2015). The country-specific emission factors were applied to the refrigeration and air conditioning sub-applications for the entire time period.

For the aerosols, foam blowing, fire extinguishing, solvents, and miscellaneous sub-applications, default 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 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). For the calculation of the net consumption of a HFC in a specific sub-application, Equation 7.1 from Volume 3, Chapter 7 (IPCC, 2006) has been adapted to the Canadian context and used. Refer to Annex 3.3 for additional details on methodology.

The lifecycle of each HFC is tracked by sub-application and year, then 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, in-service and end-of-life losses are also calculated.

In this way, the mathematically expanded version of the method discussed in Volume 3, Chapter 7, Section 7.1.2.2 (IPCC, 2006) and subsequent sections are applied. Emissions for each lifecycle stage are estimated for each sub-application by multiplying the HFC quantity in that stage by its corresponding emission factor. The HFC emission estimation equations applied for each unique sub-application are explained in more detail in Annex 3.3.

4.16.3. Uncertainties and Time-Series Consistency

A Monte Carlo uncertainty assessment was performed for the consumption of HFCs. It took into account the uncertainties associated with all sub-applications, such as residential/commercial refrigeration, stationary/mobile air conditioning, etc. To determine the uncertainty for a sub-application, the uncertainties related to activity data (Cheminfo Services, 2005c) and emission factors from Volume 3, Chapter 7 (IPCC, 2006) were used. It should be noted that the overall category uncertainty can vary throughout the time series because it is dependent on the magnitude of each of the sub-application emission estimates, which changes from year to year. The uncertainty associated with the category as a whole for 2020 was ±11%.

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

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

4.16.5. Category-Specific Recalculations

Recalculations for this category include updated activity data for 2017–2019 and updated proxy variables for all sub-applications for 2011–2019. The magnitude of the recalculations ranged from -400 kt CO_2 eq in 2017 to +23 kt CO_2 eq in 2016.

4.16.6. Category-Specific Planned Improvements

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Research into the commercial and industrial refrigeration emission factors, market share and other characteristics in Canada will be examined for application in future inventories. A data gap exists with the in-item data that is available up to 2010. To fill this gap, sources of statistics and import/export data will be searched and examined. Another planned improvement is to obtain more information on HFC destruction activities in Canada to further improve end-of-life emission factors.

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

4.17.1. Category Description

Perfluorocarbon (PFC) consumption in Canada began in 1995. Like Hydrofluorocarbons (HFCs), PFCs are also used as substitutes for Ozone-Depleting Substances (ODS) being phased out under the Montreal Protocol (IPCC, 2006). However, the uses of PFCs are very limited compared to HFCs in Canada. Canadian applications that have used PFCs as Substitutes for ODS over the time series include Refrigeration and Air Conditioning, Foam Blowing Agents, and Solvents.

PFC releases contributed to about 9.5 kt CO_2 eq in 2020, a 330% increase from 2005.

4.17.2. Methodological Issues

The 2006 IPCC Tier 1a/2a methodologies were used to estimate emissions from the consumption of PFCs in various applications for the years 1995 to 2020. Details of the methods are found in the following subsections. The 1995–2000 activity data was obtained through the 1998 and 2001 PFC surveys conducted by Environment Canada. As 2001 and 2002 data was unavailable, emission estimates were developed on the basis of the assumption that the use quantities in various applications stayed constant after 2000. Environment Canada conducted a voluntary collection of 2003–2007 PFC use data from major distributors in 2008 and 2009. The data from the major distributors was then integrated with existing PFC use data. The 2008 and 2009 PFC use data from major distributors was voluntarily collected in 2009 and 2010. 2014–2020 PFC data was collected from gas distributors in 2019, 2020 and 2021 voluntary surveys. 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 2017–2020 HFC/PFC blend activity data was collected through mandatory HFC surveys in 2018, 2019, 2020 and 2021. 2016 HFC/PFC blend activity data was interpolated between the 2015 and 2017 activity data. The PFC component of the blend activity data was disaggregated using IPCC 2006, Volume 3, Table 7.8.

Emission factors applied for the use of PFCs as ODS Substitutes are presented in Table A6.2-12.

Refrigeration and Air Conditioning (CRF Category 2.F.1, PFCs)

The IPCC Tier 2a methodology, i.e., equations 12, 13 and 14 from Volume 3, Chapter 7, section 7.5 of the 2006 IPCC Guidelines, was used to estimate the emissions from the assembly, operation and disposal of the following sub-applications: commercial refrigeration and stationary air conditioning systems. No other refrigeration and air conditioning sub-applications have been reported in surveys throughout the time series.

The assembly losses (k values) and annual operating leakage rates (x values) used were chosen from a range of values that were provided for each sub-application in the 2006 IPCC Guidelines. Loss and leakage rates by sub-application can be seen in Table A6.2-12.

The refrigerant “bank” used for this calculation includes the amount of PFCs contained in imported or manufactured equipment in Canada and excludes the amount of PFCs exported and lost during assembly.

PFC use in Canada began in 1995. It is assumed that there were no PFC emissions from the disposal of refrigeration and stationary air conditioning systems between 1995 and 2009 since these systems have an average lifespan of 15 years (IPCC 2006). An additional assumption is that there are no recovery or recycling technologies in place and therefore 100% of the quantities remaining in systems are released once the end of the lifespan is reached, i.e., any remaining refrigerant in a refrigeration system built in 1995 would be emitted in the year 2010. Fluctuations in annual emissions are to be expected during years where the lifespans have been reached and the remaining PFCs in the systems are disposed of.

Over the time series, perfluoromethane (CF_4), perfluoroethane (C_2F_6), and perfluoropropane (C_3F_8) have been used as commercial refrigerants or in commercial refrigerant blends, and as of 2020, a small quantity of C_2F_6 continues to be imported annually in R-508B blends for the service and maintenance of commercial refrigerators.

In addition, C_2F_6 (or blends containing it) have been used in stationary air-conditioning. Use was last reported in 2008, although in-service and end-of-life emissions continue to occur.

Uses of PFCs in commercial refrigeration and stationary air-conditioning contribute a total of 7.4 kt CO_2 eq in 2020.

Foam Blowing Agents (CRF Category 2.F.2, PFCs)

The use of perfluoropentane (C_5F_{12}) in closed-cell foam was reported in the 1995–1997 activity data collection that took place in 1998. A facility used C_5F_{12} for the manufacturing of rigid phenolic foam boards until it closed in August 1997. Since then, no other uses of PFCs in closed-cell foam have been reported.

Uses of PFCs in open-cell foams has never been reported in any data collection. Therefore, emissions from this source are expected to be negligible.

To estimate emissions from closed-cell foams, the IPCC Tier 1a methodology was applied using IPCC 2006 default emission factors. 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 10% 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 4.5% of the original charge per year over a period of approximately 20 years (IPCC, 2006).

The estimated in-service emissions from the C_5F_{12} used as a closed-cell foam blowing agent expired in 2017.

Fire Protection (CRF Category 2.F.3, PFCs)

Uses of PFCs in Fire Protection applications has never been reported in any data collection. Therefore, emissions from this source are expected to be negligible.

Aerosols (CRF Category 2.F.4, PFCs)

Uses of PFCs as aerosol propellants has never been reported in any data collection. Therefore, emissions from this source are expected to be negligible. Emissions from PFCs imported in aerosol cans that are used as solvents are reported in the Solvents category.

Solvents (CRF Category 2.F.5, PFCs)

Uses of CF_4, C_2F_6, perfluorocyclobutane (c-C_4F_8), C_5F_{12}, and perfluorohexane (C_6F_{14}) as solvents has been recorded during the time series. Main sub-applications include electronics cleaning, laboratory solvents, and carrier solvents for various products (e.g., protective coating, mould release agents, lubricants).

The IPCC Tier 1a methodology presented in the 2006 IPCC Guidelines was used to estimate PFC emissions from solvents. A product lifetime of two years was assumed and a default IPCC emission factor of 50 percent of the initial charge/year was used (IPCC, 2006). Equation 7.5 from Volume 3, Chapter 7, section 7.2, of the 2006 IPCC Guidelines was used to estimate emissions for each year and is calculated to be half of the PFCs used as solvents in the estimated year plus half of the PFCs used as solvents in the previous year. The amount of PFCs used each year is equal to the amount of PFCs produced and imported as solvents and excludes the amount of PFCs exported as solvents.

In 2020, emissions from the uses of CF_4 and C_2F_6 in solvent applications contributed 2.0 kt CO_2 eq.

4.17.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for PFC consumption for the years 1995–2008. As in the case of HFC consumption, uncertainties related to activity data (IPCC, 2006) and emission factors (Japan Ministry of the Environment, 2009) were taken into account in the assessment for PFC consumption. The uncertainty associated with the category as a whole for the time series ranged from ±9% to ±23%. The current year uncertainty is assumed to be 23%, equal to the highest and most recent (2008) uncertainty in the range assessed. The base year uncertainty is zero since the use of PFCs as ODS substitutes did not begin until 1995.

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

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

In addition, checks have been performed to ensure that there is no double-counting between the same-year activity data from the voluntary surveys of PFCs collected from gas distributors and the mandatory surveys on HFC/PFC blends.

4.17.5. Category-Specific Recalculations

There have been recalculations for years 2009–2019 due to the incorporation of HFC/PFC blend data collected for activity data years 2008–2015 and 2017–2020 and the associated 2016 interpolation. The revised 2008 activity data does not affect 2008 emissions because it only related to refrigeration applications, where the in-service emissions do not begin until one year after importation. In addition, 2019 activity data from some gas distributors was incorporated (2019 data for these distributors was formerly calculated to be the average of 2014–2018 survey data) and there were some revisions to the categorical allocation of existing 2014–2019 PFC activity data based on additional research. As well, 2014–2018 PFC activity data attributed to use as a heat transfer medium within the Other Contained Product Uses (CRF Category 2.G.4) category was reassigned to the Refrigeration and Air Conditioning category following an email correspondence with the gas distributor that reported it. Finally, the 2010–2013 interpolation period between the voluntary PFC data surveys from gas distributors for 2009 and 2014 activity data was recalculated.

The recalculations result in an increase of emissions for all years 2009–2019. The maximum impact is +6.6 kt CO_2 eq (280%) in 2019.

4.17.6. Category-Specific Planned Improvements

Refrigeration and Air Conditioning (CRF Category 2.F.1, PFCs)

There are no planned improvements for this category.

Foam Blowing Agents (CRF Category 2.F.2, PFCs)

The closed-cell sub-application (phenolic laminates) that PFCs are used for is known. Emissions estimates for this category will be updated to a IPCC Tier 2 methodology that uses sub-application specific emission factors.

Solvents (CRF Category 2.F.5, PFCs)

Some of the recent (2014–2020) voluntary data surveys completed by gas distributors are annual sales reports with company names and the quantities sold and no additional information on end-use. A large portion of the quantity of PFCs attributed to use as solvents is based on research conducted by inventory compilers. Given the wide variety of possible uses of solvents (and PFCs), the categorical allocation and emissions profiles of solvent uses have a high degree of uncertainty. Users of PFCs as solvents will be contacted to confirm the categorical allocation and emissions profile of their solvent use (if possible).

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

4.18.1. Category Description

The Other Product Manufacture and Use category includes emissions from the use of Sulphur Hexafluoride (SF_6) in electrical equipment (CRF category 2.G.1), Nitrous Oxide (N_2O) emissions from medical applications (CRF category 2.G.3.a), N_2O emissions from use as a propellant (CRF category 2.G.3.b) and Perfluorocarbon (PFC) Emissions from Other Contained Product Uses (CRF category 2.G.4) such as uses as an electrical insulator or as a dielectric coolant, which are not ODS substitutes or electronics industry-related.

In electric utilities, SF_6 is used as an insulating and arc-quenching medium in high-tension electrical equipment, such as electrical switchgear, stand-alone circuit breakers and gas-insulated substations. In Canada, SF_6 is primarily used in high-voltage circuit breakers and related equipment. Emissions that occur during equipment use are a result of leakages during gas transfer and handling operations and leakages during normal operation of the equipment. In order to keep equipment properly charged and operational, utilities must fill their equipment to replace the amount that has escaped.

Nitrous Oxide of Canada (NOC) in Maitland, Ontario, is the only known producer of compressed N_2O for commercial sales in Canada. It supplies N_2O to two of the three primary N_2O gas distributors that essentially account for the total commercial market in Canada. These companies sell cylinders of N_2O to a relatively large number of sub-distributors. It is estimated that there may be 9000 to 12 000 final end-use customers for N_2O in Canada, including dental offices, clinics, hospitals and laboratories (Cheminfo Services, 2006). In addition to domestic sales of N_2O produced in Canada, a portion of N_2O used is imported. Quantities of N_2O imported were obtained by to the 2006 Cheminfo study for 1990 to 1997; through Statistics Canada for 2008 to 2011; and linearly interpolated from 2012 onwards due to changes in the disaggregation of Statistics Canada information.

Of all applications in which N_2O can be used in Canada, only anaesthetic and propellant uses of N_2O are considered emissive. Anaesthetic use represents the largest type of N_2O end use in Canada and it is assumed that none of the N_2O is metabolized (IPCC 2006). Use as a propellant in food products is the second-largest type of end use in Canada, with only emissions coming from N_2O used in whipped cream being considered as significant. None of the N_2O is reacted during the anaesthetic and propellant processes; therefore, all N_2O used is emitted to the atmosphere (Cheminfo Services, 2006).

Other areas where N_2O can be used include production of sodium azide (a chemical that is used to inflate automobile airbags), atomic absorption spectrometry and semiconductor manufacturing. According to the distributors surveyed during the 2006 study, approximately 82% of their N_2O sales volume is used in dentistry/medical applications, 15% in food processing propellants and only 3% for the other uses (Cheminfo Services, 2006).

PFCs can be used as electrical insulation or as a dielectric coolant in contained product use applications, including waveguide radar systems and circuit breakers. Emissions of PFCs occur over the product lifetime, such as during product assembly, through slow leaks or normal operations (while the equipment is in-service) and at the end-of-life during deconstruction or landfilling of the equipment.

Note that emissions from use of solvents in dry cleaning, printing, metal degreasing and a variety of industrial applications, as well as household use, are not estimated.

The Other Product Manufacture and Use category contributed about 726 kt (<0.1%) to Canada's total emissions in 2020, a 33% increase from 2005.

4.18.2. Methodological Issues

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

A modified Tier 3 method was used to estimate SF_6 emissions from electrical equipment in utilities for certain years (i.e., 2006–2020) of the time series, in place of the previous top-down approach (which assumed that all SF_6 purchased from gas distributors replaces SF_6 lost through leakage). The SF_6 emission estimates by province for 2006–2020 are provided by the Canadian Electricity Association (CEA), and BC Hydro, which collectively represent electricity companies across Canada. BC Hydro was a member of CEA, prior to 2017, and Hydro-Québec joined CEA in 2017. CEA and BC Hydro data was prepared following the SF_6 Emission Estimation and Reporting Protocol for Electric Utilities ("the Protocol") (Environment Canada and Canadian Electricity Association). Note that CEA and BC Hydro do not provide corresponding activity data. However, the quantification of emissions in the methodologies used is based on the mass of SF_6 injected into the equipment or contained in the cylinders. The national SF_6 estimate for each year during the 2006–2020 period was the sum of all provincial estimates. The Protocol is the result of a collaborative effort between Environment Canada, CEA and Hydro-Québec.

In summary, the Protocol explains how the (country-specific) modified Tier 3 method was derived from the IPCC Tier 3 life-cycle methodology. It also explains the different options available for estimating the equipment life-cycle emissions. These are equal to the sum of SF_6 used to top up the equipment and the equipment disposal and failure emissions (which are equal to either nameplate capacity less recovered quantity for disposal emissions or simply to nameplate capacity for failure emissions). A more detailed description of the methodology is provided in Annex 3.3.

Estimates were not available from CEA or Hydro-Québec for the years 1990 to 2005 because a systematic manner for taking inventory of the quantities of SF_6 from these organizations only started in the 2006 data year. Hence, the application of the Protocol was not possible. Surveys of SF_6 distributors were used to obtain usage data prior to the application of the Protocol. To resolve this issue of data availability and to ensure a consistent time series, an overlap technique (IPCC 2006, Volume 1, Chapter 5) was applied. In this case, the overlap was assessed between four sets of annual estimates (2006–2009) derived from the distributor surveys and obtained under the Protocol.

Emissions at provincial/territorial levels were estimated on the basis of the national emission estimates (obtained from the use of the overlap approach) and the percent of provincial shares (based on the reported 2006–2009 data).

Nitrous Oxide Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF Category 2.G.3.b)

N_2O emission estimates for these categories are based on a consumption approach. Since it is virtually impossible to collect consumption data from all end users, it is assumed that domestic sales and imports (obtained directly from NOC) equal domestic consumption. Equation 8.24 of the 2006 IPCC Guidelines was used to estimate N_2O emissions and covers more than one calendar year because both supply and use are assumed to be continuous over the year; for example, N_2O supplied in the middle of a calendar year is not fully used until the middle of the following calendar year.

The producer and distributors were surveyed to obtain sales data by market segment and qualitative information to establish the 2005 Canadian N_2O sales pattern by application (Cheminfo Services, 2006). The sales patterns for 2006–2019 are assumed to be the same as that for 2005. The amounts of N_2O sold for anaesthetic and propellant purposes are calculated from the total domestic sales volume and their respective share of sales.

Provincial and territorial estimates were developed by distributing the national-level estimates on the basis of provincial/territorial population data (Statistics Canada, n.d.[d]).

Perfluorocarbon Emissions from Other Contained Product Uses (CRF Category 2.G.4)

The activity data on PFCs used in Other Contained Products was collected in the same manner as for PFCs used in Product Uses as Substitutes for ODS (CRF category 2.F; refer to section 4.17). Over the time series, perfluoromethane (CF_4), perfluoroethane (C_2F_6) and perfluorohexane (C_6F_{14}) have been used for electrical insulation within contained products and perfluoropropane (C_3F_8) and C_6F_{14} have been used as dielectric coolants within contained products.

The IPCC Tier 1 method for other contained applications of ODS substitutes (IPCC, 2006) is used to calculate PFC Emissions for Other Contained Product Uses. Since no emission factors are available in the 2006 IPCC Guidelines, default emission factors from the IPCC 2000 Good Practice Guidance document are used. They assume a leakage rate of approximately 1% during the manufacturing process and an annual leakage rate of 2% during the equipment lifetime of 15 years (IPCC, 2000). It is assumed is that there are no recovery or recycling technologies in place and therefore 100% of the PFCs remaining in Other Contained Products are released once the end of the lifespan is reached. These emission factors are presented in Table A6.3-2, and are applied to the PFC data in accordance with Equation 7.19 of the 2006 IPCC Guidelines.

4.18.3. Uncertainties and Time-Series Consistency

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

A Tier 1 uncertainty assessment was performed for the category of SF_6 from Electrical Equipment. It should be noted, however, that the uncertainty assessment was done using 2007 data. It is expected that emission estimates of this submission would have much lower uncertainty values. The uncertainty for the category as a whole was estimated at ±30.0%. Depending on the years, the data source and methodology used for SF_6 from electrical equipment could vary, as explained in section 4.17.2 (Methodological Issues).

Nitrous Oxide Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF Category 2.G.3.b)

A Tier 1 uncertainty assessment was performed for the categories of N_2O Emissions from Medical Applications and Propellant Usage. It took into account the uncertainties associated with domestic sales, import, sales patterns and emission factors. The uncertainty for these combined categories was evaluated at ±18%. It is expected that the uncertainty for this sector would not vary considerably from year to year as the data sources and methodology applied are the same.

Perfluorocarbon Emissions from Other Contained Product Uses (CRF Category 2.G.4)

A Tier 1 uncertainty assessment was performed for the category of PFC Emissions from Other Contained Product Uses. Uncertainties related to the gas distributor and facility activity data are assumed to be 2% and the emission factor uncertainty was assessed to be 50% (Japan Ministry of the Environment, 2009). The current year uncertainty is 51%, and the base year uncertainty is zero since emissions of PFCs for these applications did not begin until 1995.

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

The categories of N_2O Emissions from Medical Applications and Propellant Usage, and PFC Emissions from Other Contained Product Uses have undergone checks as outlined in Canada's General QC (Tier 1) Checklist Guidance (Environment Canada, 2015). The checks performed were consistent with QA/QC requirements as promoted by Chapter 6, Volume 1, of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

The category of SF_6 Consumption in Electrical Equipment has undergone informal quality control checks throughout the emission estimation process.

4.18.5. Category-Specific Recalculations

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

There were recalculations of less than 1.3 kt CO_2 eq for SF_6 emissions from electrical equipment for 2016 and 2017, and -53 kt CO_2 eq in 2019 due to updates in activity data.

Perfluorocarbon Emissions from Other Contained Product Uses (CRF Category 2.G.4)

Recalculations for PFC Emissions from Other Contained Product Uses occurred for years 2010–2019 due to the reallocation of 2014–2018 data from the heat transfer medium sub-application of this category to the Refrigeration and Air Conditioning category (CRF Category 2.F.1) after clarification with the reporter. 2010–2013 activity data was re-interpolated between 2009 and 2014 using the revised 2014 activity data. In addition, 2019 activity data from some gas distributors was incorporated (2019 data for these distributors was formerly calculated to be the average of 2014–2018 survey data). This resulted in decreases in emissions for all affected years (2010–2019), with a maximum decrease of -0.71 kt CO_2 eq (-2.3%) in 2019.

4.18.6. Category-Specific Planned Improvements

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

As mentioned previously, SF_6 is used as an insulating and arc-quenching medium in electrical transmission and distribution equipment. To enhance performance in cold weather, SF_6 gas can be mixed with carbon tetrafluoride (CF_4) gas. Currently, Canada only reports SF_6 from this source category (CRF category 2.G.1). There are plans to collect CF_4 emission data to report in future inventory submissions.

Sulphur Hexafluoride and Perfluorocarbon Emissions from Other Product Use (CRF Category 2.G.2)

During the collection of 2014–2020 SF_6 and PFC sales data from major Canadian gas distributors, purchasers were identified who may be involved in activities mentioned in the 2006 IPCC Guidelines (vol. 3, section 8.3). Previously, preliminary research was conducted and found that the applications seemed to not exist at a detectable level. Follow-ups with these purchasers to verify the uses of SF_6 and PFCs is ongoing. Once follow-ups are complete, a Tier 1 emissions estimate will be conducted for the existing data years to determine significance. If emissions are significant (i.e. more than 500 kt CO_2 eq or greater than 0.05% of the national emissions total), efforts will be made to develop a emission estimates for the entire time series and they will be reported. If emissions are insignificant, this category will continue to reported as “NE” (not estimated).

Nitrous Oxide Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF Category 2.G.3.b)

There are plans to develop an updated Canadian N_2O sales pattern by application in future inventory submissions in the emissions estimates of the N_2O Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF category 2.G.3.b) categories. The current sales breakdown is assumed to be the same as 2005.

Perfluorocarbon Emissions from Other Contained Product Uses (CRF Category 2.G.4)

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

AGRICULTURE (CRF SECTOR 3)

5.1. Overview

The Agriculture sector contributed 7% of Canada's total greenhouse gas (GHG) emissions annually since 1990, except in 2020 where the contribution rose to 8%. Emissions within the sector increased by 34% between 1990 and 2020. Emission sources from the Agriculture sector include the Enteric Fermentation (methane [CH_4]) and Manure Management (nitrous oxide [N_2O] and CH_4) categories for emissions associated with livestock production and the Agricultural Soils (N_2O) and Field Burning of Agricultural Residues (CH_4 and N_2O) categories for emissions associated with crop production. Carbon dioxide emissions from lime and urea application are reported in the Agriculture sector; however, CO_2 emissions from and removals by agricultural lands are reported in the Land Use, Land-Use Change and Forestry (LULUCF) sector under the Cropland category (see Chapter 6). GHG emissions from on-farm fuel combustion are included in the Energy sector (Chapter 3).

The largest sectors in Canadian agriculture are beef cattle (non-dairy), swine, cereal and oilseed production. There is also a large poultry industry and a large dairy industry. Sheep are raised, but production is highly localized and small compared to the beef, swine, dairy and poultry industries. Other alternative livestock, namely bison,[1] llamas, alpacas, horses, goats, elk, deer, wild boars, foxes, minks, rabbits, and mules and asses, are produced for commercial purposes, but production is small.

Canadian agriculture is highly regionalized as a result of historic and climatic influences. Approximately 75% of beef cattle and more than 90% of wheat, barley and canola are produced on the Prairies, a semiarid to subhumid ecozone, while approximately 75% of the dairy cattle herd, 60% of swine and poultry and more than 90% of corn and soybean are produced on the humid mixedwood plains ecozone in eastern Canada.

In 1990, there were 10.5 million beef cattle in Canada, 1.4 million dairy cattle, 10 million swine and 101 million poultry. Beef cattle and swine populations peaked in 2005 at 15 million head each. Since 2005, beef populations have decreased to 11 million head. Swine populations decreased to 12.5 million head in 2009, increased to 14 million head in 2016, and have since remained stable. Since 1990, poultry populations have increased to 154 million, whereas dairy cattle populations have decreased until recently, fluctuating around values slightly less than 1 million head in 2020.

As a result of changes in cropping practices in Canada, canola production increased from 3.3 Mt in 1990 to 19 Mt in 2020, corn production from 7 Mt to 14 Mt, and soybean production from 1.3 Mt to 6.4 Mt. From 1990 to 2002, wheat production fell off sharply, decreasing from 32 Mt to 16 Mt. However, production has since increased, reaching 35 Mt in 2020. With the changes in crop production, inorganic nitrogen consumption has more than doubled, from 1.2 Mt N in 1990 to 2.9 Mt N in 2020, and land under conservation tillage has increased by 18 Mha.

As a result of the combined changes in livestock and cropland production, Canada's total greenhouse gas (GHG) emissions from the Agriculture sector rose from 41 Mt CO_2 eq in 1990 to 55 Mt CO_2 eq in 2020 (Table 5–1). This 34% increase is mainly due to emissions associated with greater use of inorganic nitrogen fertilizers (143% increase in N shipments), recent declines in the proportion of perennial land, higher populations of swine (38% increase), and changes in weight, feed and manure handling practices in the beef, dairy and swine industries.

1 In the Common Reporting Format (CRF) tables, bison emissions are reported under the Intergovernmental Panel on Climate Change (IPCC) category "buffalo" although the species referred to is the North American bison (*Bison bison*) that is raised for meat production using methods similar to beef cattle. In the text of the NIR, this animal category will be discussed as bison.

Emissions of CH_4 from livestock accounted for 25 Mt CO_2 eq in 1990 and 28 Mt CO_2 eq in 2020, and mean estimates lie within an uncertainty range of -16% to +20%. Over the 1990 to 2020 time series, mean CH_4 emissions are estimated to have increased by 2.8 Mt CO_2 eq, an 11% increase. The observed increase in emissions falls within an uncertainty range of 10% to 17%. Emissions of N_2O from agricultural soils and livestock accounted for 15 Mt CO_2 eq in 1990 and 25 Mt CO_2 eq in 2020; mean estimates lie within an uncertainty range of approximately -27% to +29%. Over the time series, mean N_2O emissions increased by 9.5 Mt CO_2 eq, an increase of 63%.

Emissions from the Agriculture sector peaked in 2005, and decreased to 49 Mt CO_2 eq in 2011, with reductions in emissions from animal production as livestock populations decreased (see 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 perennial land area has decreased. These trends, in combination with high crop production in recent years, have caused emissions to increase from their low point in 2011 to 55 Mt CO_2 eq in 2020.

Table 5–1 **Short- and Long-Term Changes in GHG Emissions from the Agriculture Sector**

GHG Source Category		GHG Emissions (kt CO_2 eq)									
		1990	2000	2005	2014	2015	2016	2017	2018	2019	2020
Agriculture TOTAL[a]		**41 000**	**51 000**	**54 000**	**51 000**	**52 000**	**53 000**	**52 000**	**53 000**	**53 000**	**55 000**
Enteric Fermentation (CH_4)		**22 000**	**28 000**	**31 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**
Dairy Cattle		4 000	3 400	3 200	3 200	3 200	3 200	3 300	3 400	3 500	3 500
Beef Cattle[b]		18 000	23 000	26 000	20 000	20 000	20 000	20 000	20 000	19 000	19 000
Others[c]		730	1 100	1 300	1 100	1 100	1 100	1 100	1 100	1 100	1 100
Manure Management		**6 100**	**7 900**	**8 700**	**7 600**	**7 700**	**7 800**	**7 900**	**7 800**	**7 800**	**7 800**
Dairy Cattle	CH_4	430	560	680	870	870	880	890	920	940	950
	N_2O	520	460	350	270	260	260	260	270	270	270
Beef Cattle[b]	CH_4	810	1 100	1 200	1 000	1 000	1 000	1 000	1 000	1 000	1 000
	N_2O	1 900	2 700	3 000	2 300	2 300	2 300	2 300	2 300	2 300	2 200
Swine	CH_4	1 000	1 500	1 800	1 500	1 600	1 700	1 700	1 700	1 700	1 700
	N_2O	100	70	70	50	50	50	50	50	50	50
Poultry	CH_4	160	190	190	200	200	200	200	200	200	200
	N_2O	430	530	540	590	600	610	610	610	610	610
Others[d]	CH_4	40	50	60	50	50	40	40	40	40	40
	N_2O	90	140	170	140	130	120	120	120	120	110
Indirect Source of	N_2O	600	680	720	600	610	620	610	610	610	610
Agricultural Soils (N_2O)		**11 000**	**13 000**	**13 000**	**17 000**	**18 000**	**18 000**	**17 000**	**19 000**	**19 000**	**21 000**
Direct Sources		8 800	10 000	10 000	13 000	14 000	15 000	14 000	15 000	15 000	16 000
Synthetic Nitrogen Fertilizers		4 400	5 800	5 400	8 600	8 900	9 000	8 300	9 300	9 400	11 000
Organic Nitrogen Fertilizers		1 200	1 400	1 500	1 500	1 500	1 500	1 500	1 500	1 500	1 500
Crop Residue Decomposition		2 500	2 900	3 100	3 800	4 000	4 400	4 400	4 300	4 200	4 500
Cultivation of Organic Soils		60	60	60	60	60	60	60	60	60	60
Mineralization of Soil Organic Carbon		230	250	270	150	710	400	320	390	500	830
Conservation Tillage[e]		-410	-990	-1 200	-2 100	-2 300	-2 300	-2 200	-2 300	-2 400	-2 500
Irrigation		560	720	780	1 100	1 100	1 200	1 100	1 200	1 200	1 300
Manure on Pasture, Range and Paddock		220	240	260	210	210	200	200	200	200	200
Indirect Sources		2 600	3 100	3 100	3 700	3 800	3 900	3 800	3 900	3 900	4 200
Crop Residue Burning (CH_4 & N_2O)		**220**	**130**	**40**	**50**	**60**	**50**	**50**	**50**	**50**	**50**
Lime and Urea Application (CO_2)		**1 200**	**1 600**	**1 400**	**2 500**	**2 600**	**2 500**	**2 400**	**2 600**	**2 700**	**3 000**

Notes:

a. Totals may not add up due to rounding.

b. Beef Cattle includes dairy heifers. This category corresponds to “Non-Dairy Cattle” in the CRF tables.

c. Others, Enteric Fermentation, includes bison, goats, horses, sheep, llamas/alpacas, swine, deer/elk, wild boars.

d. Others, Manure Management, includes bison, goats, horses, sheep, llamas/alpacas, foxes, minks, rabbits, deer/elk, wild boars.

e. The negative values reflect a reduced N_2O emission due to the adoption of conservation tillage.

In this submission, emissions were calculated as being 5.8 Mt CO_2 eq lower in 1990, 5.7 Mt CO_2 eq lower in 2005 and 5.8 Mt CO_2 eq lower in 2019 than in the previous submission, for recalculations of -12%, -10%, and -10%, respectively (Table 5–2).

Recalculations were primarily the result of the revision of the methodology used to calculate direct N_2O emissions from agricultural soils, which reduced emission factors for mainly dry areas of the prairies and for the application of nitrogen to perennial lands. To a lesser extent, changes resulted from (i) the implementation of the climate-specific EF_4 emission factor from the 2019 Refinement to the 2006 IPCC Guidelines; (ii) a correction to inorganic N fertilizer activity data for 2019; (iii) a correction to the IPCC default nitrogen excretion rates for swine, based on a corrigenda to Volume 4, Chapter 10 of the 2006 IPCC Guidelines; and (iv) the implementation of methodologies to estimate changes in SOC impacted by crop productivity changes and manure application (see Chapter 6). Lastly, minor adjustments were made due to the spatial distribution of crop areas and livestock populations and error corrections. (See Table 5–2, Table 5–3 and Annex 3.4).

Rice is not produced in Canada and is not a source of CH_4 emissions. Prescribed burning of savannas is not practised in Canada.

For each emission source category, a brief introduction and a brief description of methodological issues, uncertainties and time-series consistency, quality assurance/quality control (QA/QC) and verification, recalculations, and planned improvements are provided in this chapter. The detailed inventory methodologies and sources of activity data are described in Annex 3.4.

Table 5–2 **Quantitative Summary of Recalculations for the Agriculture Sector in 2022 NIR**

		Recalculations (kt CO_2 eq)							
		1990	2000	2005	2015	2016	2017	2018	2019
Previous submission (2021 NIR)		47 000	57 000	60 000	58 000	59 000	58 000	59 000	59 000
Current submission (2022 NIR)		41 000	51 000	54 000	52 000	53 000	52 000	53 000	53 000
Change due to continuous improvement or refinement:									
Revised Methodology for the Calculation of Soil N_2O									
Agricultural Soils	kt CO_2 eq	-5 507	-5 426	-5 141	-5 563	-5 642	-5 550	-5 481	-5 840
	%	-12	-9.5	-8.6	-10	-10	-10	-9.2	-9.9
Implementation of EF_4 from the 2019 Refinement to the 2006 IPCC Guidelines									
Manure Management	kt CO_2 eq	-29	-92	-119	-90	-93	-93	-91	-89
	%	-0.06	-0.16	-0.20	-0.15	-0.16	-0.16	-0.15	-0.15
Agricultural Soils	kt CO_2 eq	-107	-236	-248	-316	-298	-294	-303	-312
	%	-0.23	-0.41	-0.41	-0.54	-0.50	-0.50	-0.51	-0.53
Correction to Inorganic Fertilizer N Activity Data from Statistics Canada									
Agricultural Soils	kt CO_2 eq	0	0	0	0	0	0	0	361.2
	%	0	0	0	0	0	0	0	0.61
Implementation of updated N excretion rate for Swine									
Manure Management	kt CO_2 eq	-20	-15	-14	-11	-11	-11	-11	-12
	%	-0.04	-0.03	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
Agricultural Soils	kt CO_2 eq	-26	-39	-43	-45	-47	-46	-46	-46
	%	-0.056	-0.068	-0.072	-0.077	-0.080	-0.080	-0.077	-0.077
Changes to Soil SOC impacting N Mineralization									
Agricultural Soils	kt CO_2 eq	-63	-179	-144	123	-209	-318	-280	-195
	%	-0.13	-0.31	-0.24	0.21	-0.35	-0.54	-0.47	-0.33
Revision of Activity Data and Error Correction									
Manure Management	kt CO_2 eq	8.6	13	16	14	14	15	15	14
	%	0.018	0.022	0.026	0.023	0.024	0.025	0.025	0.024
Agricultural Soils	kt CO_2 eq	-13	-35	-15	5.2	-27	0.47	-52	293
	%	-0.029	-0.061	-0.025	0.0089	-0.045	0.00081	-0.088	0.50
Field Burning of Agricultural Residues	kt CO_2 eq	0	0	0	0	0	-0.006	0	0
	%	0	0	0	0	0	-0.00001	0	0
Liming and Application of Urea and Other Carbon-Containing Fertilizers	kt CO_2 eq	0	0	0	0	0	0	0	47
	%	0	0	0	0	0	0	0	0.080

Table 5–3 **Qualitative Summary of the Revisions to Methodologies, Corrections and Improvements Carried out for Canada's 2022 Submission**		
Correction or Improvement	Recalculation Categories Affected	Years Affected
Revised methodology for the calculation of N_2O emissions from agricultural soils	Direct N_2O emissions from agricultural soils	Complete time series
Implementation of the disaggregated EF_4 emission factor from the 2019 Refinement to the 2006 IPCC Guidelines	Indirect N_2O emissions from agricultural soils	Complete time series
Correction to inorganic fertilizer N activity data provided by Statistics Canada	Direct and indirect N_2O emissions from agricultural soils	2019
Implementation of updated N excretion rate for Swine, based on a revision to Volume 4, Chapter 10 of the 2006 IPCC Guidelines	Direct and indirect N_2O emissions from manure management and agricultural soils	Complete time series
Revisions to N mineralization from soil organic carbon from the implementation of methodologies to estimate changes in SOC impacted by crop productivity changes and manure application	Direct N_2O emissions from agricultural soils	Complete time series
Revision of activity data and error correction	CH_4 emissions from manure management, direct and indirect N_2O emissions from manure management and agricultural soils, CH_4 and N_2O emissions from crop residue burning, CO_2 from urea application	Complete time series

5.2. Enteric Fermentation (CRF Category 3.A)

5.2.1. Source Category Description

Methane (CH_4) is produced during the normal digestive process of enteric fermentation by herbivores typically raised in agricultural animal production. Microorganisms break down carbohydrates and proteins into simple molecules for absorption through the gastrointestinal tract, and CH_4 is produced as a by-product. This process results in an accumulation of CH_4 in the rumen that is emitted by eructation and exhalation. Some CH_4 is released later in the digestive process by flatulence, but this accounts for less than 5% of total emissions. Large ruminant animals, such as cattle, generate the most CH_4.

In Canada, animal production varies from region to region. In western Canada, beef cattle production dominates, combining both intensive production systems with high animal densities finished in feedlots and low-density, pasturing systems for cow-calf operations. Most dairy production occurs in eastern Canada in high-production, high-density facilities, and production has intensified significantly since 1990, affecting both milk productivity and management approaches. Eastern Canada has also traditionally produced swine in high-density, intensive production facilities. Over the past 20 years, some swine production has shifted to western Canada. Other animals that produce CH_4 by enteric fermentation, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boars and sheep, are raised as livestock, but populations of these animals have traditionally been low. In Canada, over 95% of Enteric Fermentation emissions come from cattle.

5.2.2. Methodological Issues

The diversity of animal production systems and regional differences in production facilities complicate emission estimation. For each animal category/subcategory, CH_4 emissions are calculated, by province, by multiplying the animal population of a given category/subcategory by its corresponding regionally derived emission factor.

For cattle, CH_4 emission factors are estimated using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodology, based on the equations provided in the 2006 IPCC Guidelines (IPCC, 2006). A national study by Boadi et al. (2004) broke down cattle subcategories, by province, into subannual production stages and defined their physiological status, diet, age class, sex, weight, growth rate, activity level and production environment. These data were integrated into IPCC Tier 2 equations to produce annual emission factors for each individual animal subcategory that take into account provincial production practices. The data describing each production stage were obtained by surveying beef and dairy cattle specialists across the country.

For dairy cattle, the basic subcategory classes developed by Boadi et al. (2004) were accurate for the mid-2000s when the Tier 2 model was populated; however, it was recognized that certain dairy production parameters were not static over time and these parameters could impact all aspects of emissions from the dairy sector. Further work was carried out and implemented in the 2018 inventory analysis to refine estimates of certain Tier 2 parameters for dairy and to create a time series that better captures changes in dairy production practices. Increased milk production associated with improved genetics, as well as improved feed quality in dairy cattle herds over the 1990–2020 time period, are reflected in a 24% increase in CH_4 emission factors from this animal category. As milk production increases, the requirement of energy for lactation (NEl) becomes greater and requires increased food consumption.

In beef cattle, changes in mature body weight influence maintenance and growth energy (NE_m and NE_g) requirements and, as a consequence, feed consumption. From 1990 to 2003, larger breeds became popular and emission factors increased by 7.4% during that period. Since then, non-dairy cattle weights have remained relatively stable, while slaughter animal weights have continued to increase, but at a lower rate. Emission factors have since decreased as a result of a combination of the stabilization of cattle weights and a shift in cattle subcategory populations. Since 2005, beef cow and replacement heifer populations have decreased substantially, while finishing animal populations (slaughter heifers and steers) have remained constant. As a result, the proportion of finishing animals in the national herd has increased from 17% to 20%. Since finishing animals have a lower emission factor, the overall emission factor for the Non-Dairy Cattle category has decreased from its peak in 2005.

For non-cattle animal categories, CH_4 emissions from the process of enteric fermentation continue to be estimated using the IPCC Tier 1 methodology. The poultry, rabbits and fur-bearing animal categories are excluded from the estimates for the Enteric Fermentation category since no emission factors are currently available.

Activity data consist of domestic animal populations for each animal category/subcategory, by province, and are obtained from Statistics Canada (Annex 3.4, Table A3–1). The data are based on the Census of Agriculture, conducted every five years and updated annually by semi-annual or quarterly surveys for cattle, swine and sheep.

5.2.3. Uncertainties and Time-Series Consistency

An uncertainty analysis was performed on the methodology used to estimate CH_4 emissions from agricultural sources using a Monte Carlo technique. The analysis considered the uncertainty in the parameters defined in Boadi et al. (2004) as they are used within the IPCC Tier 2 methodology equations. Details of this analysis can be found in Annex 3.4, section A3.4.2.4. Uncertainty distributions for parameters were taken from Karimi-Zindashty et al., (2012), although some additional parameters and updates were included in this analysis. For 2019, uncertainty ranges from the 2012 analysis are applied to new emission estimates. An uncertainty analysis of the updated dairy model has not yet been performed and reported uncertainty estimates are based on the methodology of Boadi et al. (2004).

The uncertainty range for CH_4 emissions from the Enteric Fermentation category was similar in 1990 and 2020, and mean estimates in 2020 lie within a range of -14% to +17% (Table 5–4). Over the time series of 1990 to 2020, mean emissions are estimated to have increased by 1.3 Mt CO_2 eq, a 6% increase. The observed increase falls within an uncertainty range of +4% to +13%.

The uncertainty in emissions was mainly associated with the calculation of the emission factor. The range of uncertainty around the calculation of the Non-Dairy Cattle Tier 2 emission factors was the highest (41%). Calculations of uncertainty in emissions and emission factors were the most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular the methane conversion rate (Y_m) and the factor associated with the estimation of the net energy of maintenance (Cfi) (Karimi-Zindashty et al., 2012).

The methodology and parameter data used in the calculation of emission factors are consistent throughout the entire time series (1990–2020), with the exception of milk production for dairy cattle. The time series of milk production from 1990 to 1998 is estimated. Two milk production data sets exist in Canada: (1) publishable records that represent production data for genetically elite animals within the Canadian herd from 1990 to present, and (2) management records that provide a more accurate estimate of production from the entire Canadian dairy herd from 1999 to present. An estimate of milk production for the entire Canadian herd from 1990 to 1998 was calculated on the basis of the average ratio between the publishable and the management data from 1999 to 2007.

Table 5–4 **Uncertainty in Estimates of CH_4 Emissions from Enteric Fermentation**

Animal Category	Uncertainty Source		Mean Value[a,b]	2.5% Prob.	97.5% Prob.
Dairy Cattle	Population (1 000 head)		974	923 (-5.2%)	1 025 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		143	122 (-15%)	171 (+19%)
	Emissions (Mt CO_2 eq)		3.5	2.9 (-16%)	4.2 (+20%)
Non-dairy Cattle	Population (1 000 head)		10 776	10 570 (-1.9%)	10 996 (+2.0%)
	Tier 2 Emission Factor (kg/head/year)		71	60 (-15%)	84 (+18%)
	Emissions (Mt CO_2 eq)		19	16 (-16%)	23 (+21%)
Other Animals	Emissions (Mt CO_2 eq)		1.1	0.87 (-18%)	1.2 (+18%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	22	19 (-16%)	27 (+21%)
		2020	24	20 (-14%)	28 (+17%)
	Trend	1990–2020	1.3 (+6.0%)	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 2020.

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 2020.

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 take into account specific regional management influences on emissions, replacing IPCC defaults currently used in the emission model, as has been done for Dairy Cattle. Details of this review can be found in Annex 3.4. A recent top-down quality assurance study was carried out using low-altitude aircraft-based flux technology (Desjardins et al., 2018). Though reconciling the top-down estimates with the bottom-up estimates was challenging due to difficulties in differentiating agricultural CH_4 emissions from wetland emissions, the top down estimates were consistent with the bottom-up estimates in areas where wetland emissions were minimal.

5.2.5. Recalculations

No recalculations to Enteric Fermentation occurred in the 2022 NIR submission (Table 5–5).

Table 5–5 **Recalculations of Emission Estimates and Their Impact on Emission Trends and Total Agricultural Emissions from Enteric Fermentation, Manure Management CH_4 and Manure Management N_2O**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change Category Emissions (%)	Old Trend (%)	New Trend (%)
Manure Management CH_4	1990	2021	2 453	8.5	0.35	Long term (1990–2019)	
		2022	2 461			58	58
	2005	2021	3 893	15	0.39		
		2022	3 908			Short term (2005–2019)	
	2019	2021	3 876	14	0.37	0	0
		2022	3 891				
Manure Management - Direct N_2O	1990	2021	3 062	-20	-0.64	Long term (1990–2019)	
		2022	3 042			9	10
	2005	2021	4 102	-14	-0.34		
		2022	4 088			Short term (2005–2019)	
	2019	2021	3 348	-12	-0.36	-18	-18
		2022	3 336				
Manure Management - Indirect N_2O	1990	2021	613	-29	-4.8	Long term (1990–2019)	
		2022	584			14	5
	2005	2021	838	-118	-14		
		2022	720			Short term (2005–2019)	
	2019	2021	700	-89	-13	-16	-15
		2022	611				

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 timeline for changes to dairy feed in recent years.

A study with Canadian experts in the beef industry to update and improve the beef production model, intended to characterize variability in animal management strategies in different regions across Canada, was carried out. Work is ongoing to evaluate how, and if, other drivers of change can be integrated into the IPCC Tier 2 calculation structure.

5.3. Manure Management (CRF Category 3.B)

In Canada, the animal waste management systems (AWMS) typically used in animal production include (1) liquid storage, (2) solid storage and drylot, and (3) pasture and paddock. To a lesser extent, AWMS also include other systems such as composting and biodigesters. No manure is burned as fuel.

Both CH_4 and N_2O are emitted during handling and storage of livestock manure. The magnitude of emissions depends on the quantity of manure handled, its characteristics, and the type of manure management system. In general, poorly aerated manure management systems generate high CH_4 emissions but relatively low N_2O emissions, whereas well-aerated systems generate high N_2O emissions but relatively low CH_4 emissions.

Manure management practices vary regionally, by animal category, and over time. Dairy, swine and poultry production occurs in modern high-density production facilities. The dairy industry has experienced a shift in manure storage practices since 1990, with larger operations with liquid systems being replaced by smaller operations with solid systems. The swine industry produces large volumes of liquid manure, and there has been an increase in the use of liquid manure systems in swine production since 1990, while poultry manure is predominantly managed in solid form. Both swine and poultry manure are spread on a limited land base. Feedlot beef production results in large volumes of dry lot and solid manure, whereas low-density pasturing systems for beef result in widely dispersed manure in pastures and paddocks. Other animals, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boars, sheep, and mules and asses, are generally raised in pastured and/or medium-density production facilities producing mainly solid manure. Fur-bearing animals also produce solid manure.

5.3.1. CH_4 Emissions from Manure Management (CRF Category 3.B (a))

5.3.1.1. Source Category Description

Shortly after manure is excreted, the decomposition process begins. In well-aerated conditions, decomposition is an oxidation process producing CO_2. However, if little oxygen is present, carbon is reduced, resulting in the production of CH_4. The quantity of CH_4 produced depends on manure characteristics and on the type of manure management system. Manure characteristics are, in turn, linked to animal category and animal nutrition.

5.3.1.2. Methodological Issues

Methane emissions from Manure Management are calculated for each animal category/subcategory by multiplying its population by the corresponding emission factor (see Annex 3.4 for detailed methodology). The animal population data are the same as those used for the Enteric Fermentation emission estimates (section 5.2.2). Methane emission factors for Manure Management are estimated using the IPCC Tier 2 methodology (IPCC, 2006).

Tier 2 parameters were taken from expert consultations described in Boadi et al. (2004) and Marinier et al. (2004, 2005) or from the 2006 IPCC Guidelines. For dairy and beef cattle, the Boadi et al. (2004) Tier 2 animal production model was used to derive gross energy of consumption (GE). However, for dairy cattle and swine, some parameters within the model were replaced with updated values in order to better capture trends in feeding practices and/or animal weights, as described in Annex 3.4. In particular, for dairy cattle, the digestibility (DE) of feed is responsive to animal diet, and for swine, volatile solids excreted in manure are adjusted based on trends in body weights and growth rates. Volatile solids (VS) were estimated using Equation 10.23 of the 2006 IPCC Guidelines and manure ash contents from Marinier et al. (2004). For all other livestock, parameters taken from Marinier et al. (2004) were used to calculate VS on the basis of ash content and digestible energy derived from expert consultations. Urinary energy (UE) coefficients were applied according to the 2006 IPCC Guidelines. VS for swine were corrected for animal mass as described in Annex 3.4. For sheep and poultry categories, different parameters were used for animal subcategories based on animal size for lambs and adult sheep and turkeys, broilers and layers in the poultry category.

Emission factors were derived using the CH_4 producing potential (B_0), CH_4 conversion factors (MCF) and the proportion of manure handled by AWMS for each animal category. For major livestock categories other than dairy and swine, the MCF was taken from the 2006 IPCC Guidelines and AWMS proportions were taken from Marinier et al. (2005) for each province, taking into account regional differences in production practices and manure storage systems. For swine and dairy cattle, a manure storage system time series was developed in order to track changes in the proportion of manure in AWMS subsystems with and without crust and covers. Values of MCF taken from the 2006 IPCC Guidelines were assigned to AWMS subsystems, and a weighted MCF was calculated for each AWMS based on the proportion of manure in each subsystem. For minor animals (fur-bearing animals, rabbits, deer and elk, and mules and asses), Tier 1 emission factors were used. A more complete description of the derivation of the proportional distribution of manure storage systems is provided in Annex 3.4, section A3.4.3.3.

Increases in cattle emission factors over the 1990–2020 period (see Annex 3.4.3) reflect higher gross energy intake for dairy cattle due to changes in feed, herd characteristics and increased milk productivity. Most importantly, for dairy, emission factors also reflect trends in manure storage practices, primarily, a shift from solid systems to liquid systems. For non-dairy cattle, changes are due to changes in live body weights (see section 5.2.2). Changes in swine emission factors (see Annex A3.4.3.6) for sows is related to the shift in swine production from eastern to western Canada and for growing swine are a result of increases in growth rates and final carcass weights.

5.3.1.3. Uncertainties and Time-Series Consistency

The uncertainty analysis of CH_4 emissions from agricultural sources using the Monte Carlo technique included CH_4 emissions from management of manure. The analysis used parameter estimates and uncertainty distributions from Marinier et al. (2004) supplemented with information from Karimi-Zindashty et al. (2012) and additional and updated parameters specific to this analysis. Details of this analysis can be found in Annex 3.4, section A3.4.3.8.

The CH_4 emission estimate of 3.9 Mt CO_2 eq from manure management of Canadian livestock in 2020 lies within an uncertainty range of -28% to +23% (Table 5–6). The CH_4 emission estimate from manure management in 1990, 2.5 Mt CO_2 eq, has a slightly larger uncertainty range, -44% to +36%, due to greater uncertainty associated with the type of manure management systems in 1990. The estimate of a 58% increase in mean emissions between 1990 and 2020 lies within an uncertainty range of +45% to +66%.

As was the case with the Enteric Fermentation category, most uncertainty in the emission estimate was associated with the calculation of the emission factor. The uncertainty range around the mean emission factor was as high as 110% in the case of dairy cattle. The uncertainty in emissions was most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular the MCF that was applied to all regions of Canada and all animal types and the maximum methane production capacity (B_0) (Karimi-Zindashty et al., 2012). An uncertainty analysis on the new dairy and swine models has not yet been performed, but because the MCF factor is driving uncertainty for manure management, it is not expected that changes to these models would have a large impact on national manure management uncertainty. The introduction of an AWMS time series for the dairy and swine sectors may however, play an important role in influencing the trend uncertainty for manure management emissions.

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2020), with the exception of milk production for dairy cattle and bull weights. Milk production from 1990 to 1999 in Ontario and the western provinces, and bull carcass weights, were estimated as described in section 5.2.3.

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

Animal Category	Uncertainty Source		Mean Value[a]	2.5% Prob.[b]	97.5% Prob.
Dairy Cattle	Population (1 000 head)		974	923 (-5.2%)	1 025 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		39	22 (-45%)	53 (+37%)
	Emissions (Mt CO_2 eq)		0.95	0.52 (-45%)	1.30 (+37%)
Non-dairy Cattle	Population (1 000 head)		10 776	10,570 (-1.9%)	10 996 (+2.0%)
	Tier 2 Emission Factor (kg/head/year)		3.7	2.8 (-25%)	5.4 (+45%)
	Emissions (Mt CO_2 eq)		1	0.7 (-27%)	1.52 (+51%)
Swine	Population (1 000 head)		14 043	13,710 (-2.4%)	14 382 (+2.4%)
	Tier 2 Emission Factor (kg/head/year)		4.8	2.2 (-54%)	7.0 (+45%)
	Emissions (Mt CO_2 eq)		1.7	0.9 (-49%)	2.41 (+42%)
Other Animals	Emissions (Mt CO_2 eq)		0.24	0.17 (-31%)	0.28 (+14%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	2.5	1.4 (-44%)	3.3 (+36%)
		2020	3.9	2.8 (-28%)	4.8 (+23%)
	Trend	1990–2020	1.4 (+58%)	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 2020.

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 2020.

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 form. The IPCC Tier 2 CH_4 emission factors for manure management practices by all animal categories derived from Marinier et al. (2004) have been reviewed by independent experts (Patni and Desjardins, 2004). These documents have been archived in electronic form.

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Internal Tier 2 QC checks carried out in 2010–2011 included a complete review and rebuild of calculation methodology, input data and review and compilation of Canadian research on manure management (MacDonald and Liang 2011). No specific bias can be clearly identified in the IPCC Tier 2 model parameters due to the high variability in research results and the lack of supporting information for research carried out on manure storage installations. There is no clear standard for evaluating whether IPCC parameters are appropriate for estimating emissions from manure management systems in the Canadian context. More standardized and detailed research is required in Canada to improve upon the current Tier 2 methodology. Details of this review can be found in Annex 3.4, section A3.4.3.7.

5.3.1.5. Recalculations

Minor recalculations occurred to methane emissions from manure management for all years due to a correction to the weighting of swine emission factors, and revisions to the spatial distribution of populations, which altered the weighting of manure management system fractions for bulls and calves. These changes resulted in an increase in emissions of 8.5 kt CO_2 eq in 1990 and 15 kt CO_2 eq in 2005 and 14 kt CO_2 eq in 2019. The recalculations did not alter the short-term or long-term trend (Table 5–5).

5.3.1.6. Planned Improvements

Analysis of the manure management model suggested that improvements could be made to the values used for the distribution of AWMS based on Statistics Canada's farm environmental management surveys (FEMS). Those data, combined with Canadian publications on livestock management (Sheppard et al., 2009a, 2009b, 2010, 2011a, 2011b; Sheppard and Bittman, 2011, 2012), have provided the basis for a new manure management time series for dairy and swine production in Canada, and work is being considered for other major livestock categories. Further refinements to parameters used in the calculation of VS based on changes in animal feed are being considered for implementation in the medium-term.

5.3.2. N_2O Emissions from Manure Management (CRF Category 3.B (b))

5.3.2.1. Source Category Description

The production of nitrous oxides (N_2O) during storage and treatment of animal waste occurs during nitrification and denitrification of nitrogen contained in the manure. Nitrification is the oxidation of ammonium (NH_4+) to nitrate (NO_3−), and denitrification is the reduction of NO_3− to N_2O or N_2. Manure from the Non- Dairy Cattle, Sheep, Goats Horses, Deer and Elk, Mules and Assess, Wild Boar and Fur-bearing Animals categories are mainly handled with a solid and dry lot system, which is the type of manure management system that emits the most N_2O. N_2O emissions from urine and dung deposited by grazing animals are reported separately (see section 5.4.1.4).

5.3.2.2. Methodological Issues

N_2O emissions from Manure Management are estimated for each animal category by multiplying the animal population of a given category by its nitrogen excretion rate and by the emission factor associated with the AWMS.

For dairy cattle, nitrogen excretion is calculated using the mass balance approach provided in the IPCC Tier 2 methodology. Nitrogen intake is calculated based on GE and the percentage crude protein in the animal diet, and nitrogen retention is calculated using milk production and cattle weight statistics as described in Annex 3.4. Nitrogen excretion is based on the difference between nitrogen intake and retention. Default IPCC N_2O emission factors are assigned to AWMS subsystems (Annex 3.4.3.3), and weighted AWMS N_2O emission factors are developed using the proportion of manure handled by each AWMS subsystem.

For swine, nitrogen excretion is calculated for market and breeding animals using the IPCC Tier 1 methodology, using a country-specific animal mass time series for market swine. Default IPCC N_2O emission factors are assigned to AWMS subsystems (Annex 3.4.3.3), and weighted AWMS N_2O emission factors are developed using the proportion of manure handled by each AWMS subsystem.

For all other livestock categories, nitrogen excretion is estimated using the IPCC Tier 1 methodology. The average annual nitrogen excretion rates for domestic animals are taken from the 2006 IPCC Guidelines.

The animal characterization data are the same as those used for estimates for Enteric Fermentation (section 5.2) and Manure Management (section 5.3.1). The 2006 IPCC default emission factors for a developed country with a cool climate are used to estimate manure nitrogen emitted as N_2O for each type of AWMS.

5.3.2.3. Uncertainties and Time-Series Consistency

An uncertainty analysis using the Monte Carlo technique was carried out to estimate emissions of N_2O from agricultural sources (Karimi-Zindashty et al., 2014). For N_2O emissions from Manure Management, the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines and all uncertainty in AWMS systems, animal populations and characterizations were identical to those used in the analysis of CH_4 from Enteric Fermentation and Manure Management defined in sections 5.2.3 and 5.3.1.3. Details of this analysis can be found in Annex 3.4, section A3.4.6.

The estimate of direct N_2O emissions of 3.3 Mt CO_2 eq from Manure Management in 2020 lies within an uncertainty range of 1.9 Mt CO_2 eq (-43%) to 5.0 Mt CO_2 eq (+51%) (Table 5–7). Most uncertainty is associated with the IPCC Tier 1 emission factor (±100% uncertainty). Due to the size of the N_2O model, the initial uncertainty analysis was limited to providing sound estimates of uncertainty for emission source categories and a basic sensitivity analysis. A complete analysis of the trend uncertainty has not yet been completed due to limitations in software capabilities. An uncertainty analysis of the new dairy and swine models has not yet been performed.

The same methodology, emission factors and data sources are used for the entire time series (1990–2020).

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 are documented and archived in both paper and electronic form. A complete Tier 2 QC was carried out on all calculation processes and parameters during the rebuilding of the agricultural N_2O emission database.

There are very few published data on N_2O emissions from manure management and storage in Canada or in regions with practices and climatic conditions comparable to those of Canada. More standardized and detailed research is required in Canada to improve on the current methodology.

5.3.2.5. Recalculations

Direct N_2O emissions from manure management were recalculated for all years (Table 5–5) due to a revision to the nitrogen excretion rate for swine, and changes in the spatial distribution of livestock. The net impact of these changes was a decrease in emissions of 20 kt CO_2 eq in 1990, 14 kt CO_2 eq in 2005 and 12 kt CO_2 eq in 2019. The recalculations increased the long-term trend from 9% to 10% but did not alter the short-term trend (Table 5–5).

5.3.2.6. Planned Improvements

Data from direct measurements of N_2O emissions from manure management in Canada are scarce. Recent scientific advances in analytical techniques allow direct measurements of N_2O emissions from point sources. However, it will likely take several years before N_2O emissions can be reliably measured and verified for various manure management systems in Canada.

As noted in section 5.3.1.6, implementation of an AWMS time series is the main source of improvement available for this emission source. Improvements to dairy and swine have been implemented based on Statistics Canada farm environmental management surveys, and plans are in place to incorporate this analysis for other livestock categories.

Furthermore, as noted in section 5.2.6, data have been collected to develop a time series that accounts for changes in animal nutrition and country-specific nitrogen excretion rates. These data have been integrated for dairy cattle, but similar analysis is still to be completed for swine. For select other livestock categories, changes will be incorporated over the medium term.

Further uncertainty analyses will be carried out to establish trend uncertainty and consider the changes in the livestock models over the medium term.

5.3.3. Indirect N_2O Emissions from Manure Management (CRF Category 3.B (c))

5.3.3.1. Source Category Description

The production of N_2O from manure management can also occur indirectly through NH_3 volatilization and leaching of N during storage and handling of animal manure. A fraction of the nitrogen in manure that is stored is transported off-site through volatilization in the form of NH_3 and NO_x and subsequent redeposition. Furthermore, solid manure exposed to rainfall will be prone to loss of N through leaching and runoff. The nitrogen that is transported from the manure storage site in this manner is assumed to undergo subsequent nitrification and denitrification elsewhere in the environment and, as a consequence, to produce N_2O.

5.3.3.2. **Methodological Issues**

Indirect emissions of N_2O from manure management are estimated by applying N loss factors to the quantity of manure N contained in each AWMS, and then multiplying by an N_2O emission factor. The N loss factors are calculated differently for both dairy cattle and swine, compared with other livestock categories.

For dairy cattle and swine, the amount of manure nitrogen subject to loss by leaching and volatilization of NH_3 and NO_x during storage is estimated using a revised version of the Canadian NH_3 emission model (Sheppard et al., 2010; Sheppard et al., 2011b; Chai et al., 2016) to generate ecoregion-specific N loss factors by animal type and manure management system.

For all other livestock categories, the amount of manure nitrogen subject to losses from volatilization of NH_3 during storage is calculated for each animal type and manure management system using default values provided in the 2006 IPCC Guidelines. Leaching losses are not estimated because no country-specific leaching loss factors are available.

Emission factors of N_2O from volatilization during manure storage and handling in dry and wet climates are taken from the 2019 Refinement to the 2006 IPCC Guidelines, whereas the N_2O emission factors for leaching of N from manure storage and handling are taken from the 2006 IPCC Guidelines, for all livestock categories.

5.3.3.3. **Uncertainties and Time-Series Consistency**

A full uncertainty analysis using the Monte Carlo technique has not been carried out to estimate indirect emissions of N_2O from manure management. The uncertainty associated with livestock populations, manure N excretion rates, AWMS, fractions of N leaching and NH_3 volatilization along with indirect N_2O emission factors are available but has not been used in a Monte Carlo analysis to date. Uncertainty is assumed to be equivalent to the uncertainty associated with indirect emissions from agricultural soils.

The same methodology, emission factors and data sources are used for the entire time series (1990–2019).

5.3.3.4. **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) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodology and databases are documented and archived in electronic form.

5.3.3.5. **Recalculations**

Indirect N_2O emissions from manure management were recalculated due to the implementation of the default N_2O emission factors (EF_4) from the 2019 Refinement to the 2006 IPCC Guidelines, which decreased emissions in drier regions and increased emissions in more humid regions. Minor revisions occurred as a result of changes in the spatial distribution of livestock. The net impact of these changes was a reduction in emissions of 0.005 kt CO_2 eq in 1990 and in increases of 0.001 kt CO_2 eq in 2005 and 0.05 kt CO_2 eq in 2018. The recalculations did not alter the short-term or long-term emission trends (Table 5–5).

5.3.3.6. **Planned Improvements**

As noted in section 5.3.1.6, country-specific NH_3 volatilization fractions and N leaching coefficients stratified by livestock subcategory and AWMS have been implemented for dairy and swine, and similar emission factors have been developed for beef cattle. Non-Dairy Cattle Tier 2 parameters may be revised as necessary, based on more recent information.

5.4. N_2O Emissions from Agricultural Soils (CRF Category 3.D)

N_2O emissions from agricultural soils consist of direct and indirect emissions. N_2O emissions from anthropogenic nitrogen inputs occur both directly from the soils to which the nitrogen is added and indirectly. Changes in crop rotations and management practices, such as tillage and irrigation, affect direct N_2O emissions by altering the mineralization rates of organic nitrogen, nitrification and denitrification. Indirect emission occur through two pathways: (1) the volatilization of nitrogen from inorganic fertilizer and manure applied to fields as NH_3 and NO_x and its subsequent deposition off-site; and (2) the leaching and runoff of inorganic fertilizer, manure, biosolids and crop residue N.

5.4.1. Direct N_2O Emissions from Managed Soils (CRF Category 3.D.1)

Direct sources of N_2O from soils include the application of organic and inorganic nitrogen fertilizers, crop residue decomposition, losses of soil organic matter through mineralization, and cultivation of organic soils. In addition, Canada also reports two country-specific sources of emissions/removals: tillage practices and irrigation. Emissions/removals from these sources are estimated on the basis of nitrogen inputs from the application of organic and inorganic nitrogen fertilizers and crop residue nitrogen.

Table 5–7 **Uncertainty Estimates for N_2O Emissions from Manure Management and Agricultural Soils**				
Emission Source		Mean Value[a]	2.5% Prob.[b]	97.5% Prob.
		Mt CO_2 eq		
Manure Management				
Direct Emissions		3.3	1.9 (-43%)	5.0 (+51%)
Indirect Emissions		0.61	0.24 (-60%)	1.0 (+70%)
Agricultural Soils (N_2O)		**21**	**13 (-36%)**	**31 (+52%)**
Direct N_2O Emissions from Managed Soils		16	12 (-28%)	22 (+34%)
	Inorganic N Fertilizers	11	6.8 (-35%)	15 (+43%)
	Organic N Fertilizers	1.5	1.0 (-33%)	2.2 (+41%)
	Crop Residues	4.5	2.9 (-35%)	6.5 (+45%)
	Cultivation of Organic Soils	0.061	0.013 (-79%)	0.12 (+96%)
	Mineralization Associated with Loss of Soil Organic Matter	0.83	0.54 (-35%)	1.2 (+45%)
	Urine and Dung Deposited by Grazing Animals	0.2	0.080 (-60%)	0.35 (+75%)
	Soil N Mineralization/Immobilization	-1.2	-0.67 (-44%)	-1.8 (+55%)
Indirect N_2O Emissions from Managed Soils		4.2	1.7 (-60%)	7.1 (+70%)
	Atmospheric Deposition	1	0.25 (-75%)	2.1 (+110%)
	Leaching and Runoff	3.2	0.64 (-80%)	6.4 (+100%)

Notes:

a. Mean value reported from database.

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

5.4.1.1. Inorganic Nitrogen Fertilizers

5.4.1.1.1. Source Category Description

Inorganic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen that is not taken up by the plant or prior to being taken up by the crop undergoes transformations, such as nitrification and denitrification, which can release N_2O. Emission factors associated with fertilizer application depend on many factors, such as soil texture, climate, topography, farming practices and environmental conditions (Gregorich et al., 2005; Rochette et al., 2008a; Rochette et al., 2018).

5.4.1.1.2. Methodological Issues

Canada has developed a Tier 2 methodology using country-specific emission factors to estimate N_2O emissions from inorganic nitrogen fertilizer application on agricultural soils, which takes into account moisture regimes, soil texture, nitrogen sources, cropping systems, and topographic conditions. Emissions of N_2O are estimated for each ecodistrict and are scaled up to provincial and national scales. The amount of nitrogen applied to the land is estimated from yearly nitrogen fertilizer shipments to Canadian agriculture markets. All inorganic nitrogen fertilizers sold by retailers are assumed to be applied for crop production purposes in Canada. The quantity of fertilizers applied to forests is deemed negligible. More details on the inventory method can be found in Annex 3.4.

5.4.1.1.3. Uncertainties and Time-Series Consistency

The uncertainty analysis, using the Monte Carlo technique on the methodology used to estimate emissions of N_2O from agricultural sources noted in section 5.3.2.3, included all direct and indirect emissions from soils (Table 5–7). For N_2O emissions from fertilizer, the analysis considered the uncertainty in the parameters defined in the previous country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors, the uncertainty in provincial fertilizer sales, and the uncertainty in crop areas and production at the ecodistrict level. An updated Monte Carlo uncertainty analysis is planned to quantify uncertainty included in the updated country-specific soil N_2O emission factors. The quantification of uncertainty is expected to be improved due to the larger and more complete dataset for quantifying emission factors. As a consequence, uncertainty analysis will rely less on expert judgement to establish probability distributions for factors used in deriving regional emission factors.

Based on past analysis, it is estimated that N_2O emissions of 11 Mt CO_2 eq from the application of fertilizers on agricultural soils in 2020 lies within a range of 6.8 Mt CO_2 eq (-35%) to 15 Mt CO_2 eq (+43%) (Table 5–7).

The same methodology and emission factors are used for the entire time series (1990–2020).

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_2O associated with inorganic fertilizer nitrogen applications on agricultural soils in Canada vary on a site-by-site basis. There is, however, agreement between the previous IPCC default emission factor of 1% (IPCC, 2006), the revised humid environment emission factor of 1.6% (IPCC, 2019), the measured emission factor of 1.2% in eastern Canada, excluding emissions during the spring thaw period (Gregorich et al., 2005; Desjardins et al., 2010), and the range of emission factors developed in this revised methodology.

5.4.1.1.5. Recalculations

Recalculations are primarily due to the implementation of revised soil N_2O emission factors specific to nitrogen sources and cropping systems. The emission factors are based on a new exponential relationship relating emission factors to precipitation using updated Canadian literature (see Annex 3.4), and are further responsive to changes in annual and perennial crop areas.

Other recalculations were due to a correction to N fertilizer shipment activity data provided by Statistics Canada for year 2019, and minor changes to the spatial distribution of livestock and crop areas.

Emissions decreased by 1.3, 1.5 and 1.9 Mt CO_2 eq in 1990, 2005 and 2019, respectively (Table 5–8). The short-term trend increased from +64% to +76%, while the long-term trend increased from +98% to +111%.

5.4.1.1.6. Planned Improvements

The current method does not account for mitigation measures that reduce soil N_2O emissions. These mitigation measures may include practices such as enhanced efficiency fertilizers, split nitrogen application as well as nitrogen fertilizer placement. Canada plans to develop more robust ratio factors to account for these mitigation measures in the medium-term of three to 5 years as research results and activity data become available.

Table 5–8 **Recalculations of N_2O Emission Estimates and Their Impact on Emission Trends from Fertilizer Application, Crop Residue Decomposition, and Urine and Dung Deposited by Grazing Animals**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change in Category Emissions (%)	Old Trend (%)	New Trend (%)
Inorganic N Fertilizers	1990	2021	5 720	-1 273	-22	Long term (1990–2019)	
		2022	4 447			98	111
	2005	2021	6 891	-1 540	-22		
		2022	5 351			Short term (2005–2019)	
	2019	2021	11 319	-1 917	-17	64	76
		2022	9 403				
Organic N Fertilizers	1990	2021	2 061	-903	-44	Long term (1990–2019)	
		2022	1 158			16	33
	2005	2021	2 547	-1 061	-42		
		2022	1 486			Short term (2005–2019)	
	2019	2021	2 385	-844	-35	-6	4
		2022	1 541				
Crop Residue Decomposition	1990	2021	4 415	-1 908	-43	Long term (1990–2019)	
		2022	2 507			43	69
	2005	2021	4 879	-1 802	-37		
		2022	3 077			Short term (2005–2019)	
	2019	2021	6 304	-2 077	-33	29	37
		2022	4 228				
Urine and Dung Deposited by Grazing Animals	1990	2021	224	-0.22	-0.10	Long term (1990–2019)	
		2022	224			-9	-9
	2005	2021	258	-0.34	-0.13		
		2022	258			Short term (2005–2019)	
	2019	2021	203	-0.36	-0.18	-21	-21
		2022	203				

5.4.1.2. Organic Nitrogen Fertilizers Applied to Soils

5.4.1.2.1. Source Category Description

The application of organic nitrogen sources as fertilizer to agricultural soils can increase the rate of nitrification and denitrification and result in enhanced N_2O emissions. Emissions from this category include (1) all manure managed by drylot, liquid and other animal waste management systems, and (2) human biosolids managed by municipal waste water treatment plants.

5.4.1.2.2. Methodological Issues

Like the methodology used to estimate N_2O emissions from inorganic nitrogen fertilizers, the method used to estimate N_2O emissions from organic manure applied to agricultural soils is a Tier 2 methodology using country-specific emission factors that takes into account moisture regimes (long-term growing season precipitation and potential evapotranspiration), soil texture, nitrogen sources, cropping systems, and topographic conditions. Emissions are calculated by multiplying the amount of organic nitrogen applied to agricultural soils by a weighted emission factor calculated for each ecodistrict, summed at the provincial and national levels. All manure that is handled by AWMS, 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. Biosolid nitrogen is applied to specific crop types per ecodistrict based on provincial regulations and crop requirements, and subsequent emissions are calculated using the country-specific Tier 2 emission factors for organic N.

5.4.1.2.3. Uncertainties and Time-Series Consistency

In the case of N_2O emissions from organic nitrogen fertilizer application, the uncertainty analysis considered the uncertainty in the parameters used in producing estimates of manure N noted in section 5.3.2.3 and the uncertainty defined in the previous country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors, as noted in section 5.4.1.1.3. An updated Monte Carlo uncertainty analysis is planned, in order to quantify the uncertainty included in the updated country-specific soil N_2O emission factors, including the ratio factor used for organic nitrogen. The quantification of uncertainty associated with emissions from organic N application is expected to be improved due to the larger and more complete dataset for differentiating organic nitrogen fertilizers from inorganic nitrogen fertilizers (Rochette et al., 2018; Liang et al., 2020) providing improved probability distributions around parameters.

Based on past analysis, it is estimated that N_2O emissions of 1.5 Mt CO_2 eq from application of Canadian livestock manure in 2020 lies within an uncertainty range of 1.0 Mt CO_2 eq (-33%) to 2.2 Mt CO_2 eq (+41%) (Table 5–7). The main source of uncertainty in the calculation of emissions from organic nitrogen fertilizer includes the slope of the regression equation for estimating N_2O emission factors, animal N excretion rates, emission factor modifiers for texture (RF_TX), tillage (RF_TILL) and N content of the biosolids.

The same methodology and emission factors are used for the entire time series (1990–2020).

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 are documented and archived in electronic form.

5.4.1.2.5. Recalculations

Recalculations are primarily due to the implementation of revised soil N_2O emission factors, specific to nitrogen sources and cropping systems. The emission factors implement a new exponential relationship between emission factors and precipitation based on updated Canadian literature (see Annex 3.4), and include ratio factors to adjust the emission factors for organic nitrogen and application to perennial cropland (see Annex 3.4). Additional recalculations to activity data occurred from the implementation of a revised nitrogen excretion rate for Swine, based on a corrigenda to Volume 4, Chapter 10 of the 2006 IPCC Guidelines.

Minor recalculations in organic fertilizers (manure and biosolids) occurred due to the changes in distribution of crops and livestock populations, which subsequently altered the spatial distribution of N on the agricultural landscape.

The emissions decreased by 0.9, 1.1, and 0.8 Mt CO_2 eq. in 1990, 2005 and 2019, respectively (Table 5–8). The short-term trend increased from -6% to +4%, and the long-term trend increased from +16% to +33%.

5.4.1.2.6. Planned Improvements

The current method does not account for mitigation measures that reduce soil N_2O emissions. These mitigation measures may include practices such as emission reductions associated with timing of application.

5.4.1.3. Crop Residues (CRF Category 3.D.1.4)

5.4.1.3.1. Source Category Description

When a crop is harvested, a portion of the crop is left in the field to decompose. The remaining plant matter is a nitrogen source that undergoes nitrification and denitrification and can thus contribute to N_2O production.

5.4.1.3.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of nitrogen contained in crop residues on annual and perennial cropland multiplied by corresponding emission factor at the ecodistrict level and scaled up to the provincial and national levels. The amount of nitrogen contained in crop residues is estimated using country-specific crop characteristics (Janzen et al., 2003). Emission factors are determined using the same approach as for organic nitrogen fertilizer application (section 5.4.1.2.2).

5.4.1.3.3. Uncertainties and Time-Series Consistency

For N_2O emissions from crop residue decomposition, the uncertainty analysis considered the uncertainty in crop production, as well as the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emissions of 4.5 Mt CO_2 eq from crop residue decomposition in 2020 lies within an uncertainty range of 2.9 Mt CO_2 eq (-35%) to 6.5 Mt CO_2 eq (+45%) (Table 5–8). The main sources of uncertainty in the calculation of emissions from crop residue decomposition include the slope of the regression equation for estimating N_2O emission factors and emission factor modifiers for texture (RF_TX) and tillage (RF_TILL). An updated Monte Carlo uncertainty analysis is planned, in order to account for uncertainty included in the updated country-specific soil N_2O emission factors, including the ratio factor used for organic nitrogen.

The same methodology and emission factors are used for the entire time series (1990–2020).

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) 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.

5.4.1.3.5. Recalculations

Recalculations are primarily due to the implementation of revised soil N_2O emission factors, as described in section 5.4.1.2.5. Minor recalculations occurred due to the changes in distribution of crops, which subsequently altered the spatial distribution of N and weighting of emission factors between perennial and annual crops.

Emissions decreased by 1.9 Mt CO_2 eq in 1990, 1.8 Mt CO_2 eq in 2005 and 2.1 Mt CO_2 eq in 2019, respectively (Table 5–8). As a result of these changes, the short-term emission trend increased from +29% to +37% and the long-term trend increased from 43% to 69%.

5.4.1.3.6. Planned Improvements

Future improvements will focus on differentiating organic nitrogen fertilizers from crop residue N over the mid-term of three to five years.

5.4.1.4. Urine and Dung Deposited by Grazing Animals (CRF Category 3.D.1.3)

5.4.1.4.1. Source Category Description

When urine and dung are deposited by grazing animals, nitrogen in the manure undergoes various transformations, such as ammonification, nitrification and denitrification. During these transformation processes, N_2O can be emitted.

5.4.1.4.2. Methodological Issues

N_2O emissions from manure excreted by grazing animals are calculated using a country-specific IPCC Tier 2 method that was derived from field flux measurements (Rochette et al., 2014; Lemke et al., 2012). Details of these new emission factors can be found in Annex 3.4, section A3.4.5. Emissions are calculated for each animal category by multiplying the number of grazing animals for that category by the appropriate nitrogen excretion rate and by the fraction of manure nitrogen available for conversion to N_2O.

5.4.1.4.3. Uncertainties and Time-Series Consistency

The uncertainty of the new estimates of N_2O emissions associated with urine and dung deposited by grazing animals was estimated on the basis of the previous uncertainty analysis using the parameters and uncertainty distributions defined in the Tier 1 methodology of the 2006 IPCC Guidelines with the exception of new emission factors. Animal populations, the proportion of animals on pasture systems and their characterizations were identical to those used in the analysis of CH_4 from the Enteric Fermentation and Manure Management categories defined in sections 5.2.3 and 5.3.1.3.

Under these assumptions, the estimate of N_2O emissions of 0.2 Mt CO_2 eq from pasturing Canadian livestock in 2020 lies within an uncertainty range of 0.08 Mt CO_2 eq (-60%) to 0.35 Mt CO_2 eq (+75%) (Table 5–7).

The same methodology and emission factors are used for the entire time series (1990–2020).

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

Revisions to the distribution of livestock populations resulted in small changes to N_2O emissions from urine and dung deposited by grazing animals. Emissions decreased by 0.22 kt CO_2 eq in 1990, 0.34 kt CO_2 eq in 2005 and 0.36 kt CO_2 eq in 2019 (Table 5–8), with no changes in long- or short-term trends.

5.4.1.4.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source. Further uncertainty work will be carried out to take into account changes made to the PRP model and to establish trend uncertainty over the medium term.

5.4.1.5. Mineralization Associated with Loss of Soil Organic Matter (CRF Category 3.D.1.5)

5.4.1.5.1. Source Category Description

Carbon loss in soils as a result of changes to land management practices, crop productivity and manure application, is accounted for within the Cropland category of the LULUCF sector (Chapter 6). Nonetheless, nitrogen mineralization associated with the loss of soil organic carbon contributes to the overall N balance of agricultural lands. This nitrogen, once in an inorganic form, is prone to loss in the form of N_2O during either nitrification or denitrification. As a result, this nitrogen must be taken into account because of its contribution to soil N_2O emissions.

5.4.1.5.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of nitrogen contained in soil organic matter that is lost as a result of changes in cropland management practices, crop productivity and/or manure application, multiplied by the emission factor at the ecodistrict level and scaled up to the provincial and national levels.

The quantity of soil organic carbon loss at an ecodistrict level from 1990 to 2020 is taken from carbon reported for the Cropland Remaining Cropland category of LULUCF, excluding the effect of forest land conversion to cropland (FLCL) within 20 years (i.e., N_2O emissions resulting from disturbance of CLCL, as the FLCL disturbances are already reported under LULUCF), perennial above-ground biomass and cultivation of histosols. A dataset containing soil organic carbon and nitrogen for all major soils in Saskatchewan was used to derive an average C:N ratio for cropland soils. Ecodistrict-based soil N_2O emission factors (EF_BASE) are the same as those used for the estimation of emissions from organic fertilizer application to annual crops. Emission factors are based on climate and soil characteristics for the individual ecodistrict in which carbon mineralization occurs.

5.4.1.5.3. Uncertainties and Time-Series Consistency

Uncertainty parameters are based on the standard deviation of the soil database, uncertainty estimates of carbon loss and the uncertainty around ecodistrict-based emission factors. Impacts to agricultural soil uncertainty will be re-evaluated during the next full round of uncertainty assessments when they are renewed. Due to the small contribution to total emissions, this source would not likely affect overall emission uncertainty. Currently, uncertainty estimates for this category are considered to be the same as uncertainty in emissions from crop residue decomposition.

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

Recalculations to N_2O emissions from the mineralization of soil organic matter occurred in all years 1990 to 2019 due to the implementation of methodologies to estimate soil organic carbon from changes in crop productivity and manure application, as described in Chapter 6.5.1.1. Emissions decreased by 0.26 kt CO_2 eq in 1990, 0.22 kt CO_2 eq in 2005, and 0.49 kt CO_2 eq in 2019 . The long-term trend increased from 104% to 122%, and the short-term trend decreased from 102% to 83%.

5.4.1.5.6. Planned Improvements

Similar to the crop residue N, future improvements will focus on differentiating N_2O emission factors between organic and inorganic N sources. The uncertainty for this category will be calculated in the next round of uncertainty analysis.

5.4.1.6. Cultivation of Organic Soils (CRF Category 3.D.1.6)

5.4.1.6.1. Source Category Description

Cultivation of organic soils (histosols) for crop production usually involves drainage, lowering the water table and increasing aeration, which enhance the decomposition of organic matter and nitrogen mineralization. The enhancement of decomposition upon the cultivation of histosols can result in greater denitrification and nitrification and thus in higher N_2O production (Mosier et al., 1998).

5.4.1.6.2. Methodological Issues

The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils. Emissions of N_2O are calculated by multiplying the area of cultivated histosols by the IPCC default emission factor.

Areas of cultivated histosols at a provincial level are not surveyed in the Census of Agriculture. Consultations with numerous soil and crop specialists across Canada have resulted in an estimated area of 16 kha of cultivated organic soils in Canada, a constant level for the period 1990–2020 (Liang et al., 2004a).

5.4.1.6.3. Uncertainties and Time Series Consistency

For N_2O emissions from organic soils, the uncertainty analysis considered the uncertainty in the area of cultivated organic soils and in the default emission factor.

The N_2O emission estimate of 0.061 Mt CO_2 eq from organic soils in 2020 lies within an uncertainty range of 0.01 Mt CO_2 eq (-79%) to 0.12 Mt CO_2 eq (+96%) (Table 5–7). The main source of uncertainty is in the IPCC Tier 1 default emission factor.

The same methodology and emission factors are used for the entire time series (1990–2020).

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 both paper and electronic form.

5.4.1.6.5. Recalculations

There were no recalculations in this source of emission estimates.

5.4.1.6.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.7. Changes in N_2O Emissions from Adoption of No-Till and Reduced Tillage

5.4.1.7.1. Source Category Description

This category is not derived from additional nitrogen inputs (i.e., fertilizer, manure or crop residue). Rather, it is implemented as a modification to N_2O emission factors to account for the change from conventional to conservation tillage practices—namely, reduced tillage (RT) and no-tillage (NT).

5.4.1.7.2. Methodological Issues

Compared with conventional or intensive tillage, the practice of direct seeding or no-tillage, as well as reduced tillage, results in changes to several factors that influence N_2O production, including decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content (McConkey et al. 1996, 2003; Liang et al., 2004b). As a result, compared with conventional tillage, conservation tillage (i.e., RT and NT) generally reduces N_2O emissions for the Prairies (Malhi and Lemke, 2007), and can increase N_2O emissions for the non-Prairie regions of Canada (Liang et al., 2020; Rochette et al., 2008b). Following an expert review process with Canadian agricultural research scientists, the tillage factor for prairie regions from Liang et al. (2020) was implemented, while the factor for non-prairie regions was not implemented, pending further analysis. The net result across the country is a reduction in emissions. This reduction is reported separately as a negative estimate (Table 5–7).

Changes in N_2O emissions resulting from the adoption of NT and RT are estimated through the modification of soil N_2O emission factors and applied to inorganic fertilizers, organic nitrogen applied to cropland, and crop residue nitrogen decomposition. This subcategory is kept separate from the fertilizer and crop residue decomposition source categories to preserve the transparency in reporting. However, this separation causes negative emissions to be reported. An empirically derived tillage factor (RF_TILL), defined as the ratio of mean N_2O fluxes on NT or RT to mean N_2O fluxes on IT (N_2ONT/N_2OIT), represents the effect of NT or RT on N_2O emissions (see Annex 3.4).

5.4.1.7.3. Uncertainties and Time-Series Consistency

For N_2O emissions from the adoption of conservation tillage practices, the uncertainty analysis considered the uncertainty in tillage practice areas, manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emission reductions of -2.4 Mt CO_2 eq from conservation tillage practices in 2020 lies within an uncertainty range of -44% to +55% based on the uncertainty range of combined emissions of tillage, irrigation and summerfallow practices (Table 5–7). Tillage practice calculations are dependent on all soil emission calculations, and uncertainty is therefore influenced by all factors described in previous uncertainty sections, in particular the emission factor modifier for tillage (RF_TILL).

The same methodology and emission factors are used for the entire time series (1990–2020).

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 both paper and electronic form.

5.4.1.7.5. Recalculations

Both the tillage ratio factors, and the soil N_2O emission factors to which they are applied, were revised in this submission, resulting in significant recalculations across the time series. Changes to the soil N_2O emission factors, and a description of tillage factors, are provided in Annex 3.4.

The changes increased the impact of tillage adoption on N_2O emissions by 0.11 Mt CO_2 eq in 1990, 0.34 Mt CO_2 eq in 2005 and 0.90 Mt CO_2 eq in 2019. These recalculations increased the impact of tillage adoption on the trend from 407% to 491% in the long term, and from 75% to 101% in the short term (Table 5–9).

5.4.1.7.6. Planned Improvements

Work is ongoing to develop level and trend uncertainty estimates using the IPCC Tier 2 method. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

Table 5–9 **Recalculations of N_2O Emission Estimates and Their Impact on Emission Trends from Conservation Tillage Practices and Irrigation**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change in Category Emissions (%)	Old Trend (%)	New Trend (%)
Conservation Tillage Practices	1990	2021	-295	-110.9	37.6	Long term (1990–2019)	
		2022	-406			407	491
	2005	2021	-852	-341.5	40.1		
		2022	-1193			Short term (2005–2019)	
	2019	2021	-1494	-903.2	60.4	75	101
		2022	-2398				
Irrigation	1990	2021	281	276.9	98.44	Long term (1990–2019)	
		2022	558			47	120
	2005	2021	332	451.9	136.0		
		2022	784			Short term (2005–2019)	
	2019	2021	413	812.4	196.8	24	56
		2022	1 225				

5.4.1.8. N_2O Emissions from Irrigation

5.4.1.8.1. Source Category Description

As in the case of tillage practices, the effect of irrigation on N_2O emissions is not derived from additional nitrogen input but rather reflects changes in soil conditions that affect N_2O emissions. Higher soil water content under irrigation increases the potential for N_2O emissions through increased biological activity, reducing soil aeration (Jambert et al., 1997) and thus enhancing denitrification.

5.4.1.8.2. Methodological Issues

The methodology is country-specific and is based on the assumptions that (1) irrigation water stimulates N_2O production in a way similar to rainfall and (2) irrigation is applied at rates such that the combined amounts of precipitation and irrigation water are equal to potential evapotranspiration at local conditions. Consequently, the effect of irrigation on N_2O emissions from agricultural soils was estimated using an EF_BASE estimated at a P=PE (precipitation equivalent to potential evapotranspiration) for the irrigated areas of a given ecodistrict (Liang et al., 2020). To improve transparency, the effect of irrigation on soil N_2O emissions is also reported separately from other source categories.

5.4.1.8.3. Uncertainties and Time-Series Consistency

For N_2O emissions from irrigation, the uncertainty analysis considered the uncertainty in irrigation areas, manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, and the uncertainty defined in the previous country-specific methodology (Rochette et al., 2008a) used to develop N_2O emission factors as noted in section 5.4.1.1.3. A future update to the uncertainty analysis is planned to account of the incorporation of updated soil N_2O emission factors, and irrigation emission factor included in this submission.

The estimate of N_2O emissions of 1.2 Mt CO_2 eq from irrigated land in 2020 lies within an uncertainty range of -44% to +55% based on the uncertainty range of combined emissions of tillage, irrigation and summerfallow practices (Table 5–7). The reporting of summerfallow emissions as a country-specific methodology, was discontinued in this submission to avoid double-counting following the introduction of a methodology for estimating soil organic carbon from changes in crop productivity. The irrigated land emission factor for a given ecodistrict is a function of all soil emission factor calculations, and uncertainty is therefore influenced by all factors described in previous uncertainty sections. An updated uncertainty analysis is planned to incorporate the revised soil N_2O emission factors included in this submission.

The same methodology and emission factors are used for the entire time series (1990–2020).

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. The majority of the recalculations to irrigation are the result of the revision of soil N_2O emission factors in this submission. A description of the revised methodology used to develop soil N_2O emission factors, including the equation used to calculate irrigation emissions, are provided in Annex 3.4.

Small changes to the distribution of crops resulted in recalculations to emissions linked to irrigation.

These changes increased emissions by 0.28 Mt CO_2 eq in 1990, 0.45 Mt CO_2 eq in 2005 and 0.81 Mt CO_2 eq in 2019. These recalculations increased the short-term trend from 24% to 56%, and the long-term trend from 47% to 120% (Table 5–9).

5.4.1.8.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source. Further uncertainty work will be carried out to establish updated level and trend uncertainty estimates over the medium term.

5.4.2. Indirect N_2O Emissions from Managed Soils (CRF Category 3.D.2)

A fraction of the nitrogen from organic and inorganic fertilizers that are applied to agricultural fields is transported off-site through volatilization in the form of NH_3 and NO_x and subsequent re-deposition or leaching and runoff. The nitrogen that is transported from the agricultural field in this manner provides additional nitrogen for subsequent nitrification and denitrification to produce N_2O.

5.4.2.1. Atmospheric Deposition of Nitrogen

5.4.2.1.1. Source Category Description

When organic or inorganic fertilizer is applied to cropland, a portion of the nitrogen is lost through volatilization in the form of NH_3 or NO_x, which can be redeposited elsewhere and undergo further transformation, resulting in N_2O emissions off-site. The quantity of this volatilized nitrogen depends on a number of factors, such as rates of fertilizer and manure nitrogen application, fertilizer types, methods and time of nitrogen application, soil texture, rainfall, temperature, and soil pH.

5.4.2.1.2. Methodological Issues

There are few published scientific data that actually determine N_2O emissions from atmospheric deposition of NH_3 and NO_x. Leached or volatilized N may not be available for the process of nitrification and denitrification for many years, particularly in the case of N leaching into groundwater. Although Indirect Soil N_2O Emissions from Agricultural Soils are a key source category for level and trend assessments for Canada, there are difficulties in defining the duration and boundaries for this source of emissions because no standardized method for deriving the IPCC Tier 2 emission factors is provided in the 2006 IPCC Guidelines.

A country-specific method is used to estimate ammonia emissions from the application of inorganic 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 derive 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 environments. Based on the analysis presented in the most recent IPCC methodological update, it was determined that the use of the default IPCC emission factors of 0.014 kg N_2O-N kg^{-1} N for wet climates and 0.005 kg N_2O-N kg^{-1} N for dry climates (IPCC, 2019) would provide more accurate estimates of indirect emissions for Canadian conditions than the default emission factor published in the 2006 IPCC Guidelines.

For dairy cattle and swine, the amount of manure nitrogen subject to losses from volatilization of NH_3 following application is estimated using a revised version of the Canadian NH_3 emission model (Sheppard et al., 2011b; Chai et al., 2016) to generate ecoregion-specific N loss factors by animal type and AWMS. For all other animal manure applied to fields, default volatilization fractions provided in the 2006 IPCC Guidelines were used to estimate N loss as NH_3.

5.4.2.1.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N_2O emissions from atmospheric deposition of N considered the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines, as well as the uncertainty in the estimate of NH_3.

The estimate of N_2O emissions of 1.0 Mt CO_2 eq from volatilization and redeposition in 2020 lies within an uncertainty range of 0.25 Mt CO_2 eq (-75%) to 2.1 Mt CO_2 eq (+110%) (Table 5–7). Most 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 (1990–2020).

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 both paper and electronic form.

5.4.2.1.5. Recalculations

Recalculations occurred as a result of: (i) the implementation of the climate-specific N_2O emission factors (EF_4) from the 2019 Refinement to the 2006 IPCC Guidelines, which decreased emissions in relatively dry regions and increased emissions in relatively humid regions and lead to an overall net decrease in emissions; (ii) an increase in inorganic fertilizer N applied in 2019 as a result of a correction to activity data; (iii) a decrease in the amount of manure N applied following a correction to the N excretion rate for swine; and (iv) revisions to activity data, including livestock populations and crop areas.

These recalculations decreased emissions by 0.11 Mt CO_2 eq in 1990, by 0.25 Mt CO_2 eq in 2005 and by 0.29 Mt CO_2 eq in 2019 (Table 5–10). The short-term trend decreased from +10% to +8%, and the long-term trend decreased from +49% to +31%.

5.4.2.1.6. Planned Improvements

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

Table 5–10 **Recalculations of N_2O Emission Estimates and Their Impact on Emission Trends from Atmospheric Deposition and Leaching and Runoff**

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change in Category Emissions (%)	Old Trend (%)	New Trend (%)
Atmospheric Deposition	1990	2021	830	-106	-13	Long term (1990–2019)	
		2022	725			49	31
	2005	2021	1 121	-247	-22		
		2022	874			Short term (2005–2019)	
	2019	2021	1 238	-291	-23	10	8
		2022	947				
Nitrogen Leaching and Runoff	1990	2021	1 960	-124	-6.3	Long term (1990–2019)	
		2022	1 836			51	63
	2005	2021	2 290	-87	-3.8		
		2022	2 203			Short term (2005–2019)	
	2019	2021	2 959	35	1.2	29	36
		2022	2 994				

5.4.2.2. Nitrogen Leaching and Runoff

5.4.2.2.1. Source Category Description

When organic and inorganic fertilizers, and crop residue, are added to cropland, a portion of the nitrogen from these sources is lost through leaching and runoff. The magnitude of this loss depends on a number of factors, such as application rate and method, crop type, soil texture, rainfall and landscape. This portion of lost nitrogen can further undergo transformations, such as nitrification and denitrification, and can produce N_2O emissions off-site.

5.4.2.2.2. Methodological Issues

There are few published scientific data that determine N_2O emissions from leaching and runoff in Canada. As in the case of N_2O emissions from volatilization and deposition of NH_3 and NO_x, this source is poorly defined because no standardized method for deriving the IPCC Tier 2 emission factors is provided in the 2006 IPCC Guidelines.

A modified IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from leaching and runoff of fertilizers, manure, and crop residue nitrogen from agricultural soils. Indirect N_2O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using the fraction of nitrogen that is lost through leaching and runoff ($FRAC_{LEACH}$) multiplied by the amount of inorganic fertilizer nitrogen and crop residue nitrogen and by an emission factor of 0.0075 kg N_2O-N/kg N (IPCC, 2006).

The default value for $FRAC_{LEACH}$ in the Revised 1996 Guidelines is 0.3. However, $FRAC_{LEACH}$ can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC, 2006), such as in the Prairies. Accordingly, it is assumed that $FRAC_{LEACH}$ would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with no moisture deficit during the growing season (May through October), the maximum $FRAC_{LEACH}$ value of 0.3 recommended by the 2006 IPCC Guidelines is assigned. The minimum $FRAC_{LEACH}$ value of 0.05 is assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts, $FRAC_{LEACH}$ is estimated by the linear extrapolation of the two end-points described above.

5.4.2.2.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N_2O emissions from nitrogen leaching and runoff considered the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines and the uncertainty in the estimate of total N.

The estimate of N_2O emissions of 3.2 Mt CO_2 eq from nitrogen leaching and runoff in 2020 lies within an uncertainty range of 0.64 Mt CO_2 eq (-80%) to 6.4 Mt CO_2 eq (+100%) (Table 5–7). Most uncertainty is associated with the IPCC Tier 1 emission factor of 0.75% of total N leached (uncertainty range of 0.05% to 2.5%).

The same methodology and emission factors are used for the entire time series (1990–2020).

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

Recalculations occurred as a result of (i) an increase in inorganic fertilizer N applied in 2019 due to a correction to activity data; (ii) a decrease in the amount of manure N applied following a correction to the N excretion rate for swine; and (iii) revisions to the spatial distribution of activity data, specifically livestock populations and crop areas.

These changes decreased emissions by 124 kt CO_2 eq in 1990, and 87 kt CO_2 eq in 2005 but increased emissions by 0.35 kt CO_2 eq in 2019. The short-term trend increased from +29% to +36%, and the long-term trend increased from +51% to +63%.

5.4.2.2.6. Planned Improvements

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

5

5.5. CH_4 and N_2O Emissions from Field Burning of Agricultural Residues (CRF Category 3.F)

5.5.1. Source Category Description

Crop residues are sometimes burned in Canada, as a matter of convenience and for the purpose of disease control through residue removals. However, this practice has declined in recent years because of concerns over soil quality and environmental issues. Field burning of agricultural residues is a net source of CH_4, CO, NO_x and N_2O (IPCC, 2006).

5.5.2. Methodological Issues

There are no published data on emissions of N_2O and CH_4 from field burning of agricultural residues in Canada. Thus, the IPCC default emission factors and parameters from the 2006 IPCC Guidelines were used for estimating emissions.

A complete time series of activity data on the type and percent of each crop residue subject to field burning was developed based on Statistics Canada's Farm Environmental Management Survey (FEMS)[2] and on expert consultations (Coote et al., 2008).

Crop-specific parameters required for estimating the amount of crop residue burned, such as moisture content of the crop product and ratio of above-ground crop residue to crop product, were obtained from Janzen et al. (2003) and are consistent with the values used to estimate emissions from crop residue decomposition.

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

5.5.3. Uncertainties and Time-Series Consistency

The uncertainties associated with CH_4 and N_2O emissions from field burning of agricultural residues were determined using an IPCC Tier 1 method (IPCC, 2006).

The uncertainties associated with CH_4 and N_2O emissions from field burning of agricultural residues are the amount of field crop residues burned and emission factors. On the basis of the area of specific seeded crop, the uncertainty in the amount of crop residues burned is estimated to be ±50% (Coote et al., 2008). The uncertainties associated with the emission factors are not reported in the 2006 IPCC Guidelines but are assumed to be similar to those associated with burning of Savanna and grassland: ±40% for CH_4 and ±48% for N_2O (IPCC, 2006). The level uncertainties for CH_4 and N_2O emission estimates were estimated to be ±64% and ±69%, respectively.

5.5.4. 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 both paper and electronic form.

5.5.5. Recalculations

There were no recalculations in this category for the years 1990, 2005 or 2019. The long-term and short-term trends remained at -78% and +15%, respectively.

5.5.6. Planned Improvements

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

5.6. CO_2 Emissions from Liming (CRF Category 3.G)

5.6.1. Source Category Description

In Canada, limestone is often 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 aluminium, and improve the crop growth environment. During this neutralization process, CO_2 is released in bicarbonate equilibrium reactions that occur in the soil. The rate of release will vary with soil conditions and the compounds applied.

5

5.6.2. Methodological Issues

Emissions associated with the use of lime were calculated from the amount of lime applied annually and the proportion of carbonate in the minerals used for liming soils that breaks down and is released as CO_2. Methods and data sources are outlined in Annex 3.4.

5.6.3. Uncertainties and Time-Series Consistency

The 95% confidence limits for data on annual lime consumption in each province were estimated to be ±30%. This uncertainty was assumed to include the uncertainty in lime sales, uncertainty in when lime sold is actually applied, and uncertainty in the timing of emissions from applied lime. The uncertainty in the emission factor was considered to be -50% based on the 2006 IPCC Guidelines (IPCC, 2006). The overall mean and uncertainties were estimated to be 0.21 ± 0.14 Mt CO_2 eq for the level uncertainty.

The same methodology is used for the entire time series of emission estimates (1990–2020).

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

There were no recalculation to this category in this submission, and no changes to the short-term or long-term trends.

5.6.6. Planned Improvements

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

5.7. CO_2 Emissions from Urea Application (CRF Category 3.H)

5.7.1. Source Category Description

When urea ($CO(NH_2)_2$) or urea-based nitrogen fertilizers is applied to a soil to augment crop production, CO_2 is released on hydrolysis of the urea. According to the 2006 IPCC Guidelines, the quantity of CO_2 released to the atmosphere should be accounted for as an emission. In addition to urea, Canadian farmers also use significant amounts of urea ammonium nitrate (28-0-0) with a mixture of 30% $CO(NH_2)_2$.

5.7.2. Methodological Issues

Emissions associated with urea application were calculated from the amount of urea or urea-based fertilizers applied annually, and the quantity of carbon contained in the urea that is released as CO_2 after hydrolysis. Methods and data sources are outlined in Annex 3.4.

5.7.3. Uncertainties and Time-Series Consistency

The 95% confidence limits for data on the annual urea or urea-based fertilizer consumption were estimated to be ±15%. The uncertainty estimate associated with the emissions was based on simple error propagation using survey uncertainty and an uncertainty of -50% associated with the emission factor specified in the 2006 IPCC Guidelines. The overall mean and uncertainties were estimated to be 2.4 ± 1.2 Mt CO_2 eq for the level uncertainty.

The same methodology and data sources are used for the entire time series of emission estimates. Urea consumption in Canada increased significantly from 1990 to 2020 with a relatively high inter-annual variability in a range of up to ±25% annually. Although we cannot identify specific factors that result in interannual variability, urea-based fertilizer shipments in Canada vary due to price fluctuations, climate factors influencing crop production, and other factors.

5

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 years 1990 or 2005, however, a correction to inorganic N fertilizer activity data for the year 2019 resulted in an increase in emissions of 47 kt CO_2 eq. The long-term trend increased from +205% to +211%, and the short-term trend increased from +99% to +103%.

5.7.6. Planned Improvements

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

CHAPTER 6

LAND USE, LAND-USE CHANGE AND FORESTRY (CRF SECTOR 4)

6.1. Overview

The Land Use, Land-Use Change and Forestry (LULUCF) sector reports greenhouse gas (GHG) fluxes between the atmosphere and Canada's managed lands as well as those associated with land-use change and emissions from harvested wood products (HWP) derived from these lands. The assessment includes emissions and removals of carbon dioxide (CO_2) associated with carbon (C) stock changes; additional emissions of CO_2, methane (CH_4), nitrous oxide (N_2O) and carbon monoxide (CO)[1] due to controlled biomass burning; CO_2, CH_4 and N_2O emissions from drained forest organic soils and from wetland drainage and rewetting due to peat extraction; and N_2O released following land conversion to cropland.

The estimated net GHG flux in the LULUCF sector, calculated as the sum of CO_2[2] and non-CO_2 emissions and CO_2 removals, amounted to net removals of 64 Mt in 1990, 4.2 Mt in 2005 and 6.8 Mt in 2020.[3] When applied to the national totals, the net flux estimates decrease by 11% in 1990, by 0.6% in 2005 and by 1.0% in 2020, the total Canadian GHG emissions. Table 6–1 provides the net flux estimates for 1990, 2005 and recent years in the major LULUCF sector categories and subcategories. The full time series of LULUCF sector estimates is available in Table 10 of the common reporting format (CRF) series.

The Forest Land and Cropland categories have the largest influence on sectoral totals. The net fluxes reported in the LULUCF sector were negative (removals) for all years of the time series but removals decreased over the period between 1990 and 2005 driven by the trend towards declining net removals from Forest Land being partially attenuated by a trend towards increasing removals in Cropland.

Emissions and removals from the forest sector in Canada consist of the net fluxes from commercially mature forests stands either of harvest origin or that have recovered from natural disturbances and the corresponding emissions from HWP that have been extracted from Canadian forests and reached their end of life. Forest management has resulted in a decrease in net removals from Forest Land from 200 Mt in 1990 to 130 Mt in 2007. The decrease in removals reflects the influence of forest harvest and an interaction with increased insect-related mortality that have together resulted in a net reduction in C removals from the atmosphere by commercially mature stands. Since 2007, net removals have fluctuated in Forest Land, increasing to 150 Mt in 2009 when harvest rates reached the lowest point in the 31-year time series and declining again to 130 Mt in 2020 with the loss of significant areas of mature managed forest to wildfire.

1 Emissions of CO are reported as CO in CRF Table 4, but not included in the sectoral totals, and are instead reported as indirect CO_2 in CRF Table 6. Unless otherwise indicated, all emissions and removals reported for the LULUCF sector do not include emissions of indirect CO_2 from CO.

2 Unless otherwise indicated, all emissions and removals are in CO_2 equivalents.

3 All figures associated with estimates and activity data have been rounded according to the protocol described in Annex 8, except in cases where there is a requirement to explain specific details of estimates or trends that may be masked by rounding.

Table 6–1 **LULUCF Sector Net GHG Flux Estimates, Selected Years**

Sectoral Category		Net GHG Flux (kt CO_2 eq)[b]							
		1990	2005	2015	2016	2017	2018	2019	2020
Land Use, Land-Use Change and Forestry TOTAL[a]		**-64 000**	**-4 200**	**- 78**	**-11 000**	**-17 000**	**-8 500**	**-16 000**	**-6 800**
a.	**Forest Land**	**-200 000**	**-130 000**	**-130 000**	**-140 000**	**-140 000**	**-130 000**	**-140 000**	**-130 000**
	Forest Land Remaining Forest Land	-200 000	-130 000	-130 000	-140 000	-140 000	-130 000	-140 000	-130 000
	Land Converted to Forest Land	-1 100	-950	-500	-440	-390	-340	-300	-240
b.	**Cropland**	**380**	**-22 000**	**-10 000**	**-17 000**	**-23 000**	**-19 000**	**-14 000**	**-9 600**
	Cropland Remaining Cropland	-9 000	-26 000	-14 000	-20 000	-27 000	-22 000	-17 000	-13 000
	Land Converted to Cropland	9 300	3 800	3 400	3 400	3 300	3 400	3 500	3 500
c.	**Grassland**	**0.6**	**0.9**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
	Grassland Remaining Grassland	0.6	0.9	1.2	1.2	1.2	1.2	1.2	1.2
	Land Converted to Grassland	NO	NO	NO	NO	NO	NO	NO	NO
d.	**Wetlands**	**5 400**	**3 100**	**3 000**	**3 100**	**3 100**	**2 800**	**2 900**	**2 900**
	Wetlands Remaining Wetlands	1 500	2 600	2 500	2 700	2 700	2 500	2 700	2 700
	Land Converted to Wetlands	3 900	480	500	460	420	250	240	250
e.	**Settlements**	**1 900**	**1 700**	**2 500**	**2 500**	**2 400**	**2 200**	**2 200**	**2 200**
	Settlements Remaining Settlements	-4 200	-4 400	-4 400	-4 400	-4 400	-4 400	-4 400	-4 400
	Land Converted to Settlements	6 100	6 000	6 900	6 900	6 800	6 600	6 700	6 600
f.	**Other Land**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**	**NE, NO**
g.	**Harvested Wood Products**	**130 000**	**150 000**	**140 000**	**140 000**	**140 000**	**140 000**	**130 000**	**130 000**
	Forest Conversion[c]	*21 000*	*16 000*	*17 000*	*17 000*	*17 000*	*16 000*	*16 000*	*16 000*
	Indirect CO_2[d]	*820*	*960*	*770*	*700*	*630*	*580*	*490*	*470*
	Natural Disturbances[e]	*-27 000*	*54 000*	*260 000*	*99 000*	*230 000*	*260 000*	*160 000*	*8 800*

Notes:

NE = Not estimated

NO = Not occurring

a. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

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

c. Not a reporting category, it overlaps with the subcategories of Land Converted to Cropland, Land Converted to Wetlands, Land Converted to Settlements and Harvested Wood Products.

d. Indirect emissions of CO_2 from the atmospheric oxidation of CO that results from controlled biomass burning, reported in CRF table 6.

e. Not a reporting category, this line is only for transparency purposes and shows the net balance of emissions/removals that result from natural disturbances in managed forests.

Emissions from the Harvested Wood Products category,[4] which is closely linked to Forest Land, have remained relatively stable, varying around 140 Mt from year to year. In 2020, there was a sharp decline in harvest rates and emissions decreased close to the minimum observed in 2009 (Table 6–1). Emissions are influenced primarily by the trend in forest harvest rates during the reporting period and also the long-term impact of harvest levels before 1990, as some of the C in HWP from harvest prior to 1990 is emitted during the reporting period.

The combined net flux from Forest Land and Harvested Wood Products—from forest harvest, not including HWP resulting from forest conversion activities and firewood harvest from non-forest lands since 1990—amounted to net removals of 75 Mt in 1990, 6.5 Mt in 2020, and net emissions of 9.5 Mt in 2005. These estimates represent the combined totals of net removals from Forest Land and net emissions from HWP from forests.

Emissions and removals from stands dominated by uncontrollable natural disturbances are tracked separately from those in forest stands dominated by the impacts of anthropogenic activities. Natural disturbances result in important emissions and subsequent removals of GHGs within the managed forest and display large interannual variability that mask trends in forest management activities (refer to section 6.3.1.2 for more details). Since 1990, emissions and removals from natural disturbances have ranged from removals of 50 Mt in 1992 to peak emissions of 260 Mt in 2015 and 2018. Emissions and removals have tended to be higher since the mid-2000s compared to the early part of the inventory reporting period (Table 6–1) due to increased frequency of wildfires and the tracking of insect disturbances.

Changes in agricultural land management practices in Western Canada, such as the extensive adoption of conservation tillage combined with reduced summerfallow and increasing crop yields which has, in turn, increased C input to soils, have resulted in an increase in net removals of CO_2 from Cropland in 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 adoption rate of conservation tillage, the conversion of perennial lands to annual crop production and, in recent years,

4 Includes HWP from managed forests and deforested lands (forest conversion) and firewood harvested from non-forest lands.

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 failure and peaks in yield as a result of variability in weather has resulted in high interannual variability in soil C inputs and, therefore, in emissions and removals. This variability is observed in peak emissions associated with drought in Western Canada in the early 2000s (reaching 7.6 Mt) and in peak removals in 2009 (36 Mt) and 2014 (44 Mt) associated with high crop yields making interpretation of short-term trends more challenging.

Over the 1990–2020 period, net emissions in the Wetlands category (peat extraction and flooded lands) ranged from 5.5 Mt (1993) to 2.8 Mt (2018). Trends in this category are mainly driven by the creation of large reservoirs before 1990, resulting in higher emissions over the 1990–1993 period. Emissions from flooded lands accounted for 36% of all emissions in the Wetlands category in 2020, compared to 82% in 1990. Emissions from the Land Converted to Wetlands category decreased over the reporting period from 3.9 Mt to 0.2 Mt.

Net emissions reported in the Settlements category fluctuated between 1.1 Mt (1997) and 2.6 Mt (2016), mainly driven by rates of conversion from forested land, which accounted for 6.6 Mt of emissions in 2020. Relatively steady removals of around 4.3 Mt per year from the growth of urban trees offset these emissions by an average of 71% over the reporting period.

Forest conversion is not a reporting category per se since it overlaps with the Land Converted to Cropland, Land Converted to Wetlands, Land Converted to Settlements and Harvested Wood Products categories. Greenhouse gas emissions due to forest conversion decreased from 21 Mt in 1990 to 16 Mt in 2020, including the emissions from HWP resulting from forest conversion activities since 1990. This decline in emissions combines decreases of 4.2 Mt and 1.8 Mt in immediate and residual emissions from forest conversion to cropland and to wetlands, respectively, an increase of 0.5 Mt in immediate and residual emissions from forest conversion to settlements, and an increase of 0.8 Mt in emissions from the resulting HWP since 1990.

In order to avoid double counting, estimates of C stock changes in CRF Tables 4.A to 4.E exclude C emissions emitted as CO_2, CH_4 and CO due to biomass burning and CO_2, CH_4 emissions from drainage and rewetting of organic soils. Carbon emissions from biomass burning emitted as CO_2 and CH_4 are reported in CRF Table 4(V) along with emissions of N_2O. Carbon emissions from drainage of forest organic soils and from wetland drainage and rewetting due to peat extraction, and emitted as CO_2 and CH_4, are reported in CRF Table 4(II) along with emissions of N_2O. Carbon emissions in the form of CO are reported as CO in CRF Table 4, but not included in the sectoral totals, and are instead reported as indirect CO_2 in CRF Table 6. Emissions and removals of CO_2 and emissions of CH_4, N_2O and CO are automatically tallied in CRF Table 4.

This year's submission includes significant recalculations in reported estimates for Forest Land, Cropland and Harvested Wood Products categories. The most notable recalculations were due to (i) updated methods to estimate changes in soil organic carbon (SOC) impacted by crop productivity changes and manure application, (ii) revisions to forest harvest and HWP activity data from the National Forestry Database (NFD) based on provincial input, replacing previously reported value projected from 2018 activity data (affecting mainly 2019), (iii) updated model parameters based on latest forest product statistics from the Food and Agriculture Organization (FAO), and (iv) updates to residential bioenergy activity data based on the 2019 Households and the Environment Survey (HES) carried out by Statistics Canada.

Other less significant recalculations occurred in Forest Land due to a retroactive update of wildfire and insects activity data. Additional recalculations occurred in land categories associated with forest conversion as a result of the completion of the northern deforestation mapping, the addition of three hydro-related large events, and in the Wetlands category due to updates in the activity data of peat extraction for the year 2019.

The combined impact of these and other minor recalculations in the LULUCF sector (Table 6–2) increased the estimates of net removals by 6.7 Mt (+12%) for 1990 and switched the previously reported net sources of emissions of 8.2 Mt in 2005 and 9.9 Mt in 2019 to net sinks of 4.2 Mt and 16 Mt that represent net changes of 12 Mt (-152%) and 26 Mt (-261%) respectively.

Refer to Table 6–3 and Table 8–4 for more details on implemented changes.

Estimates for all forest-related categories are developed using the same modelling framework. Therefore, changes to the forest model and distribution of disturbances on the landscape can result in changes in the forest stands available for modelling subsequent events, such as forest conversion, resulting in indirect recalculations to land conversion categories as well as C transfers to HWP.

Environment and Climate Change Canada (ECCC) has established governance mechanisms for LULUCF sector 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 of Forest Land and Cropland, and it collaborates with many groups of scientists and experts across several government levels and research institutions to produce estimates from other categories of land use.

Table 6–2 **Summary of Recalculations in the LULUCF Sector**

Sectoral Category			1990	2005	2015	2016	2017	2018	2019
Land Use, Land-Use Change and Forestry TOTAL[a]		**kt**	**-6 700**	**-12 000**	**-4 100**	**-11 000**	**-18 000**	**-17 000**	**-26 000**
		%	**12%**	**-152%**	**-102%**	**-11 215%**	**-2 544%**	**-201%**	**-261%**
a.	**Forest Land**	**kt**	**77**	**- 950**	**- 880**	**- 740**	**- 780**	**-1 100**	**-4 600**
		%	**0.0%**	**0.7%**	**0.7%**	**0.5%**	**0.6%**	**0.8%**	**3.5%**
	Forest Land Remaining Forest Land	kt	77	- 950	- 880	- 740	- 780	-1 100	-4 600
		%	0.0%	0.7%	0.7%	0.6%	0.6%	0.8%	3.5%
	Land Converted to Forest Land	kt	-	-	-	-	-	-	-
		%	-	-	-	-	-	-	-
b.	**Cropland**	**kt**	**-7 200**	**-12 000**	**-3 500**	**-11 000**	**-18 000**	**-14 000**	**-9 600**
		%	-95%	111%	50%	168%	313%	301%	229%
	Cropland Remaining Cropland	kt	-7 100	-12 000	-3 200	-10 000	-17 000	-14 000	-9 500
		%	371%	80%	30%	103%	185%	161%	122%
	Land Converted to Cropland	kt	- 150	- 97	- 320	- 290	- 370	- 420	- 140
		%	-1.5%	-2.5%	-8.6%	-7.8%	-10%	-11%	-3.8%
c.	**Grassland**	**kt**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		%	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Grassland Remaining Grassland	kt	-	-	-	-	-	-	-
		%	-	-	-	-	-	-	-
d.	**Wetlands**	**kt**	**64**	**50**	**120**	**170**	**110**	**67**	**300**
		%	1.2%	1.6%	4.1%	5.8%	3.7%	2.5%	11%
	Wetlands Remaining Wetlands	kt	-30	48	35	33	32	31	240
		%	-2.0%	1.9%	1.4%	1.3%	1.2%	1.2%	9.9%
	Land Converted to Wetlands	kt	95	2.0	84	140	77	36	58
		%	2.5%	0.4%	20%	43%	23%	17%	31%
e.	**Settlements**	**kt**	**77**	**-99**	**- 71**	**110**	**180**	**- 180**	**72**
		%	**4.2%**	**-5.7%**	**-2.7%**	**4.6%**	**8.3%**	**-7.7%**	**3.3%**
	Settlements Remaining Settlements	kt	-	-	-	-	-	-	-
		%	-	-	-	-	-	-	-
	Land Converted to Settlements	kt	77	-99	- 71	110	180	- 180	72
		%	1.3%	-1.6%	-1.0%	1.6%	2.8%	-2.7%	1.1%
g.	**Harvested Wood Products**	**kt**	**270**	**190**	**220**	**370**	**480**	**-1 300**	**-12 000**
		%	0.2%	0.1%	0.2%	0.3%	0.3%	-0.9%	-8.4%
	Forest Conversion[b]	*kt*	*390*	*-180*	*- 81*	*350*	*350*	*- 190*	*290*
		%	*1.9%*	*-1.1%*	*-0.5%*	*2.1%*	*2.2%*	*-1.1%*	*1.8%*

Notes:

Hyphen (-) indicates no recalculations

a. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

b. Not a reporting category.

Planned improvements include continued refinements to the isolation of anthropogenic emissions and removals from Forest Land, refinements to the HWP model structure and activity data, completion of uncertainty estimates in 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 Table 8-5.

The remainder of this chapter provides detail on each LULUCF sector category. Section 6.2 gives an overview of the representation of managed lands; section 6.3 provides a short description of Forest Land; section 6.4 describes the Harvested Wood Products category; sections 6.5 to 6.8 describe the Cropland, Grassland, Wetlands and Settlements land categories; and section 6.9 is devoted to the cross-category estimates of forest conversion to other land uses.

Table 6–3 **Summary of Changes in the LULUCF Sector**

List of Changes	Change Category	Years Affected
Forest Land		
Industrial forestry activity data for 2019 updated from the National Forestry Database (NFD)	Activity data updates	2019–2020
Small retroactive updates to spruce budworm (SBW) disturbances in Manitoba for years 2016–2019	Activity data updates	2016–2020
Updated residential bioenergy consumption 2018–2020 based on updates from 2019 Statistics Canada HES and some minor corrections to year 1996	Activity data updates	1996, 2018–2020
Retroactive update of 1990–2019 wildfire area burned estimates	Continuous improvement	Complete time series
Northern deforestation mapping and addition of three hydro-related large events	Continuous improvement	Complete time series
Cropland		
Implementation of Tier 2 method from 2019 IPCC Refinement (IPCC, 2019) for estimating change in soil organic carbon impacted by crop productivity changes, and elimination of emission/removal estimates for summerfallow reduction	Methodological updates	Complete time series
Implementation of country specific method for estimating change in SOC impacted by manure application	Methodological updates	Complete time series
Change in cropland area due to a new land-use coverage series (v3.3)	Continuous improvement	Complete time series
Northern deforestation mapping	Continuous improvement	Complete time series
Grassland		
No recalculations		
Wetlands		
Updates of 2019 activity data from NRCan for peat extraction	Activity data updates	2019–2020
Addition of three hydro-related large deforestation events	Continuous improvement	2012–2020
Settlements		
Northern deforestation mapping and addition of three hydro-related large deforestation events	Continuous improvement	Complete time series
Harvested Wood Products		
Industrial forestry activity data for 2019 updated from the NFD	Activity data updates	2019–2020
Updated HWP model parameters based on latest FAO forest product statistics that impacted years 2019 and 2020	Activity data updates	2019–2020
Updated residential bioenergy consumption 2018–2020 based on updates from 2019 Statistics Canada HES and some minor corrections to year 1996	Activity data updates	1996, 2018–2020
Updated industrial bioenergy consumption 2018–2019	Activity data updates	2018–2020
Correction of C-density of spent pulp liquor	Continuous improvement	Complete time series

6.2. Land Category Definition and Representation of Managed Lands

In order to harmonize all land-based estimates, common working definitions 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).

Forest Land includes all areas of trees 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 “what areas properly embody ‘managed forests’?” For the purpose of the GHG inventory, managed forests are those managed for timber and non-timber resources (including parks) or subject to fire protection. Annex 3.5.2 provides more detail on the implementation of the “managed forests” definition.

Agricultural land comprises both Cropland and Grassland (for agricultural use). Cropland includes all lands in annual crops, summerfallow and perennial crops (mostly forage, but also including berries, grapes, nursery crops, vegetables, and fruit trees and orchards). Grassland used for agriculture is defined as “unimproved” pasture or rangeland that is used only for grazing domestic livestock. It occurs only in geographical areas where the grassland would not naturally regrow to forest if abandoned, i.e., the natural shortgrass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. All agricultural land that is not grassland is de facto classified as Cropland, including unimproved pastures where 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 soil development 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 flooded lands (hydroelectric reservoirs) (IPCC, 2006).

The Settlements category includes all built-up land: urban, rural residential, land devoted to industrial and recreational use; roads, rights-of-way and other transportation infrastructure; and 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 in this GHG inventory.

Other Land comprises areas of rock, ice or bare soil, and all land areas that do not fall into any of the other five categories. Currently, only emissions from the conversion of Other Land to flooded land (reservoirs) and peat extraction are reported under the Wetlands category.

As a consequence of the land categorization scheme, some land-use transitions cannot occur—for example, forest conversion to agricultural grassland—since by definition these exclude areas where forests can grow naturally. Since grassland is defined as “native,” creation of grassland does not occur.

The IPCC default land-use change transition period of 20 years is used for all land-use change categories except for land conversion to flooded land (reservoirs), for which a 10-year transition period is used (IPCC, 2006), and for land conversion for peat extraction, for which a land-use change period of one year is used to represent the land conversion practices of draining and clearing of the surface vegetation layer (acrotelm) in preparation for peat extraction. However, the use of the 20-year land transition period for reporting land areas is simply procedural since higher tier estimation methods are utilized for developing 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 2020. The diagonal cells related to Forest Land show the total areas of managed forest that remain within each of the land components subject to either anthropogenic or natural disturbances, i.e., Forest Land includes all managed forest comprising areas with anthropogenic impacts for which GHG estimates are reported in CRF Tables 4.A, 4(II) and 4(V), and 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 Cropland refer to total land-use areas, those related to Grassland refer to total agricultural grassland, and those related to Wetlands and Settlements refer only to areas where activities causing GHG emissions or CO_2 removals have occurred. Grassland Converted to Settlements refers to land conversion of unmanaged tundra to

Table 6–4 **Land Use and Land-Use Change Matrix for the 2020 Inventory Year**

Initial Land Use	Final Land Use (kha)						
	Forest Land[a]		Cropland	Grassland[b]	Wetlands[c]	Settlements[c]	Other
	Anthropogenic component	*Natural disturbance component*					
Forest Land[a]	171 764	*53 781*	22	NO	0.0	27	NO
Anthropogenic component	*170 789*	*552*	*22*	*NO*	*0.0*	*27*	*NO*
Natural disturbance component	*975*	*53 229*	*NO*	*NO*	*NO*	*NO*	*NO*
Cropland	NE	*NO*	47 300	NO	NE	11	NO
Grassland	NO	*NO*	0.3	7 208	NE	0.9	NO
Wetlands[c]	NO	*NO*	NE	NO	493	NE	NO
Settlements[c]	NO	*NO*	NE	NO	NO	989	NO
Other	NO	*NO*	NO	NO	0.6	NO	NE

Notes:

NE = Not estimated

NO = Not occurring

kha = kilohectare

Non-diagonal cells refer to annual rates of land-use change, i.e., total land converted during the latest inventory year.

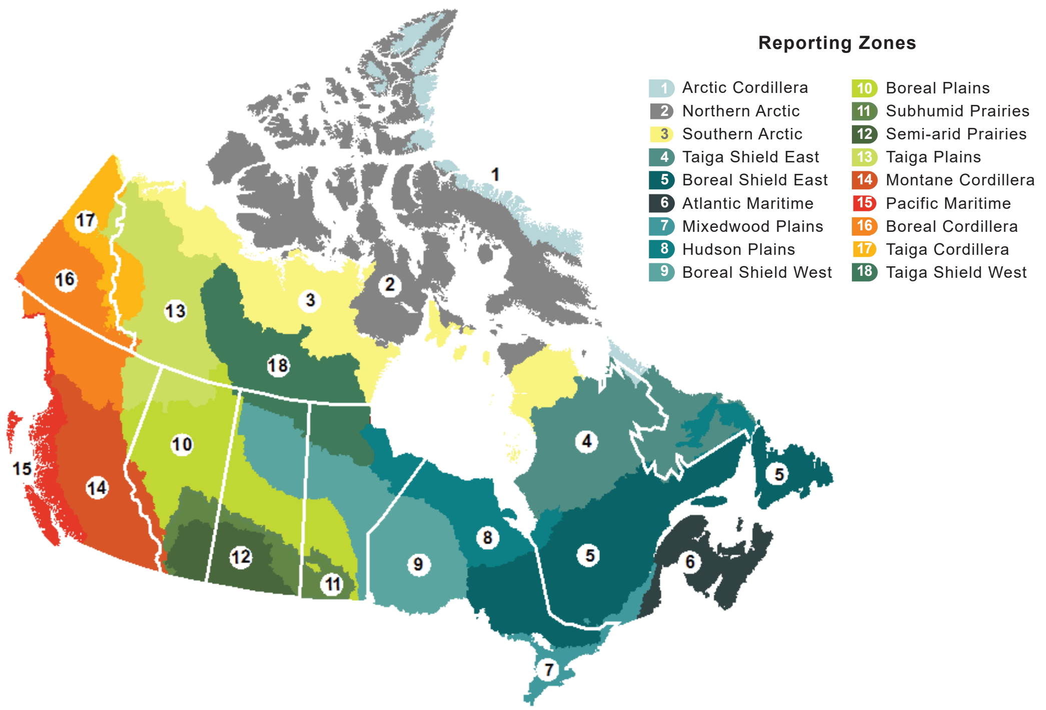
Areas presented in this table are not rounded to keep consistency within the table between numbers with different orders of magnitude, and with areas reported in the CRF Tables. However, caution is advised when interpreting these estimated areas due to the uncertainty associated with these values.

a. Includes all managed forest areas subject to either anthropogenic or natural disturbances.

b. Only includes areas of agricultural grassland.

c. Only includes areas for which estimates are reported in the CRF.

Figure 6–1 **Reporting Zones for LULUCF Estimates**



Settlements in Northern Canada (section 6.8.2.2). Column totals equal the total land area as reported in the CRF for each land category. The full time series of the land use and land-use change matrix is available in Table 4.1 ("Land Transition Matrix") of the CRF series.

The LULUCF land monitoring system includes the conversion of unmanaged forests, grassland and lands with previously undefined land use to other land categories. Unmanaged land converted to any use always becomes "managed." Parks and protected areas are included in managed lands.

The LULUCF estimates, as reported in the CRF tables, are spatially attached 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 their east and west components to form four reporting zones, and the Prairies ecozone is divided into a semi-arid and a subhumid component. Estimates are reported for 17 of the 18 reporting zones, leaving out the northernmost ecozone of Canada, the Arctic Cordillera, where no direct human-induced GHG emissions or removals are detected for this sector. More details on the spatial estimation and reporting framework can be found in Annex 3.5.1.

The areas reported in the CRF tables represent those used for annual estimate development, but not always the total land area under a land category or subcategory in a specific inventory year. For example, areas of land converted to flooded land (reservoirs) represent 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 sectoral background tables of the CRF refer to the cumulative total land area converted over the last 20 years (10 years for reservoirs and 1 year for peat extraction) and should not be confused with annual rates of land-use change. The trends observed in the land conversion categories of the CRF (e.g., Land Converted to Forest Land, Land Converted to Cropland) result from the balance between land area newly converted to a category and the transfer of lands converted more than 20 years ago (10 years for reservoirs and 1 year for peat extraction) into the "land remaining land" categories.

The remaining unmanaged land area reported in CRF Table 4.1 includes both unmanaged and managed land for which there are no estimates of emissions and removals. It is currently reported in this table to fulfill the requirement of the UNFCCC Reporting Guidelines to report the total land mass area of the country (see Annex 3.5.1 for more details).

6.3. Forest Land (CRF Category 4.A)

Forest and other wooded lands cover 400 million hectares (Mha) of Canadian territory; forest lands alone occupy 350 Mha (NRCan, 2018). Managed forests account for 230 Mha, or 65% of all forests. Four reporting zones (Boreal Shield East, Boreal Plains, Montane Cordillera and Boreal Shield West) account for 69% of managed forests.

In 2020, the net GHG balance reported for the anthropogenic component of the managed Forest Land amounted to removals of 130 Mt (Table 6–1 and CRF Table 4), while emissions from wood products originating from Canada's managed forests amounted to 120 Mt.

The Forest Land estimate includes net emissions and removals of CO_2, as well as N_2O and CH_4 emissions from slash burning and from drained forest organic soils. For the purpose of UNFCCC reporting, managed Forest Land is divided into the anthropogenic component of Forest Land Remaining Forest Land (170 Mha, net removals of 130 Mt in 2020) and Land Converted to Forest Land (0.03 Mha, net removals of 0.2 Mt in 2020) subcategories.

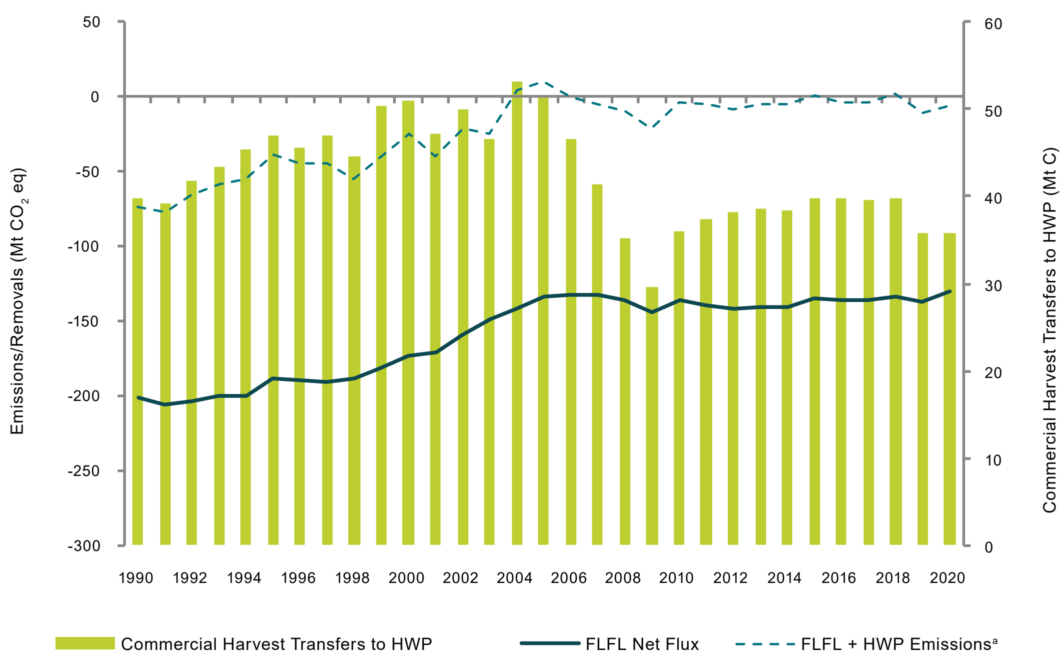
6.3.1. Forest Land Remaining Forest Land (CRF Category 4.A.1)

6.3.1.1. Sink Category Description

As trees grow, they absorb CO_2 from the atmosphere through photosynthesis, some of which is stored in vegetation (biomass), dead organic matter (DOM) and soils. Carbon dioxide and other GHGs are returned to the atmosphere by respiration and the decay and burning of organic matter. Human interactions with the land can directly alter the size and rate of these natural exchanges of GHGs in both the immediate and long term. Land-use change and land-use practices in the past still affect current GHG fluxes to and from the managed forest. This long-term effect is a unique characteristic of the LULUCF sector, which makes it very distinct from other inventory sectors.

Forest management practices (including harvesting, silvicultural treatments and regeneration) are the primary direct human influences on emissions and removals in forests. Forest harvest transfers C to HWP (section 6.4) and produces harvest residues (branches, foliage and non-commercial species), which are left to decay or are burned. Clear-cut harvesting resets stand age to 0; this 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 from Forest Land and emissions of CO_2 from wood products harvested from the forest represents the net flux between managed forests and the atmosphere (Figure 6–2).

Figure 6–2 **Emissions and Removals Related to Forest Land**



Notes:

a. Includes emissions from HWP originating from harvesting and salvage logging after natural disturbances

FLFL = Forest Land Remaining Forest Land

HWP = Harvested Wood Products

Reported estimates for net removals from management of forests in the Forest Land category include net fluxes from commercially mature forests stands of either harvest origin or that have recovered from natural disturbances. The impacts of non-anthropogenic natural disturbances (wildfires, insect infestations and windthrow) in the managed forest are also presented (Table 6–5).[5] Net removals from Forest Land decreased from 200 Mt in 1990 to 130 Mt in 2007 and have since remained relatively constant. The decrease in removals that occurred between 2000 and 2007 (Figure 6–2) is mainly due to trends in the Montane Cordillera and Boreal Plains reporting zones. In the Montane Cordillera, insect infestations and salvage harvesting of infested stands resulted in a shift in the average age of the forests of this region to younger age classes and an overall decrease in the rate of C accumulation in biomass[6] in the reporting zone. At the same time, low-level insect infestations increased tree mortality over large areas, resulting in increased emissions from decomposition. On the Boreal Plains, harvest rates also resulted in a shift in the average age of forests of that reporting zone, but insect infestation and fire also caused a reduction in the area of commercially mature forest stands and, consequently, a reduction in the rate of C uptake for the region. Reduced C uptake and increased emissions from decomposition in these regions resulted in a decrease in removals large enough to impact the national trend. More recently, low-mortality insect infestations have impacted large areas of the Boreal Shield East and Atlantic Maritime reporting zones and, since 2010, have had an effect on reported emissions and removals in these regions that will likely continue over the next few decades.

The total net flux in managed forests shown in Table 6–5 is calculated by adding reported estimates of CO_2, CH_4 and N_2O emissions and CO_2 removals caused by human activities, including CO emissions from controlled biomass burning reported as indirect CO_2, to emissions and removals that occur in areas dominated by the impact of uncontrollable natural disturbances.

Table 6–5 **Forest Land Remaining Forest Land Areas, GHG Fluxes and C Transfers, Selected Years**

Subcategories	*GHG*	1990	2005	2015	2016	2017	2018	2019	2020
Total Managed Forest Area (kha)		**230 000**	**230 000**	**230 000**	**230 000**	**230 000**	**230 000**	**230 000**	**230 000**
Areas with anthropogenic impacts		**170 000**	**170 000**	**170 000**	**170 000**	**170 000**	**170 000**	**170 000**	**170 000**
Areas with natural disturbance impacts		**56 000**	**56 000**	**54 000**	**53 000**	**54 000**	**54 000**	**54 000**	**54 000**
Net Flux – Reported and Not Reported (kt CO_2 eq)[a, b]		**-230 000**	**-80 000**	**130 000**	**-36 000**	**92 000**	**130 000**	**24 000**	**-120 000**
Reported estimates[c]		**-200 000**	**-130 000**	**-130 000**	**-140 000**	**-140 000**	**-130 000**	**-140 000**	**-130 000**
	CO_2	-200 000	-140 000	-140 000	-140 000	-140 000	-130 000	-140 000	-130 000
	CH_4	440	760	540	510	420	390	280	280
	N_2O	220	420	310	280	250	230	180	180
Reported Indirect CO_2[d]	**CO**	**400**	**720**	**500**	**430**	**380**	**360**	**250**	**250**
Emissions/removals from lands impacted by natural disturbances		**-27 000**	**54 000**	**260 000**	**99 000**	**230 000**	**260 000**	**160 000**	**8 800**
Wildfires – direct immediate emissions[e]		30 000	59 000	240 000	97 000	210 000	240 000	150 000	14 000
	CO_2	26 000	51 000	210 000	85 000	180 000	210 000	130 000	12 000
	CH_4	2 600	5 100	21 000	8 500	19 000	21 000	13 000	1 300
	N_2O	1 300	2 600	11 000	4 300	9 400	11 000	6 600	630
Wildfires – indirect CO_2 immediate emissions[e]	CO	2 600	5 100	21 000	8 500	18 000	21 000	13 000	1 200
Post-wildfire CO_2 emissions and removals[e]	CO_2	-60 000	-51 000	-34 000	-34 000	-28 000	-22 000	-22 000	-27 000
Insects – emissions and removals[f]	CO_2	310	41 000	30 000	27 000	24 000	22 000	21 000	20 000
Other natural disturbances – emissions and removals[g]	CO_2	NO	21	2.9	2.6	2.2	2.3	2.1	1.8
Carbon Transferred to HWP (kt C)[h]		**44 000**	**54 000**	**44 000**	**43 000**	**43 000**	**43 000**	**39 000**	**39 000**

Notes:

Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

NO = Not occurring

a. Negative sign indicates removal of CO_2 from the atmosphere.

b. Net flux corresponds to the sum of net GHG balance due to reported anthropogenic forest management activities, and emissions/removals due to natural disturbances, tracked but not reported in the CRF tables. Includes emissions/removals of CO_2 and emissions of CH_4, N_2O and CO.

c. Includes emissions/removals of CO_2 and emissions of CH_4 and N_2O, from forest stands dominated by the impact of anthropogenic activities.

d. Indirect emissions of CO_2 from the atmospheric oxidation of CO that result from slash burning after forest harvest are reported in CRF table 6.

e. Immediate emissions include direct and indirect CO_2 and direct non-CO_2 emissions resulting from the immediate impact of wildfires. Post-wildfire CO_2 emissions are associated with the long-term effect of wildfires on dead and soil organic matter; they include small emissions associated with insect infestations on wildfire-impacted areas. Removals of CO_2 are associated with natural stand regeneration following wildfire.

f. Includes emissions due to insect infestations, mainly residual, and removals associated with subsequent natural stand regeneration.

g. Includes the remnant impact in emissions of Hurricane Juan on Nova Scotia forests in 2003 and removals from subsequent natural stand regeneration.

h. This transfer from land categories to HWP is presented here for information purposes. Includes salvage logging after natural disturbances. The current design of the CRF tables for the LULUCF Sector does not enable representation of C transfer to the HWP in-use pool.

5 Impacts of natural disturbances with greater than 20% tree mortality.

6 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.

When all direct and indirect emissions and removals from lands impacted by natural disturbances are included, net fluxes in managed forests (reported and not reported) amount to net removals of 230 Mt in 1990, 80 Mt in 2005 and 120 Mt in 2020. Variations in net fluxes largely depend on the occurrence of natural disturbances in a given year. Figure 6–2 provides a comprehensive understanding of emissions and removals reported from the forest sector by showing both the short- and long-term impacts of human management and harvest on C stored in the forest but also the emissions occurring from the fate of HWP that are extracted from Canadian forests and reported in the Harvested Wood Products category.

6.3.1.2. Methodological Issues

Canada applies a Tier 3 methodology for estimating GHG emissions and removals in managed forests. Canada's National Forest Carbon Monitoring, Accounting and Reporting System includes 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, stock changes and CO_2 emissions and removals. The model uses regional ecological and climate parameters to simulate C transfers among pools in the forest ecosystem as well as to the HWP pool and the atmosphere. A more detailed description of forest C modelling can be found in Annex 3.5.2.1.

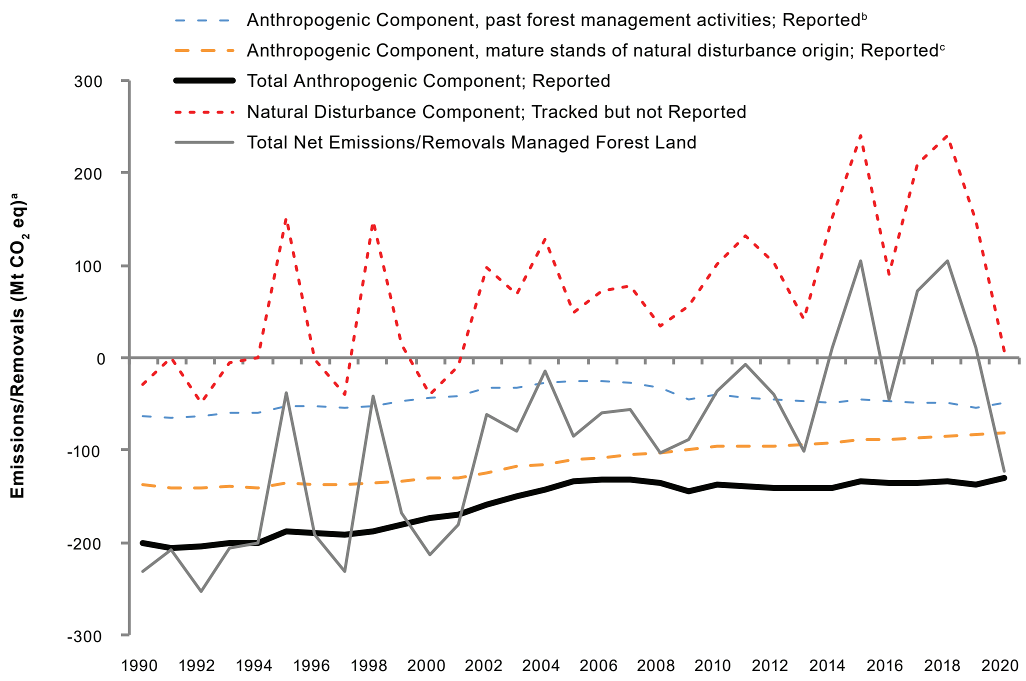
Prior to the 2017 inventory edition, emissions and removals of Forest Land displayed large interannual variability due to the impact of natural disturbances that masked the impact of forest management activities. The IPCC has recognized the issue of reporting emissions from natural disturbances for some countries and encouraged countries that use Tier 3 methodologies to work towards the development of new approaches that can improve the isolation of anthropogenic impacts (IPCC, 2010). Further, the 2019 IPCC Refinement to the 2006 Guidelines (IPCC, 2019) provides examples of approaches that have been used by countries (including Canada) to resolve this issue. Since the 2017 submission, Canada has implemented a Tier 3 approach to isolate the effect of anthropogenic activities on managed forests. This approach is based on the monitoring and compiling of emissions from forest stands impacted by anthropogenic and natural drivers separately (referred to as "anthropogenic component" and "natural disturbance component"). The anthropogenic component includes emissions and removals associated with stands that have been (1) directly affected by past forest management activities (e.g., clear-cut and partial harvest, commercial and pre-commercial thinning, and salvage logging), (2) mature stands affected by natural disturbances causing less than or equal to 20% biomass mortality (i.e., insect defoliation), or (3) mature stands affected by stand-replacing natural disturbances in the past but that have reached a regionally-determined minimum operable age (i.e., commercial maturity or pre-disturbance biomass, and therefore eligible to be scheduled for harvest). The natural disturbance component includes emissions and removals associated with large, uncontrollable natural disturbances, such as wildfires or insect outbreaks causing more than 20% biomass mortality. For 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 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 C balance in managed forests can also be found in the State of Canada's Forests report (NRCan, 2020a). Additional information on the estimation approach is provided in Annex 3.5.2.4 and in Kurz et al. (2018).

Carbon stock changes in the anthropogenic component of managed forests are reported, by reporting zone, in CRF Table 4.A. For any given pool, C stock changes include not only exchanges of GHG with the atmosphere, but also the C transfers to and from pools, for example its transfer 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 in the natural disturbance component of managed forests are reported separately, by reporting zone, in CRF Table 4.A.

Harvesting wood from managed forests results both in a transfer of C from the Forest Land category to the Harvested Wood Products category (Figure 6–2; Table 6–5) and in debris or residues that remain on site and decompose. The fate of the C embedded in wood material taken off-site is tracked in the HWP pool and reported in the Harvested Wood Products category, and the emissions from the C that decomposes on site are reported in the Forest Land category. Due to limitations in the current design of the CRF tables, the C transferred from the forest to the HWP pool is not reported in CRF Table 4.A since it would result in an automatic calculation of CO_2 emissions in the "net CO_2 emissions/removals" column of that table, which would amount to using the instant oxidation approach for HWP. Instead, and for transparency purposes, this C transfer is reported as C input into the HWP in-use pool in CRF Table 4.G without removing it from the emissions reported in the "Net emissions/removals from HWP in use" column of CRF Table 4.G. For this reason, it is important to caution against interpreting the net C stock change in the forest living biomass and DOM pools as shown in the current design of CRF Table 4.A since the losses of C from these pools are not completely represented in this table. More information on Canada's approach to HWP modelling is available in Annex 3.5.3.

Emissions of CO_2, CH_4 and N_2O from drained forest organic soils are reported in CRF Table 4(II). They are calculated using activity data derived from a combination of historical documents, consultations and provincial statistics, and Tier 1 emission factors from the 2013 IPCC Wetland Supplement to the 2006 Guidelines (IPCC, 2014). Details are provided in Annex 3.5.2.2.

Figure 6–3 **Emissions and Removals in Forest Land Remaining Forest Land by Stand Component**



Notes:

a. Not including indirect CO_2 or emissions from HWP.

b. Clear-cut and partial harvest, commercial and pre-commercial thinning, and salvage logging.

c. Stands that have reached minimum operable age (either commercial maturity threshold or pre-disturbance biomass) and are eligible to be scheduled for harvest.

Calculations of direct and indirect soil N_2O emissions from net SOC losses in stands under anthropogenic influence aggregated at the RU level indicate that potential emissions from this source can be deemed insignificant in accordance with the provisions of paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. Emissions aggregated at the RU level varied from 0 kt in 2011, 2016 and 2017 to 56 kt in 1990, which are significantly lower than 0.05% of the national total GHG emissions without LULUCF, and do not exceed 500 kt.

6.3.1.3. Uncertainties and Time-Series Consistency

Uncertainty Estimates

Numerical techniques are used to quantify uncertainties about the outputs of the CBM-CFS3 (Metsaranta et al., 2017). Modelling of Canada's managed forests is not done as a single run, but in separate "project runs" whose output is subsequently assembled. For each "project," 100 Monte Carlo runs are conducted using the base input data for the GHG estimates. Confidence intervals are obtained for each inventory year by randomly sampling 10 000 combinations of all the project runs for that year. Separate uncertainty estimates are produced for each gas. In years where there are no substantial changes, such as in this submission, Monte Carlo simulation is not performed (latest simulation was performed for the 2021 submission covering the entire 1990–2019 time series). Instead, confidence intervals for each category for the current year of submission are extrapolated.

Throughout the entire time series, the uncertainties associated with annual estimates are expressed as a 95% confidence interval, bound by 2.5th and 97.5th percentiles of the Monte Carlo run outputs. The uncertainty range of the CO_2 estimates is 77 Mt in 1990, 82 Mt in 2005 and 76 Mt in 2020 (Table 6–6). On average, the uncertain range was ±56 Mt of the annual median result produced by the Monte Carlo runs over the entire time series. Non-CO_2 emissions contribute little to total uncertainty. Probability distributions are asymmetrical around the net flux estimate and are skewed to the lower bound (greater sink), representative of the nature of the distributions of the activity data and parameters tested in the Monte Carlo analysis as they are expressed in the model. More information on the general approach used to conduct this analysis is provided in Annex 3.5.2.8, and a detailed description of methods, assumptions and discussions of the skewed nature of uncertain distribution can be found in Metsaranta et al. (2017).

Uncertainty associated with forestry drainage is not presented in Table 6–6. Due to the magnitude of the emissions from this source relative to net emissions and removals from the forest sector, it is highly unlikely to have an impact on the global uncertainty estimates of the Forest Land category.

Table 6–6 **Estimates of the Net Annual CO_2, CH_4 and N_2O Fluxes for Forest Land Remaining Forest Land, with 2.5th and 97.5th Percentiles, for Selected Years**

Gas	Inventory Year	Net Flux (Mt)	2.5th Percentile (Mt)	% Uncertainty[a] (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
CO_2	1990	-202	-268	33	-191	-5.4
	2005	-136	-188	39	-107	-21
	2020	-131	-179	37	-104	-21
CH_4	1990	0.4	0.3	-31	0.6	43
	2005	0.7	0.5	-27	1.3	76
	2020	0.2	0.1	-49	0.6	154
N_2O	1990	0.2	0.1	-36	0.3	43
	2005	0.4	0.3	-31	0.7	78
	2020	0.1	0.1	-55	0.3	151

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 reported for Annex 2.3 are taken from the error associated with the proportional error of 2020.

Time-Series Consistency

All estimates have been developed in a consistent manner. However, the forest inventory data incorporated in the analyses were not all collected in the same year across the country. Annex 3.5.2.3 explains how forest inventory data from various sources were processed to provide complete, coherent and consistent forest data for 1990 to present

6.3.1.4. Quality Assurance / Quality Control and Verification

Systematic and documented quality assurance/quality control (QA/QC) procedures are performed in four areas: workflow checks (manual), model checks (automated), benchmark checks (manual) and external reviews. 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, while maintaining its own QA/QC procedures for estimates developed internally (refer to section 1.3, Chapter 1), has implemented category-specific Tier 2 checks for estimates obtained from partners, as well as for all estimates and activity data contained in the LULUCF data warehouse (Blondel, 2018) and entered into the CRF Reporter. These procedures and their outcome are fully documented in the centralized archives.

Shaw et al. (2014) compared the C stocks 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 between model predictions and ground plot measurements was 1%, while the error in above-ground biomass, deadwood, litter and mineral soil pools was 7.5%, 30.8%, 9.9% and 8.4%, respectively. The contribution of above-ground biomass and deadwood to the error in ecosystem subtotal pools was small. However, the contribution from soils was large. The error in above-ground biomass and deadwood pools compared favourably to the standards proposed in the IPCC Good Practice Guidance (IPCC, 2003) for these pools (8% and 30% respectively). Results from this research indicate that there are important pool-, region- and species-specific variations that require further study.

As part of quality assurance efforts, the 2017 National Inventory Report (NIR) approach 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 established to classify stands impacted by insect infestations as being under anthropogenic or natural influence was justifiable. However, it recommended that the threshold criterion used to differentiate anthropogenic or 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 the revised approach was reviewed and approved by provincial forest experts.

6.3.1.5. Recalculations

There were significant recalculations in this reporting category due to (i) revisions to forest harvest activity data based on provincial data supplied to the NFD, replacing the previously reported value projected from 2018 activity data, and (ii) updates to residential bioenergy activity data based on the 2019 HES carried out by Statistics Canada. Other less significant recalculations occurred in Forest Land due to a retroactive updates of wildfire and insects activity data.

The combined effect of these changes on reported estimates resulted in a decrease of net removals of 0.1 Mt (-0.0%) in 1990, and annual increases of 1.0 Mt (+0.7%) and 4.6 Mt (+3.5%) in 2005 and 2019 respectively (see Figure 6–4).

Activity Data Updates

Industrial forestry activity data for 2019 were updated from the NFD, while forestry activity targets for 2020 were assumed to be identical to those for 2019. The current NFD harvest statistics also include some minor retroactive updates (primarily in Saskatchewan) in years 2010–2018.

Residential bioenergy consumption data 2018–2020 were updated based on updates from 2019 Statistics Canada HES and some minor corrections to year 1996.

The insects' activity data update includes small retroactive updates to spruce budworm disturbances in Manitoba for years 2016–2019 that were not available for the previous submission.

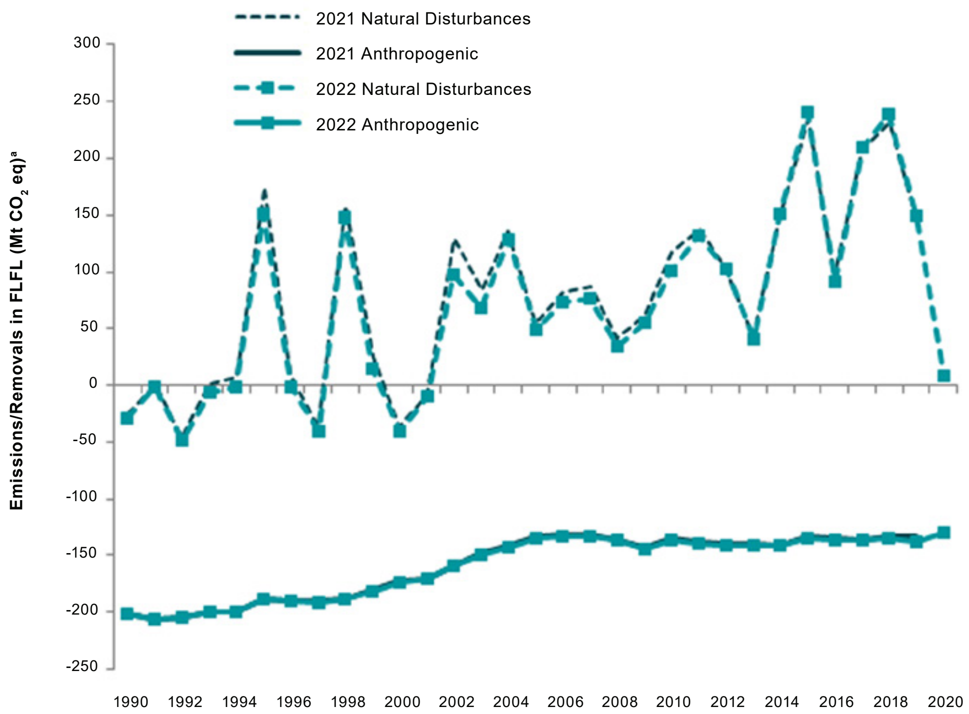
Continuous Improvement

The temporal coverage of the Canadian Wildland Fire Information System's National Burn Area Composite (NBAC) was extended to include the 1990–2003 period. Previously, these data were drawn from the Canadian Large Fire Database. The expanded NBAC product now covers all years since 1990 to the current inventory year and introduces a number of corrections to the estimates of annual area burned throughout the time series.

6.3.1.6. Planned Improvements

Planned improvements include updates to baseline inputs (data, processes and parameters) such as (1) activity data on fire and stand origin characterization as well as continuous refinements to certain parameters in the CBM-CFS3 modelling framework, such as the volume-to-biomass coefficients; and (2) improvements to the modelling of Eastern Canada's hardwood forests to better represent partial harvesting in CBM-CFS3 and to validate modelled trends using an independent Earth observation (EO)-based validation analysis. Longer-term plans also include a trend uncertainty and sensitivity analysis and an examination of how various components contribute to the asymmetrical distribution of uncertainty estimates around net flux. More details can be found in Table 8–5.

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



Note:
a. Not including indirect CO_2

6.3.2. Land Converted to Forest Land (CRF Category 4.A.2)

6.3.2.1. Category Description

This category includes all lands converted to forest land through direct human activity. Post-harvest tree planting is not included, nor is abandoned farmland where natural vegetation is allowed to establish. More precisely, the category refers to active forest establishment where the previous land use was not forest (typically, abandoned farmland).

The total cumulative area reported under the Land Converted to Forest Land category declined from 170 kha in 1990 to 30 kha in 2020. Given that activity data after 2008 are only for Ontario (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 81% of all farmland converted to Forest Land over the last 20 years occurred in Eastern Canada (Atlantic Maritime, Mixedwood Plains and Boreal Shield East reporting zones), with only 11% in the Prairie provinces (Boreal Shield West, Boreal Plains and Subhumid Prairies reporting zones) and the remaining 8.0% in Western Canada (Pacific Maritime and Montane Cordillera reporting zones).

Net removals declined throughout the period, from 1.1 Mt in 1990 to 0.2 Mt in 2020. Net C accumulation largely occurs in living biomass (58 Gg C in 2020, CRF Table 4.A). Soil C sequestration is negligible and will remain so because this category is restricted to plantations that are younger than 20 years. For the same reason, and considering the relatively low net increment of planted trees in the early years, it is important to emphasize that the category as a whole is not expected to contribute significantly to the net greenhouse gas balance of Forest Land. In considering these trends, 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 for 1970–1989 and 2003–2008 were estimated based on activity rates observed in the FAACS data, complemented with information from the Forest 2020 Plantation Demonstration Assessment (NRCan, 2005b). In addition, this submission includes the effect of new afforestation activity data for Ontario for the years 2007 to 2016 obtained through a data sharing agreement established with Forests Ontario to access their database of tree planting activities for inclusion in NIR estimates.

GHG emissions and removals on lands newly converted to forest land were estimated using CBM-CFS3, as described in Annex 3.5.2. Changes in soil C stocks are highly uncertain because of difficulties in locating data about the C stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil C at a slow rate. The limited time frame of this analysis and the magnitude of the activity relative to other land use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

6.3.2.3. Uncertainties and Time-Series Consistency

Significant challenges remain in estimating uncertainty for this category due to the lack of a consistent national system for tracking afforestation and because it is currently not possible to run a Monte Carlo simulation using the model data input structure for this category. Given these limitations, initial uncertainty estimates were developed based on expert judgement. It was assumed that the 95% confidence intervals for this category could be estimated at 10% smaller or 200% larger than the reported value.

6.3.2.4. Quality Assurance / Quality Control and Verification

Tier 2 QC checks (Dymond, 2008) specifically address estimate development in the Forest Land category. Environment and Climate Change Canada, while maintaining its own QA/QC procedures for estimates developed internally (refer to section 1.3, Chapter 1), has implemented specific procedures for estimates obtained from data partners, as well as for all estimates and activity data contained in the LULUCF data warehouse (Blondel, 2018) and entered into the CRF Reporter.

6.3.2.5. Recalculations

There were no recalculations for this category.

6.3.2.6. Planned Improvements

There is still limited access to information on afforestation activity, but continued efforts are underway to obtain more data in recent years from provincial and territorial resource management agencies. As more information becomes available in the future, uncertainty estimates will be further refined as well.

6.4. Harvested Wood Products (CRF Category 4.G)

6.4.1. Source Category Description

Emissions in the the Harvested Wood Products category are reported based on the Simple Decay Approach as described in the annex to Volume 4, Chapter 12, of the 2006 IPCC Guidelines (IPCC, 2006). The approach is similar to the Production Approach, but differs in that the HWP pool is treated as a C transfer related to wood harvest and hence does not assume instant oxidation of wood in the year of harvest (more details provided in Annex 3.5.3).

Emissions associated with this category result from the use and disposal of HWP manufactured from wood coming from forest harvest, forest conversion and firewood collection activities in Canada and consumed either domestically or elsewhere in the world. Products disposed of at the end of their useful life are assumed to be immediately oxidized.

Emissions from this source are influenced by current harvest rates and the production of short-lived products and wood waste as well as past rates of production of longer-lived wood products. Emissions have fluctuated between 130 Mt in 2009 (lowest harvest year) and a peak of 150 Mt in 1995. In 2020, the Harvested Wood Products category amounted to total emissions of 130 Mt, 2.7 Mt below 1990 value and 20 Mt below 2005 value (Table 6–7).

Harvested Wood Products emissions are inextricably linked to emissions/removals reported in Forest Land, such that the sum of net emissions/removals from Forest Land and emissions reported in the Harvested Wood Products category provides an estimate of total net emissions/removals from the managed forest (Figure 6–2).

Table 6–7 **Carbon Stocks in the HWP Pool and Emissions Resulting from Their Use and Disposal**

Source Subcategories / Commodities	Land Category	1990	2005	2015	2016	2017	2018	2019	2020
Carbon Stocks (kt C)[a]									
Inputs		**46 000**	**56 000**	**45 000**	**45 000**	**45 000**	**45 000**	**41 000**	**40 000**
Conventional Harvest[b]	Forest Land	40 000	51 000	40 000	40 000	40 000	40 000	36 000	36 000
Forest Conversion[b]	Cropland	1 200	410	550	550	590	580	510	550
	Wetlands	1.8	6.4	17	38	18	0.2	NO	NO
	Settlements	620	770	840	850	810	730	810	720
Residential Firewood[c]	Forest Land	4 200	3 100	3 900	3 700	3 700	3 500	3 200	2 900
	Cropland	230	130	110	160	210	190	150	140
	Settlements	82	83	84	84	84	84	84	84
Exports		**19 000**	**31 000**	**22 000**	**23 000**	**23 000**	**21 000**	**20 000**	**20 000**
Net Stocks[d]		**330 000**	**520 000**	**580 000**	**590 000**	**600 000**	**600 000**	**610 000**	**610 000**
Emissions (kt CO_2)[a]		**130 000**	**150 000**	**140 000**	**140 000**	**140 000**	**140 000**	**130 000**	**130 000**
Domestic Harvest		**88 000**	**75 000**	**75 000**	**72 000**	**73 000**	**76 000**	**68 000**	**66 000**
Solid Wood – Sawnwood		5 500	7 800	9 400	9 500	9 600	9 800	9 900	10 000
Solid Wood – Wood Panels		2 700	3 300	4 100	4 100	4 100	4 200	4 300	4 400
Other Solid Wood Products		920	1 900	2 200	2 200	2 200	2 200	2 200	2 200
Paper and Pulp Market		8 300	740	3 000	3 200	3 400	3 300	3 000	2 800
Firewood – Residential and Industrial		52 000	59 000	55 000	50 000	51 000	55 000	47 000	45 000
Mill Residue[e]		19 000	1 700	1 500	2 800	2 500	1 700	1 200	1 100
Worldwide from Canadian Harvest		**42 000**	**73 000**	**65 000**	**65 000**	**65 000**	**64 000**	**63 000**	**62 000**
Solid Wood – Sawnwood		9 900	16 000	18 000	19 000	19 000	19 000	19 000	20 000
Solid Wood – Wood Panels		780	4 300	5 500	5 700	5 800	6 000	6 100	6 200
Other Solid Wood Products		52	51	59	60	62	64	65	66
Paper and Market Pulp		31 000	51 000	39 000	38 000	37 000	37 000	36 000	35 000
Mill Residue[e]		460	2 100	1 900	2 600	2 400	2 100	1 900	1 900

Notes:

NO = Not occurring

a. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

b. Carbon estimated by the CBM-CFS3 model in the form of wood biomass that results from forest harvest (including salvage logging after natural disturbances on Forest Land) and forest conversion activities in Canada and that would be reported as C losses in CRF table 4.A under Forest Land Remaining Forest Land 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 carbon collected for residential firewood from forest, agricultural woody biomass and urban trees and assumed to be burned in the year of harvest. This C would be reported as C losses in CRF tables 4.A under Forest Land Remaining Forest Land, 4.B under Cropland Remaining Cropland, and 4.E under Settlements Remaining Settlements, if using instant oxidation approach for HWP.

d. Represent the quantity of carbon in the HWP pool at the end of the reporting year. Because inputs to the model consider harvest since 1900, net stocks over the reporting period may include C harvested before 1990.

e. Assumed to be disposed of in the year of harvest.

6.4.2. Methodological Issues

A country-specific model, the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP), is used to monitor and quantify the fate of C off-site from the point of forest harvest, forest conversion or firewood collection. The model tracks HWP sub-pools and C flows between sub-pools through the life-cycle of wood products (e.g., manufacturing, use, trade and disposal).

In more concrete terms, the HWP model takes the C output from wood harvest, exports a portion as roundwood, converts all harvested wood into commodities, exports some of the commodities produced, and keeps track of the additions to and removals from HWP in-use and from bioenergy.

Inputs to the model (Table 6–7) include: (1) the annual mass of C from conventional contemporary harvest and residential firewood collection in forest lands and a relatively small amount from lands converted from forest to cropland, wetlands (hydro-reservoirs) and settlements (around 2.7% of all inputs in any year) transferred from the CBM-CFS3 model (see section 6.3.1.2); and (2) an additional annual quantity of C from woody biomass collected from croplands and from urban trees on land in the Settlements category and used for residential bioenergy (Table 6–7). For the historical harvest, the input comes from the historical commodity production from Statistics Canada at a national level of spatial resolution, covering the 1900–1989 period.

Data on the annual volume of residential firewood and industrial fuelwood are provided by the Energy sector. Residential firewood data come 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 come 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 for the territories come from fuelwood and firewood harvest statistics provided by the NFD,[7] and data on industrial fuelwood come from the annual Report on Energy Supply and Demand in Canada (RESD). More information on the estimation methodology, data sources and parameters used in the model are available in Annex 3.1 (data sources) and Annex 3.5.3.

The trend in emissions from HWP disposal results from historical commodity production combined with the duration of the life cycle of various commodities (Table 6–7). The impact of any significant changes in harvest levels or in the mix of products is therefore redistributed over several subsequent years and decades as commodities are gradually retired from use.

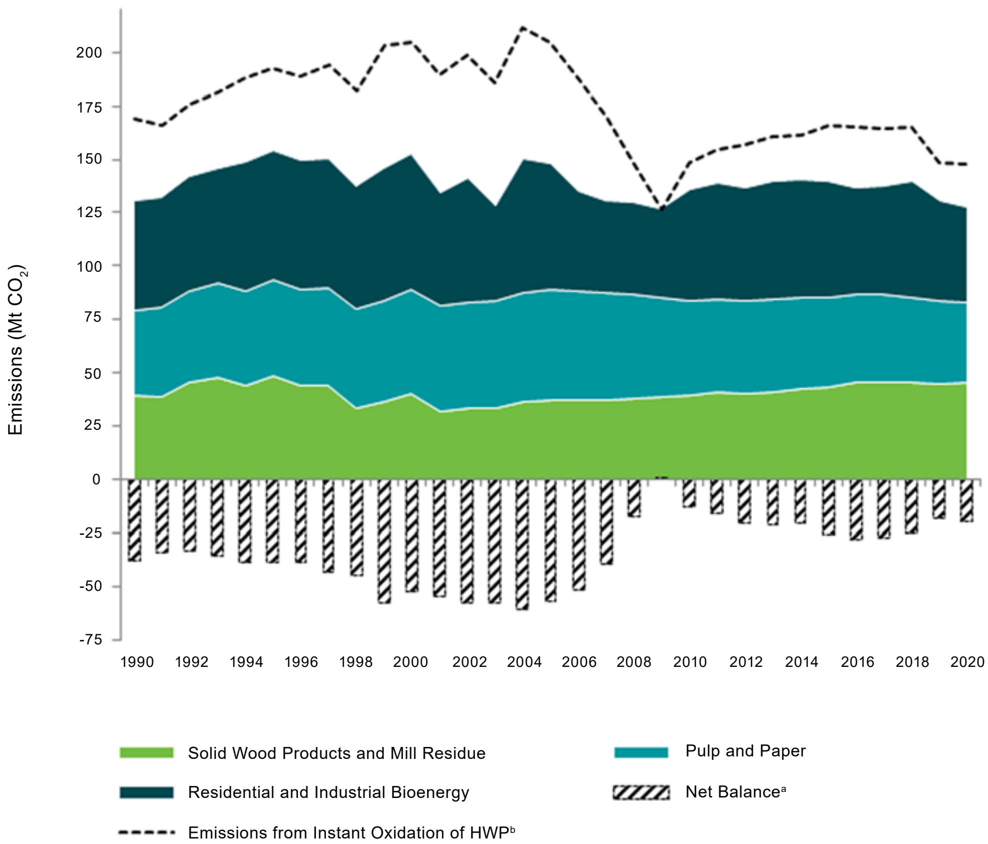
Activity data and annual estimates of C inputs, stock changes in the HWP pool and resulting net emissions for each commodity are reported in CRF Table 4.G. In line with the Simple Decay Approach, Canada has made the following assumptions to report data related to HWP in this table:

- column "B" for Gains: correspond to C inputs associated with C transferred from any wood producing land category (e.g., Forest Land) to the HWP pools used domestically and exported; these C inputs would represent C losses in CRF tables 4.A-4.F if using a reporting approach other than the Simple Decay Approach and are reported in this table for completeness and transparency purposes;
- column "C" for Losses: corresponds to C losses calculated from the combustion of firewood, from the oxidation of milling waste, and via the decay equation 12.1 from Volume 4, Chapter 12, of the 2006 IPCC Guidelines for HWP with longer half-lives;
- column "E" for annual change in stocks: calculated as the net interannual change in stocks in the HWP pool; the total annual values for these net stock are reported in Table 6–7; and
- column "F" for net emissions/removals of CO_2 from the HWP: values reported in this column correspond to CO_2 emissions associated to the C losses reported in column "C"; C gains reported in column "B" are not considered in the calculation of this column to avoid double counting of removals in the sector given that emissions due to instant oxidation of harvested wood are not reported in any of the CRF tables 4.A through 4.F.

For the 1990–2007 period, emissions resulting from the inclusion of the HWP pool (stacked areas in Figure 6–5) are considerably lower than the emissions that would result from using an instant oxidation approach (dotted line in Figure 6–5), as used in submissions prior to 2015, with differences (bars in Figure 6–5) fluctuating between -34 Mt in 1992, and -61 Mt in 2004 (highest harvest year). These large differences occur because C in wood removed from the forests in the reporting year was much higher than the C transferred to the HWP pool in past years with lower harvest rates and contained in long-lived wood products that were disposed of in the reporting year. By contrast, after 2007, though harvest rates are lower (notably in 2009), HWP emissions remain elevated relative to estimates based on instant oxidation due to the higher harvest rates in previous years that continue to contribute to estimated emissions in the reporting year.

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

Figure 6–5 **Emissions from the HWP Pool Using the Simple Decay Approach**



Notes:

a. The "Net Balance" is the difference between C transferred to the HWP pool and emissions from the HWP, a value that cannot be reported in the current structure of the CRF tables.

b. This data series represents the carbon transferred annually from the forest and other land uses into the HWP C pool in units of CO_2, i.e., the emissions that would result from using an instant oxidation approach, and is presented for reference purposes only. It includes salvage logging after natural disturbances on forests.

6.4.3. Uncertainties and Time-Series Consistency

In the assessment of the uncertainty of the Harvested Wood Products category, model parameters were varied for Monte Carlo simulations while carrying out two additional runs using minimum and maximum HWP inputs resulting from CBM-CFS3 (ecosystem) uncertainty analyses. These are used to estimate the combined uncertainty of the two systems for all C harvested since 1990 (Table 6–8). Additional parameters are used in the Monte Carlo analysis including uncertainty distributions for historical inputs (pre-1990 harvest), contemporary inputs (harvest since 1990) and five allocation parameters related to bioenergy. In years where there are no substantial changes, such as in this submission, Monte Carlo simulation is not performed (latest simulation was performed for the 2021 submission covering the entire 1990–2019 time series). Instead, confidence intervals for each category for the current year of submission are extrapolated. More details are provided in Annex 3.5.3.

Table 6–8 **Estimates of CO_2 Emissions from Harvested Wood Products, with 2.5th and 97.5th Percentiles, for Selected Years**

Inventory Year	Source of C inputs	Emissions (Mt CO_2)	2.5th Percentile (Mt)	% Uncertainty (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
1990	Conventional Harvest – since 1990	59	42	-28	70	19
	Forest Conversion – since 1990	2.7	1.8	-34	3.2	21
	Residential Firewood Collection	16	16	-3.4	17	3.6
	Historical Harvest – before 1990	53	41	-24	67	25
2005	Conventional Harvest – since 1990	118	101	-14	129	10
	Forest Conversion – since 1990	2.8	2.0	-29	3.3	16
	Residential Firewood Collection	12	11	-3.7	12	4.3
	Historical Harvest – before 1990	15	12	-24	20	32
2020	Conventional Harvest – since 1990	102	95	-7.5	108	5.1
	Forest Conversion – since 1990	3.4	2.5	-26	3.7	8.7
	Residential Firewood Collection	11	11	-4.6	12	5.0
	Historical Harvest – before 1990	11	8.2	-23	12	14

6.4.4. Quality Assurance / Quality Control and Verification

Environment and Climate Change Canada, while maintaining its own QA/QC procedures for estimates developed internally (refer to section 1.3, Chapter 1), has implemented specific procedures for estimates obtained from data partners, as well as for all estimates and activity data contained in the LULUCF data warehouse (Blondel, 2018) and entered into the CRF Reporter.

6.4.5. Recalculations

There were significant recalculations in the Harvested Wood Products category driven by (i) industrial forestry activity data for 2019 updated from the NFD,[8] (ii) updated HWP model parameters based on latest FAO forest product statistics for Canada[9] that impacted years 2019 and 2020, (iii) updated residential bioenergy consumption 2018–2020 based on updates from the 2019 Households and the Environment Survey (Statistics Canada, 2019), (iv) correction of C-density of spent pulp liquor, and (v) deforestation updates. As a combined effect of these changes, total emissions from this category were increased by 0.3 Mt (+0.2%) in 1990 and 0.2 Mt (+0.1%) in 2005, and decreased by 12 Mt (-8.4%) in 2019.

6.4.6. Planned Improvements

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

Research is ongoing to include the country-specific half-lives for a significant portion of Canada's HWP production that reflect much longer HWP residence times in housing than the IPCC default values, to develop more accurate residential biomass burning emission factors, and to improve knowledge of industrial bioenergy chain (origin of the wood) and develop a better characterization of wood feedstock serving as wood fuel for the industry sector. Further research is underway to improve the regional differentiation of HWP production and trade, so that provincial/territorial summaries more accurately reflect regional conditions.

8 National Forestry Database: http://nfdp.ccfm.org/en/index.php

9 FAOSTAT Forestry Production and Trade, available online at http://www.fao.org/faostat/en/#data/FO and FAOSTAT Forestry Trade Flows, available online at http://www.fao.org/faostat/en/#data/FT

6.5. Cropland (CRF Category 4.B)

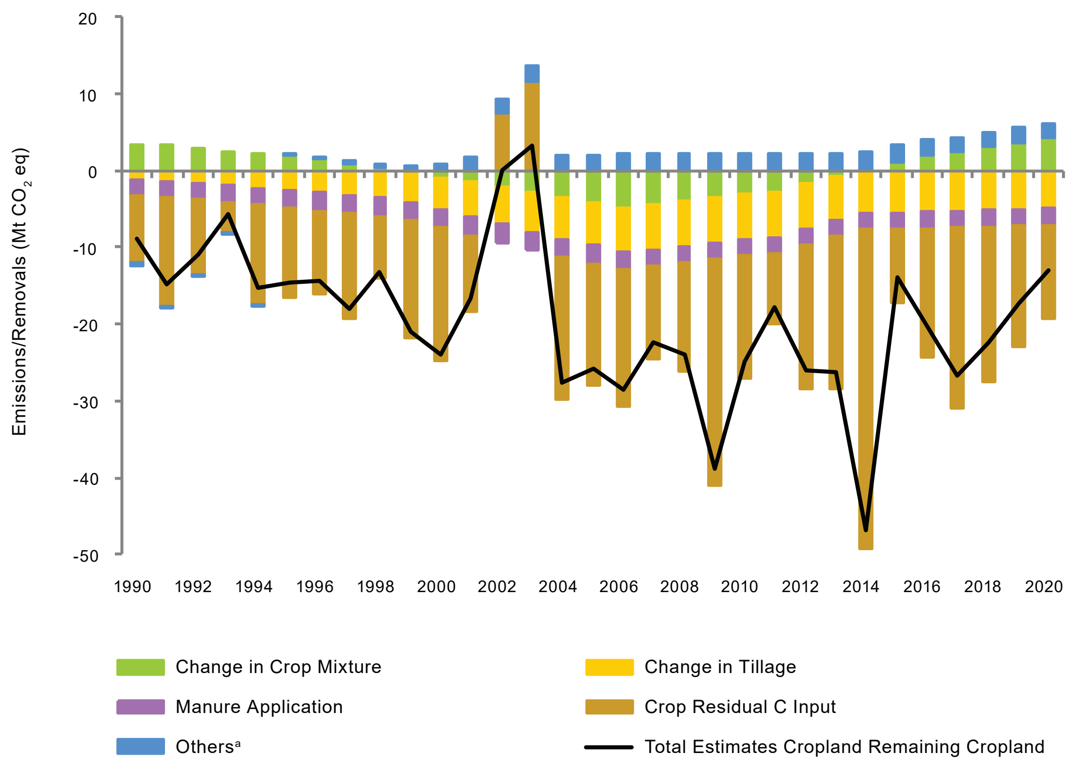
Cropland covers approximately 47 Mha of the Canadian territory. In 2020, the net GHG balance in the Cropland category amounted to removals of 9.6 Mt (Table 6–1). For the purpose of reporting under the UNFCCC, the Cropland category is divided into Cropland Remaining Cropland (net removals of 13 Mt in 2020) and Land (either Forest or Grassland) Converted to Cropland (net emissions of 3.4 Mt and 0.04 Mt, respectively, in 2020). The estimates of Land Converted to Cropland include net emissions and removals of CO_2, as well as N_2O and CH_4 emissions.

6.5.1. Cropland Remaining Cropland (CRF Category 4.B.1)

Cultivated agricultural land in Canada includes areas of field crops, summerfallow, hay fields and tame or seeded pasture. Cropland is found mainly in the nine southernmost reporting zones. About 83% of Canada's cropland is in the interior plains of Western Canada, made up of the Semiarid Prairies, Subhumid Prairies and Boreal Plains reporting zones. Another 12% of cropland is found in the Mixedwood Plains reporting zone.

The Cropland Remaining Cropland subcategory includes CO_2 emissions/removals in mineral soils, CO_2 emissions from cultivation of organic soils and CO_2 emissions/removals resulting from changes in woody biomass from specialty crops, trees and shrubs and lands not fulfilling the definition of Forest Land. An enhanced Tier 2 approach is used for estimating CO_2 emissions from and removals by mineral soils triggered by changes in tillage practices and perennial/annual crop conversion on an area base. In this submission, the IPCC Tier 2 Steady State approach (IPCC, 2019) is also used for estimating soil C storage as impacted by the change in crop productivity/crop residue C input to soils based on yield estimates. As a result, the explicit inclusion of area-based summerfallow factors is eliminated as a separate driver of changes in cropland soil C. Removals of CO_2 associated with increases in C input to soils from reductions of summerfallow area are estimated based on changes in yield exclusively to avoid double counting as regional estimates of yield change inherently include the reduction in summerfallow. In addition, a country-specific method has been developed for estimating soil C storage influenced by manure application to soils under annual crop production using manure-induced C retention factors (Liang et al., 2021).

Figure 6–6 **Emissions and Removals Related to Cropland Remaining Cropland**



Note:

a. Others include emissions/removals associated to perennial woody crops and cultivation of histosols, and residual emissions from land conversion.

Table 6–9 **Base and Recent Year Emissions and Removals Associated with Various Land Management Changes to Cropland Remaining Cropland**

Categories	Land Management Change (LMC)	Emissions/Removals (kt CO_2)[a]							
		1990	2005	2015	2016	2017	2018	2019	2020
Total Cropland Remaining Cropland		**-9 000**	**-26 000**	**-14 000**	**-20 000**	**-27 000**	**-22 000**	**-17 000**	**-13 000**
Cultivation of histosols		**300**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Perennial woody crops		**-1000**	**110**	**150**	**-4.6**	**-240**	**-170**	**-38**	**-37**
Total mineral soils		**-8 300**	**-26 000**	**-14 000**	**-21 000**	**-27 000**	**-23 000**	**-18 000**	**-13 000**
Change in crop mixture	Increase in perennial	-3 900	-13 000	-12 000	-12 000	-11 000	-11 000	-11 000	-11 000
	Increase in annual	7 300	8 700	13 000	14 000	14 000	14 000	14 000	15 000
Change in tillage	Conventional to reduced	-880	-1 000	-760	-720	-690	-660	-630	-600
	Conventional to no-till	-420	-3 700	-3 700	-3 700	-3 600	-3 600	-3 500	-3 500
	Other[b]	-0.4	-850	-1 000	-990	-970	-950	-940	-910
Crop residual C input		-8 600	-16 000	-9 600	-17 000	-24 000	-20 000	-16 000	-12 000
Manure application		-2 000	-2 400	-2 100	-2 100	-2 200	-2 200	-2 100	-2 200
Land conversion—Residual emissions[c]		170	1 700	1 800	1 800	1 700	1 700	1 700	1 700

Notes:

a. Negative sign indicates removal of CO_2 from the atmosphere.

b. Other includes reduced to no-till as well as other changes in tillage with relatively less significant impacts on emissions/removals, namely: reduced to conventional, no-till to conventional, and no-till to reduced.

c. Net residual CO_2 emissions from the conversion of Forest Land and Grassland to Cropland that occurred more than 20 years prior to the inventory year, including emissions from the decay of woody biomass and DOM.

6.5.1.1. CO_2 Emissions and Removals in Mineral Soils

Mineral soils constitute the majority of cropland areas (>99%). The amount of organic C retained in these soils is a function of crop production and the rate of decomposition of SOC. Cultivation and management practices can lead to an increase or decrease in the organic C stored in soils. This change in SOC results in a CO_2 emission to or removal from the atmosphere.

In 1990, changes in mineral soil management amounted to net CO_2 removals of 8.3 Mt (Table 6–9). The CO_2 removals by soil increased to 26 Mt in 2005 and then decreased to 13 Mt in 2020. Since 1990, on average, major field crop yields increased by 23% for barley, 82% for canola, 41% for corn, 72% for spring rye and 36% for spring wheat. This increase in crop yield reflected in C inputs to soils from crop residues resulted in net removals of CO_2 by soils of 8.6 Mt in 1990, 16 Mt in 2005, and 12 Mt in 2020. Interannual variability is high throughout the time series, reflecting weather-related impacts to crop production (Figure 6–6).

There has been a significant increase in conservation tillage from 11 Mha in 1990 to 29 Mha in 2020, and this increasing trend results in CO_2 removals by soil of 1.3 Mt in 1990, 5.6 Mt in 2005 and 5.0 Mt in 2020 (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, observed in the net change in crop mixture resulting in net emissions of 3.4 Mt in 1990 and net removals of 4.2 Mt in 2005.

Since 2006, however, there has been an increase in the proportion of annual crops in the crop mixture and a decline in the rate of adoption of conservation tillage. Manure application on annual cropland contributed to relatively constant CO_2 removals to soils varying from 2.0 to 2.4 Mt annually, reflecting changes in beef cattle, swine and poultry populations. As a result of this combination of changes in management practice, since 2006, net removals in mineral soils have decreased by roughly 13 Mt, mainly driven by the decrease in the proportion of perennial crops in the crop mixture and fluctuations in crop yield/crop residue C input.

Methodological Issues

According to the 2006 IPCC Guidelines, changes in SOC are driven by changes in soil management practices. Where 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 on SOC and selected the key management practices and management changes likely to cause changes in soil C stocks for which activity data (time series of management practices) from the Census of Agriculture (CoA) were available. A number of management practices are known to increase SOC in cultivated cropland. They include a reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting practices, and re-establishment of perennial vegetation (Janzen et al., 1997; Bruce et al., 1999). 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 derived from yield estimates produced for estimating nitrous oxide emissions from crop residue (Thiagarajan et al., 2018) as can estimates of carbon input in manure. Estimates of CO_2 changes in mineral soils were derived from the following LMCs:

- change in the proportion of annual and perennial crops
- change in tillage practices
- change 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 a management change for tillage practices and perennial/annual crop mix, and country-specific C factors based on changes in rates of crop residue carbon input multiplied by the area of land on which crop production was estimated. Soil C removals resulting from manure application is estimated using manure-induced C retention factors. Manure production rates are consistent with data developed for estimating emissions of nitrous oxide in Chapter 5. Calculations were performed at the scale of the Soil Landscapes of Canada (SLC) polygons (see Annex 3.5.1). The C emission/removal factors represent the rate of SOC change per year and per unit area that underwent a land management change.

The impact of LMCs on SOC varies with initial conditions. The most accurate estimate of soil C stock change would therefore be derived by individually considering the cumulative effects of the long-term management history of each piece of land or farm field. The inventory relies mainly on the CoA for estimates of areas of LMC (i.e., changes in tillage and crop mixtures) which are not spatially explicit. The area of LMC was determined individually for 3475 SLC polygons having agricultural activities, each one with an agricultural area in the order of 1000 to 1 000 000 ha. This is the finest possible resolution of activity data linked to an ecological land strata. The census provides information about the area of each practice for 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 gross area of LMC as is feasible for regional or national analyses.

The validity of LMC estimates using census data relies on two key assumptions: additivity and reversibility of area-based C factors. Additivity assumes that the combined effects of different LMCs or LMCs at different times would be the same as the sum of the effect of each individual LMC. Reversibility is the assumption that the C effects of an LMC in one direction (e.g., converting annual crops to perennial crops) is the opposite of the C effects of the LMC in the opposite direction (e.g., converting perennial crops to annual crops).

The various C factors associated with each particular area-based tillage practice and perennial/annual crop mix in both space and time were derived using the CENTURY model (Version 4.0) by comparing output for scenarios “with” and “without” the management change in question.

In previous versions of the NIR, an area-based C factor was also used to account for reductions in summerfallow area. It is understood that this factor was largely accounting for reductions in C inputs to soils resulting from the practice of leaving the soil fallow. However, crop productivity has continued to increase in Canada likely as a result of higher rates of fertilization and improvements to crop genetics (Fan et al., 2019). As a result, the area-based factor used for summerfallow underestimated the change in SOC associated with the change in carbon input to soils. The 2019 Refinement of 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 used in crop residue nitrogen (N) in estimates of 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 soil C sink as a result of manure application to cropland soils. Estimates of SOC change occurred only in cases in which manure was applied to annual cropping systems. Manure applications to perennial land were considered to have no net impact on soil C due to a lack of empirical data to estimate a retention factor.

A more detailed description of methodologies for determining C factors and other key parameters can be found in Annex 3.5.4.1.

Uncertainties and Time-Series Consistency

Uncertainty was estimated analytically with a Tier 1 approach. The uncertainties associated with estimates of CO_2 emissions or removals involve estimates of uncertainties for area and C factors of management changes for tillage and annual/perennial crops (McConkey et al., 2007).

The uncertainty associated with the area in a management practice for an ecodistrict varied inversely with the relative proportion of the total area of agricultural land in that ecodistrict. The relative uncertainty of the area of management practice (expressed as standard deviation of 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 crops were partitioned in two main sources: (1) process uncertainty in C change due to inaccuracies in predicting C change even if the situation of management practice was defined perfectly, and (2) situational uncertainty in C change due to variation in the location or timing of the management practice. Further details on estimating process and situational uncertainties can be found in Annex 3.5.4.1. Uncertainty estimates associated with emissions/removals of CO_2 from mineral soils were developed by McConkey et al. (2007), who reported uncertainty values at ±19% for the level and ±27% for the trend. These uncertainty estimates have not been updated since the 2011 annual submission. Changes in agricultural activity data from the incorporation of EO 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 to crop production, especially drought in the Canadian prairies. Similarly, a formal uncertainty analysis has not been conducted for the estimates of cropland C change from manure application, though uncertainty estimates associated with field measurements of manure-induced C retention are available.

Consistency in the CO_2 estimates is ensured through the use of the same methodology for the entire time series of estimates (1990–2020).

Quality Assurance / Quality Control and Verification

Tier 1 QC checks implemented by AAFC specifically address estimate development in the Cropland Remaining Cropland subcategory. Environment and Climate Change Canada, while maintaining its own QA/QC procedures for estimates developed internally (see section 1.3, Chapter 1), has implemented additional QC checks for estimates obtained from partners, as well as for all estimates and activity data contained in its LULUCF data warehouse (Blondel, 2018) and entered into the CRF Reporter. In addition, the activity data, methodologies and changes are documented and archived in both paper and electronic form.

In February 2009, Canada convened an international team of scientists and experts from Denmark, France, Japan, Sweden, the Russian Federation and the United States to conduct a quality assurance assessment of the methods. Some limitations of the current system were found with respect to activity data, which could possibly create some bias in the current C stock change estimates. In particular, the lack of a complete and consistent set of land-use data and issues with the concept and application of pseudo-rotations.

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 were highly variable, particularly for Eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. Liang et al. (2020) compiled soil C stock change data as influenced by tillage practices on agricultural soils in Canada, and reported that climate, soil texture and duration of management are the main drivers of soil C change under no-till. The analysis suggested that estimates of tillage impacts may be improved through the addition of more recent and comprehensive data. For the change from annual to perennial cropping, the mean empirical factor was 0.59 Mg C ha^{-1} yr^{-1}. This compared favourably with the range of 0.46–0.56 Mg C ha^{-1} yr^{-1} in the modelled factors in western Canadian soil zones (VandenBygaart et al. (2008). For Eastern Canada, only two empirical change factors were available, but they fell within the range of the modelled values (0.60–1.07 Mg C ha^{-1} yr^{-1} empirical versus 0.74–0.77 Mg C ha^{-1} yr^{-1} modelled).

Manure-induced C retention represents the average fraction of C input from various manures that is retained in the soil. The country-specific method using manure-induced C retention was developed through an analysis of ten long-term studies of manure application on Canadian soils in a wide range of climatic and soil conditions across Canada (Liang et al., 2021).

Several soil C models of varying complexities (i.e., RothC, ICBM, and CAMPBELL) that are capable of using measured crop yield 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 a varying degree of success against field observations (Thiagarajan et al., in preparation). Estimates of national soil C change varied significantly among these models. For comparability purposes among Annex 1 Parties, the IPCC Tier 2 Steady State approach is used for estimating the change in soil C storage as impacted by crop productivity/crop residue C input. The results of this approach were observed to be roughly equivalent to the mean of the other models.

As part of quality assurance and continuous improvements efforts, methodologies for estimating soil C storage as impacted by the change in crop productivity/crop residue C input and manure application in 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 addressing clear methodological deficiencies and the modifications further address, in part, issues identified by the 2009 international review.

Recalculations

In this submission, significant recalculations occurred due to: i) the implementation of the IPCC Tier 2 Steady State approach for estimating the change in soil C storage as impacted by crop productivity/crop residue C input, ii) the change in soil C storage as influenced by manure application, iii) elimination of summerfallow as a separate LMC to avoid double counting of SOC change with changes in crop productivity, and iv) an update to land-use coverage, which impacted cropland land management area estimates throughout the inventory time series.

The implementation of new methodologies for crop productivity and manure application increased net CO_2 removals to soil by 10 Mt for 1990, 18 Mt for 2005, and 18 Mt in 2019. The elimination of summerfallow as a separate LMC reduced soil CO_2 removals by 2.3 Mt in 1990, 6.5 Mt in 2005, and 8.4 Mt in 2019.

A new version of land-use coverage that contains revised mapping of agricultural lands throughout all years of the time series was used to generate this year's inventory. This change impacted estimates of agricultural land management areas over all interpolated years. On a national scale, land mapped as cropland ranged from 0.5% (0.25 Mha) higher in 1990 to 0.9% (0.47 Mha) lower in 2019 than cropland estimates in 2021 NIR.

The update in areas of tillage practices and perennial/annual crop mixture activity data resulted in an increase of soil CO_2 emissions of 1.3 Mt in 1990 and 0.25 Mt in 2005, and an increase of net CO_2 removals by soils of 0.1 Mt in 2019.

The combined effect of these changes was an increase in CO_2 removals by mineral soils of 7.1 Mt in 1990, 11 Mt in 2005, and 9.8 Mt in 2019.

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. Model parameters will be adapted to Canadian conditions through a Bayesian optimization. Currently, multiple models are being assessed including the IPCC Tier 2 Steady State approach. Further, a formal and complete analysis/calculation of uncertainty including tillage, annual/perennial crop mix, crop productivity/crop residue C input and manure application is also planned in a mid-term of 3 to 5 years.

6.5.1.2. CO_2 Emissions from Cultivation of Organic Soils

Category Description

In Canada, the cultivation of organic soils is defined as the conversion of organic soils to annual crop production, normally accompanied by artificial drainage, cultivation and liming. Organic soils used for agricultural production in Canada include peaty-phase gleysols, fibrisols over 60 cm thick, and mesisols and humisols over 40 cm thick (Soil Classification Working Group, 1998).

Methodological Issues

The emissions from the cultivation of organic soils were calculated by multiplying the total area of cultivated histosols by the default emission factor of 5 Mg C ha^{-1} yr^{-1} (IPCC, 2006).

Areas of cultivated histosols are not provided by the CoA; 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 1990–2020) was 16 kha, or 0.03% of the cropland area. Close to 90% of the area of cultivated histosols is located in the Boreal Shield East, Mixedwood Plains and Boreal Plains reporting zones.

Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties from the area estimates for the cultivated histosols and the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols are assessed to be ±50% (Hutchinson et al., 2007). The 95% confidence limits of the default emission factor are ±90% (IPCC, 2006). The overall mean and uncertainties associated with this source of emissions were estimated to be 0.3 ± 0.09 Mt for the level uncertainty and 0 ± 0.13 Mt for the trend uncertainty (McConkey et al., 2007).

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2020).

Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

There were no recalculations for this source category.

Planned Improvements

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

6.5.1.3. CO_2 Emissions and Removals in Woody Biomass

Category Description

Emission and removal estimates of woody biomass include trees and shrubs that occur on agricultural lands as well as perennial woody crops such as vineyards, fruit orchards and Christmas trees. A portion of tree biomass lost in croplands has been transferred to the HWP pool to meet residential bioenergy requirements. Accordingly, this C transfer is not reported as biomass loss under Cropland Remaining Cropland to avoid a double counting of emissions with the emissions from combustion as firewood, which are reported under the Harvested Wood Products category. See more details in section 6.4 and Annex 3.5.4.1.

In the definitional framework adopted in Canada for LULUCF reporting, abandoned cropland is still considered Cropland 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 for changes in woody biomass, and no abandoned or re-cultivated croplands are included in this category.

Net CO_2 fluxes from woody biomass on agricultural lands amounted to net removals of 1.0 Mt in 1990 and 0.04 Mt in 2020 and net emissions of 0.1 Mt in 2005. Emissions associated with woody biomass transferred to the HWP pool and used for residential bioenergy accounted for 0.8 Mt, 0.5 Mt and 0.5 Mt of the total firewood emissions reported under the Harvested Wood Products category in 1990, 2005 and 2020, respectively. The net contribution of agricultural woody biomass to the LULUCF sector was on average an annual sink of 0.2 Mt throughout the first decade of the time series and an annual source of 0.6 Mt throughout the second and third decades of the time series.

Methodological Issues

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yields. Vineyards and fruit trees are pruned annually, and old plants are replaced on a rotating basis for disease prevention, stock improvement or introduction of new varieties. For all three crops, it is assumed that, because of rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass C within existing farms, as C lost from harvest or replacement would be balanced by gains due to new plant growth. The approach therefore was limited to detecting changes in areas under vineyards, fruit orchards and Christmas tree plantations and estimating the corresponding C stock changes in total biomass. More information on assumptions and parameters can be found in Annex 3.5.4.1.

The category of trees and shrubs in Cropland include perennial woody cover types in farmyards, shelterbelts and hedgerows. The method tracks woody volume lost as a result of clearing and gained as a result of planting and annual growth through the use of an EO-based monitoring approach and ecozone-specific growth parameters. More information on assumptions and parameters can be found in Annex 3.5.4.1.

Uncertainties and Time-Series Consistency

Upon a loss of area with perennial woody crops, all C in woody biomass is assumed to be immediately released. It is assumed that the uncertainty for C loss equals the uncertainty associated with mass of woody biomass C. The default uncertainty of ±75% (i.e., 95% confidence limits) for woody biomass on Cropland from the 2006 IPCC Guidelines was used for vineyards, fruit orchards and Christmas trees.

If the loss in area of fruit trees, vineyards or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial to annual crop conversion with associated uncertainty that contributes to C change uncertainty. For an area of gain in fruit trees, vineyards or Christmas trees, the uncertainty in annual C change was also assumed to be the default uncertainty of ±75% (i.e., 95% confidence limits) (IPCC, 2006).

The overall mean and uncertainties associated with emissions or removals of CO_2 from vineyards, fruit orchards and Christmas trees were estimated to be 2 ± 0.2 kt for the level uncertainty and -29 ± 42 kt for the trend uncertainty (McConkey et al., 2007). The overall mean and uncertainty associated with removals of CO_2 from trees and shrubs is described in Huffman et al. (2015b) and is estimated to be -440 ± 180 kt for the annual estimate. Since removals resulting from the growth of trees and shrubs represent the biggest contribution to the overall removal/emission estimates, these two land cover types drive the uncertainty for the woody biomass subcategory, estimated to be an average of 41% for the level uncertainty. More information on the method and factors considered for the uncertainty of C stock changes in trees and shrubs can be found in Huffman et al. (2015b).

The same methodology was used for the entire time series of emission estimates (1990–2020).

Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

Recalculations were due to (i) small revisions applied to the annual amount of tree biomass transferred to the HWP pool as a source of residential firewood, and (ii) updated residential bioenergy consumption 2018–2020 based on updates from the 2019 HES (Statistics Canada, 2019) (see more details in section 6.4). As a result of these changes, there were very minor recalculations in all years of the 1990-2018 period and a decrease in net removals by 0.3 Mt (-87.5%) in 2019.

Planned Improvements

An interpolation method will be applied to improve the woody biomass time series transition between the two 1990–2000 and 2000–2010 activity data sampling periods of digital air photos. Work has begun to explore new methodologies to improve the classification and automated quantification of changes in areas under trees and shrubs in agricultural regions of Canada.

6.5.2. Land Converted to Cropland (CRF Category 4.B.2)

This subcategory includes the conversion of forest land and agricultural grassland to cropland. Emissions estimated and reported in Forest Land Converted to Cropland account for more than 90% of the total annual emissions in this category, which decreased from 9.2 Mt in 1990 to 3.5 Mt in 2020. Emissions associated to Grassland Converted to Cropland are relatively small.

6.5.2.1. Forest Land Converted to Cropland (CRF Category 4.B.2.1)

Clearing forest for use as agricultural land is still an ongoing practice in Canada, accounting for 46% of forest area conversion in 2020. The cumulative area reported under the Forest Land Converted to Cropland subcategory in CRF Table 4.B was 1300 kha over the 20 years prior to 1990 and 370 kha over the 20 years prior to 2020. Methods to determine the area converted annually are the same as those used for all forest conversion to other land-use categories and are outlined in section 6.9. In 2020, immediate emissions from forest conversion to cropland accounted for 1.4 Mt, while residual emissions from events that occurred in the last 20 years accounted for 2.0 Mt.

Methodological Issues – Dead Organic Matter and Biomass Pools

Approximately 90% of emissions originate from the biomass and DOM pools during and after conversion, with the remainder being attributed to the soil pool. Their estimation is performed in the same modelling environment as that used for Forest Land Remaining Forest Land. A general description of this modelling environment is provided in section 6.3.1.2. More information is provided in Annex 3.5.4.3.

Methodological Issues – Soils

Emissions from soils in this category include the net C stock change due to the actual conversion, a very small net CO_2 source from change in management practices in the 20 years following conversion, and the N_2O emissions from the decay of soil organic matter. Emissions/removals reported in Forest Land Converted to Cropland also include emission/removals from changes in land management practices, crop production, and manure application on this land. The soil emissions were calculated by multiplying the total area of conversion by the empirically derived emission factor along with modelling-based SOC dynamics (see Annex 3.5.4.3). Patterns of change in SOC after the conversion of forest land to cropland clearly differ between Eastern and Western Canada.

Eastern Canada

All agricultural land in the eastern part of the country was forested before its conversion to agriculture. Many observations of forest SOC comparisons with adjacent agricultural land in Eastern Canada—either in the scientific literature or the Canadian Soil Information System—show a mean C loss of 20% at depths to approximately 20–40 cm (see Annex 3.5.4.3). Average N change was -5.2%, equivalent to a loss of approximately 0.4 Mg N ha^{-1}. For those comparisons where both N and C losses were determined, the corresponding C loss was 19.9 Mg C ha^{-1}. Therefore, it was assumed that N loss was a constant 2% of C loss.

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from conversion of forest land to cropland in Eastern Canada. More details of methodologies for determining the maximal C loss and its rate constant associated with the conversion of forest land can be found in Annex 3.5.4.3.

Following an IPCC Tier 2 method, as noted for direct N_2O emissions from agricultural soils (see Agriculture sector, Chapter 5), emissions of N_2O from conversion of forest land to cropland were estimated 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 (Prairies and Peace River region of British Columbia) was grassland in the native condition. Hence, 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 data source for SOC under forest and agriculture. On average, these data suggest that there is no loss of SOC 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 agriculture, where most forest conversion is occurring, the land is marginal for arable agriculture; pasture and forage crops are the dominant management practices. As a result, for Western Canada, no loss of SOC over the long term was assumed from forest land converted to cropland managed exclusively for seeded pastures and hayland.

The C loss from forest conversion in Western Canada results from the loss of above- and below-ground tree biomass and from loss or decay of other above- and below-ground coarse woody DOM that existed in the forest at the time of forest conversion. The average N change in Western Canada for sites at least 50 years from the breaking of the land for cultivation was +52% (see Annex 3.5), reflecting substantial added N in agricultural systems compared with forest management practices. However, recognizing the uncertainty associated with actual C-N dynamics for forest conversion, conversion of forest land to cropland in Western Canada was assumed not to be a source of N_2O.

Uncertainties and Time-Series Consistency

Greenhouse gas fluxes from Forest Land Converted to Cropland result from the combination of (1) logging and burning—immediate emissions from biomass and DOM, (2) organic matter decay and subsequent CO_2 emissions in the DOM pool, and (3) net C losses from SOC. Immediate CO_2 emissions always refer to area converted in the inventory year; residual emissions, while also occurring on land converted during the inventory year, mostly come from land converted over the last 20 years. Non-CO_2 emissions are produced only by burning and occur during the conversion process.

Immediate and residual CO_2 emissions from the biomass and DOM pools represent the largest components of 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 about the median (biomass and DOM pools) or mean (soil pool) estimate values.

Table 6–10 **Uncertainty Associated with CO_2 Emission Components and Non-CO_2 Emissions from Forest Land Converted to Cropland for the 2020 Inventory Year**

Emission Components	Emissions (kt CO_2 eq)	Uncertainty (kt CO_2 eq)
Immediate CO_2 emissions	1 250	±402
Residual CO_2 emissions from the DOM pool[a]	1 755	±396
Residual CO_2 emissions from the soil pool	258	±160
CH_4 emissions	129	±42
N_2O emissions	71	±18

Note:
a. DOM = dead organic matter

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Using the estimation approach, uncertainty estimates were derived independently for the biomass and DOM pools and for soil organic matter. The uncertainty in activity data described in section 6.9.2 was incorporated in all analyses.

The fate of biomass and DOM upon forest conversion and the ensuing emissions are modelled using the same framework as that used for Forest Land. The corresponding uncertainty estimates were therefore also developed within this framework and with the same Monte Carlo runs that generated uncertainty estimates in the Forest Land category. A description of the general approach is provided in section 6.3.1.3. More information can be found in Annex 3.5.4.3.

The uncertainty in the net CO_2 flux from the soil pool was estimated analytically (McConkey et al., 2007). More information on the general approach used to conduct this analysis is provided in Annex 3.5.4.3.

Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. Quality checks were also performed externally by AAFC, which derived the estimates of SOC change. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

Recalculations occurred due to an update in the area of Forest Land Converted to Cropland. There was one additional SLC polygon added to the set of polygons used in this year's agricultural ecumene, handling new activity data on forest land conversion to cropland in RU 50 in the Northwest Territories.

The implementation of new methodologies for crop productivity and manure application contributed between 17 and 32 kt annually to soil CO_2 removals. The elimination of summerfallow as a separate LMC reduced removals by 0.5 kt annually. The update on activity data from Forest Land Converted to Cropland also resulted in small recalculations.

Overall, these changes resulted in downward adjustments of emission estimates by 25 kt in 1990 and 46 kt in 2005, and an increase of 0.1 Mt in 2019.

Planned Improvements

Planned improvements described under 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 from forest land conversion to cropland.

6.5.2.2. Grassland Converted to Cropland (CRF Category 4.B.2.2)

Conversion of native grassland to cropland occurs in the Canadian Prairies and generally results in losses of SOC and soil organic N and emissions of CO_2 and N_2O to the atmosphere. According to Bailey and Liang (2013)'s findings on burning of managed grassland in Canada, C losses from the above- or below-ground biomass or DOM upon conversion are insignificant. The authors reported that the average above-ground biomass was 1100 kg ha^{-1} in the Brown Chernozem, and 1700 kg ha^{-1} in the Dark Brown Chernozem. The above-ground biomass for the managed grassland would be lower than its respective yield under crop production (Liang et al., 2005). Total emissions from soils in 2020 amounted to 40 kt, down from 140 kt in 1990, including C losses and N_2O emissions from the conversion.

Methodological Issues

A number of studies on changes of SOC and soil organic N in grassland converted to cropland have been carried out on the Brown, Dark Brown and Black soil zones of the Canadian Prairies. The average loss of SOC was 22%, and the corresponding average change in soil organic N was 0.06 kg N lost per kg C (see Annex 3.5.4.2).

Emissions/removals reported in Grassland Converted to Cropland include residual emissions from the loss of SOC due to the land-use change and are affected by emissions/removals from changes in land management practices. The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils. More details of methodologies for determining the maximal C loss and its rate constant associated with the breaking of grassland can be found in Annex 3.5.4.2.

Similar to N_2O emissions in Forest Land Converted to Cropland, emissions of N_2O in Grassland Converted to Cropland were estimated by a Tier 2 methodology, multiplying the amount of C loss by the fraction of N loss per unit of C by a base emission factor (EF_Base). EF_Base is determined for each ecodistrict based on climate and topographic characteristics (see Annex 3.4.3).

Uncertainty and Time-Series Consistency

The conversion from agricultural grassland to cropland occurs, but within the definitional framework for managed lands, the conversion to grassland from cropland cannot occur (see section 6.2). Therefore, the uncertainty in absolute value of the area of this conversion cannot be larger than the uncertainty about the area of cropland or grassland. Hence, the uncertainty of the area of conversion was considered to be equivalent to the lower of the uncertainties of the area of either cropland or grassland in each ecodistrict. The uncertainty of SOC change was estimated as in Forest Land Converted to Cropland. The overall mean and uncertainty associated with emissions due to SOC losses from Grassland Converted to Cropland were estimated to be 40 ± 19 kt for the level uncertainty and -100 ± 45 kt for the trend uncertainty.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2020).

Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

Recalculations occurred following an update in the area of Grassland Converted to Cropland and were primarily driven by upward adjustments of the Grassland Remaining Grassland area due to the integration of the new land use mapping (see section 6.6.1.5). These adjustments had an indirect impact on this category causing a reduction in annual emissions.

The implementation of new methodologies for crop productivity, manure application and the elimination of summerfallow reduction as a separate LMC also resulted in recalculations.

All these changes reduced emissions by 0.1 Mt in 1990 and 2005, and 0.3 Mt in 2019.

Planned Improvements

Canada plans to validate the modelled soil C change factors with measured and published soil C change factors from grassland conversion as these become available.

6.6. Grassland (CRF Category 4.C)

Grassland used for agriculture is defined under the Canadian LULUCF framework as pasture or rangeland on which the only agricultural land management activity has been the grazing of domestic livestock. It occurs only in geographical areas where the grassland would not naturally grow into forest if abandoned; the natural shortgrass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. Agricultural grassland is found in three reporting zones: Semiarid Prairies (6.2 Mha), Montane Cordillera (87 ha) and Pacific Maritime (5 ha). As with Cropland, the change in management triggers a change in soil C stocks (IPCC, 2006). Very little information is available on management practices on Canadian agricultural grassland, and it is unknown whether grazed land is improving or degrading. Therefore, Canada reports this Grassland Remaining Grassland subcategory using the IPCC Tier 1 method based on no change in management practices since 1990. Within the current definitional framework as explained in section 6.2, the conversion of land to grassland is reported as not occurring under the subcategory Land Converted to Grassland (Table 6–4).

6.6.1. Grassland Remaining Grassland (CRF Category 4.C.1)

6.6.1.1. Category Description

In Canada, fires sometimes occur on managed grasslands in the form of prescribed burns to control invasive plants and stimulate the growth of native species or caused by lightning, accidental ignition, or military training exercises. Burning from managed grassland is a net source of CH_4, CO, NO_x and N_2O (IPCC, 2006).

6.6.1.2. Methodological Issues

Emissions of CH_4 and N_2O from burning of managed agricultural grassland were estimated using the IPCC Tier 1 method by taking into consideration the area of burn, fuel load and combustion efficiency for each burning event. Emission factors (2.7 g CH_4 kg^{-1} dry matter burned and 0.07 g N_2O kg^{-1} dry matter burned) were taken from the 2006 IPCC Guidelines (IPCC, 2006).

Activity data from 1990 to 2012 on area, fuel load and combustion efficiency for each burning event for managed agricultural grassland were collected through consultations (Bailey and Liang, 2013). The activity data on burning of managed agricultural grassland from 2013 to 2015 were updated in the 2018 submission.

6.6.1.3. Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties from the area estimate, average fuel load per hectare and combustion efficiency, along with emission factors. The 95% confidence limits associated with the amount of burned materials based on expert judgement are assessed to be ±50%. The 95% confidence limits of the default emission factors are ±40% for CH_4 and ±48% for N_2O (IPCC, 2006). The overall uncertainties associated with this source of emissions using error propagation were estimated to be ±64% for CH_4 and ±69% for N_2O, respectively.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2020).

6.6.1.4. Quality Assurance / Quality Control and Verification

This category has undergone Tier 1 QC checks (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data and methodologies are documented and archived in both paper and electronic form.

6.6.1.5. Recalculations

There were no recalculations in emission estimates for this source category. However, there were significant recalculations in the total area of agricultural grassland reported in CRF Table 4.C for Grassland Remaining Grassland due to integration of the new version of the land use coverage used to generate this year's inventory (see more details in the Recalculations sub-heading under section 6.5.1.1). As a result of this change, total area of agricultural grassland was increased by 0.3 Mha in 1990, 0.7 Mha in 2005 and 0.9 Mha in 2019. These upward adjustments of the Grassland Remaining Grassland area meant that the area of Grassland Converted to Cropland decreased, compared to the last year's submission, resulting in reduced emissions as noted in section 6.5.2.2.

6.6.1.6. Planned Improvements

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

6.7. Wetlands (CRF Category 4.D)

In Canada, a wetland is defined as land that is saturated with water long enough to promote anaerobic processes, as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity that are adapted to a wet environment. In other words, any land area that can keep water long enough to let wetland plants and soils develop. As such, wetlands cover about 14% of the land area of Canada (ECCC, 2016). The Canadian Wetland Classification System groups wetlands into five broad categories: bogs, fens, marshes, swamps and shallow water (National Wetlands Working Group, 1997).

However, for the purpose of this report and in line with the land categories as defined in IPCC (2006), the Wetlands category is restricted to those wetlands that are not already in the Forest Land, Cropland or Grassland categories. There is no corresponding area estimate for these wetlands in Canada.

In accordance with IPCC guidance (IPCC, 2006), two types of managed wetlands are considered where human intervention has directly altered the water table level and thereby the dynamics of GHG emissions/removals: (1) peatlands drained for peat extraction and (2) flooded land (namely, the creation of hydroelectric reservoirs). Owing to their differences in nature, GHG dynamics and the general approaches for estimating emissions and removals, these two types of managed wetlands are considered separately.

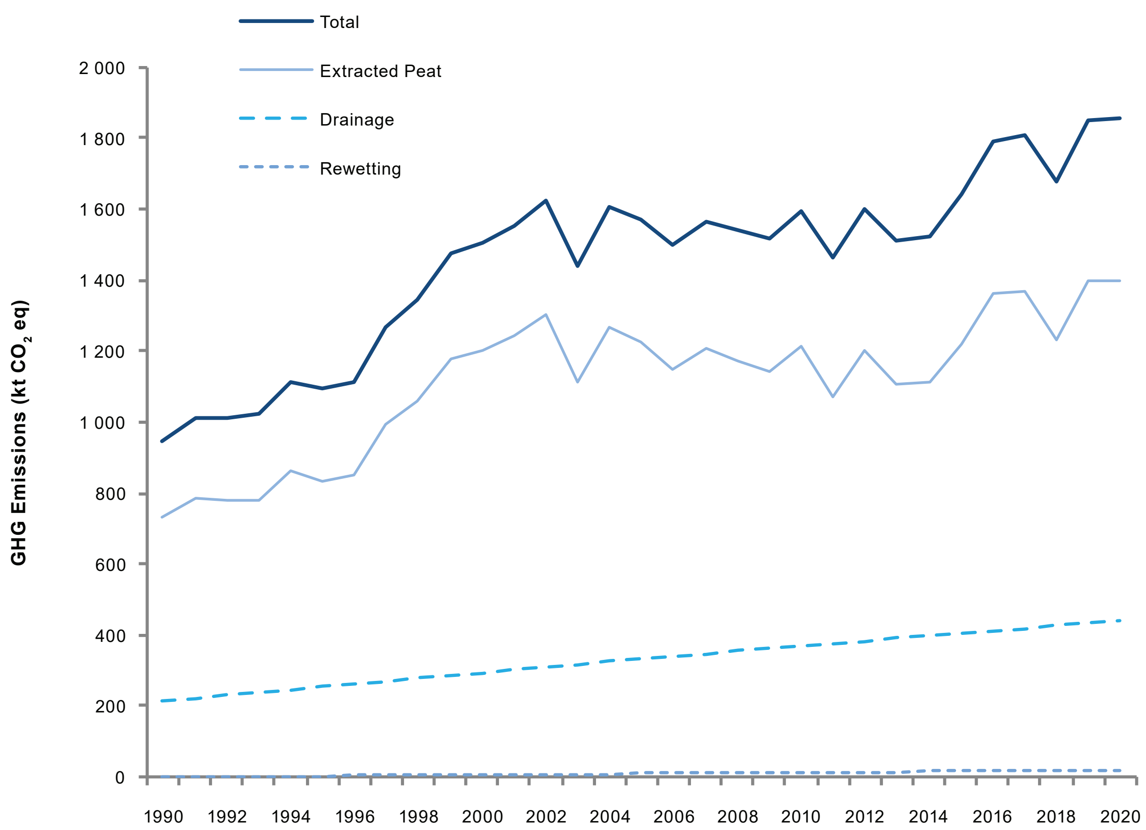
6.7.1. Peat Extraction (CRF Categories 4.D.1.1 and 4.D.2.1)

6.7.1.1. Source Category Description

Of the estimated 114 Mha of peatlands in Canada (NRCan, 2011), approximately 35 kha have been drained for peat extraction. Some 18 kha are currently being actively managed. The other 17 kha consist of peatlands that are no longer under production. In the Canadian context, generally only bog peatlands with a peat thickness of 2 m or greater and an area of 50 ha or greater are of commercial value for peat extraction (Keys, 1992). Peat production is concentrated in the provinces of New Brunswick, Quebec, Alberta and Manitoba. Canada produces peat for non-energy applications such as horticulture.

Emissions from peat extraction increased from 0.9 Mt in 1990 to 1.9 Mt in 2020 (Figure 6–7). The largest sources of emissions are from the decay of extracted peat and peatland drainage. Trends in extracted peat are driven by both an expansion in the active peat production area from 13 kha in 1990 to 18 kha in 2006 and interannual variations in weather conditions, which impact peat drying and thus harvesting. Emissions from peatland drainage continue to grow as more peatland areas are drained and subsequently de-commissioned, with an increasing proportion of de-commissioned sites undergoing rehabilitation, rewetting and restoration.

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



6.7.1.2. Methodological Issues

Estimates were developed using a Tier 2 methodology, in accordance with guidance from a combination of the 2006 IPCC Guidelines (IPCC, 2006) and 2013 IPCC Wetlands Supplement (IPCC, 2014). The approach is based on domestic science and land management practices specific to peat extraction in Canada. Emission estimates for drained and rewetted sites include on-site CO_2, CH_4 and N_2O emissions and off-site CO_2 emissions from waterborne C losses and from the decay of extracted peat. Domestic emission factors were derived from flux measurements reported by multiple research studies (refer to Annex 3.5.6.1). An EO mapping approach was used to determine the extent of peatland areas converted for peat extraction for 1990, 2007 and 2013 time periods and to identify the proportion of land category types converted (Forest Land and Other Land). Converted areas were allocated into four land management subcategories based on image interpretation and industry information: active extraction, abandoned, rehabilitated and restored areas. National peat production statistics were used to estimate the annual amount of extracted peat (NRCan, 2020b). Areas associated with peat extraction are reported in CRF Table 4.D under Land Converted to Peat Extraction for the first year after conversion and under Peat Extraction Remaining Peat Extraction thereafter, and the associated emissions are reported in CRF Table 4(II) under Peat Extraction Lands. More information on the estimation methodology can be found in Annex 3.5.6.1.

6.7.1.3. Uncertainty and Time-Series Consistency

A formal uncertainty assessment has not yet been carried out for this category. The most important sources of uncertainty are in the converted areas estimated from mapping, emission factors for the various categories of de-commissioned sites (e.g., rehabilitated and restored) and variations in the moisture content of extracted peat.

6.7.1.4. Quality Assurance / Quality Control and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures being implemented for Canada’s GHG inventory. The same procedures apply to this category as well. Industry and academic experts associated with the Canadian Sphagnum Peat Moss Association and Peatland Ecology Research Group provided QC, validation of mapping estimates and a review of domestically derived emission factors.

6.7.1.5. Recalculations

Recalculations for this category were due to updated peat production statistics in 2019 and resulted in an increase in emissions of 0.2 Mt kt for that year.

6.7.1.6. Planned Improvements

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

Refinements in the approach for estimating emissions and removals from non de-commissioned peat extraction sites are being considered. However, they depend on the availability of monitoring data indicating the state of naturally regenerating sites and the success rate of rehabilitation, rewetting and restoration activities. Advances in domestic science combined with increased monitoring of sites post-extraction will inform further improvements.

An uncertainty assessment is planned for future submissions.

6.7.2. Flooded Land (CRF Categories 4.D.1.2 and 4.D.2.2)

6.7.2.1. Source Category Description

This category includes, in theory, all lands that have been flooded regardless of purpose. Owing to methodological limitations, only large hydroelectric reservoirs created by land flooding were included. Existing water bodies dammed for water control or energy generation were not considered if flooding was minimal (e.g., Manitoba's Lake Winnipeg, the Great Lakes).

Since 1970, land conversion to flooded lands 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 as new lands were flooded. In 2020, 55% of the 46 kha of reservoirs flooded for 10 years or less were previously forested (mostly unmanaged forests). Total emissions from reservoirs declined from 4.5 Mt in 1990 to 1.1 Mt in 2020.

6.7.2.2. Methodological Issues

Two concurrent estimation 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 for all non-flooded C pools were estimated as in all forest conversion events, using the CBM-CFS3 (refer to section 6.9 and Annex 3.5.2.5). Emissions from the burning of non-flooded DOM are reported in CRF Table 4(V) under Land Converted to Wetlands and from the decay of residues remaining on site are reported in CRF Table 4.D under Land Converted to Flooded Land, for the first 10 years post-clearing, and in Flooded Land Remaining Flooded Land beyond this period. The construction of large reservoirs in northern Quebec (Toulnustouc, Eastmain-1, Peribonka), whose impoundments were completed in 2005, 2006 and 2008, respectively, resulted in 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 under Forest Land Converted to Settlements.

The second methodology is applied to estimate CO_2 emissions from the surface of reservoirs whose flooding has been completed. The default approach to estimate emissions from 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 largest proportion of any submerged vegetation does not decay for an extended period. A domestic approach was developed and used to estimate emissions from reservoirs based on measured CO_2 fluxes above reservoir surfaces from multiple research studies (refer to Annex 3.5.6.2), consistent with the descriptions of IPCC Tier 2 methodology (IPCC, 2006) and following the guidance in Appendix 2 of the 2006 IPCC Guidelines (IPCC, 2006). Annex 3.5.6.2 of this NIR contains more detail on this estimation methodology. The assessment includes CO_2 emissions only. Emissions from the surface of flooded lands are reported in CRF Table 4.D under Land Converted to Flooded Land for a period of 10 years after flooding, in an attempt to minimize the potential double counting of dissolved organic carbon (DOC) lost from the watershed and subsequently emitted from reservoirs. Therefore, only CO_2 emissions are calculated for hydroelectric reservoirs where flooding had been completed between 1981 and 2020.

For each reservoir, the proportion of pre-flooding area that was forest is used to apportion the resulting emissions to the subcategories Forest Land Converted to Flooded Land and Other Land Converted to Flooded Land.

It is important to note that fluctuations in the area of Land Converted to Flooded Land reported in the CRF tables are not indicative of changes in current conversion rates, but rather reflect the difference between land areas recently flooded (less than 10 years before the inventory year) and older reservoirs (10 years or more before the inventory year), whose areas are transferred out of the inventory. The reporting system does not encompass all reservoir areas in Canada.

6.7.2.3. Uncertainties and Time-Series Consistency

For Forest Land Converted to Flooded Land, refer to section 6.9, Forest Conversion. Annex 3.5.6.2 discusses the uncertainty associated with the Tier 2 estimation methodology.

Owing to current limitations in 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. The possibility of double counting in the Wetlands category is, however, limited to watersheds containing managed lands, which would exclude several large reservoirs in Taiga Shield East and Boreal Shield East reporting zones. Much of the DOC in these zones originates from unmanaged lands and is not subject to reporting.

6.7.2.4. Quality Assurance / Quality Control and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures being implemented for Canada's GHG inventory. The same procedures apply to this category as well. For Forest Land Converted to Flooded Land, also refer to the corresponding subheading in section 6.9, Forest Conversion.

Canada's approach to estimating emissions from forest flooding is more realistic temporally than the default approach (IPCC, 2006), which assumes that all biomass C on flooded forests is immediately emitted. Canada's method is more refined in that it distinguishes forest clearing and flooding; emissions from the former are estimated as in all forest clearing associated with land-use change. Further, in Canada's approach, emissions from the surface of reservoirs are derived from measurements, rather than from an assumption (immediate decay of all submerged biomass) that clearly is not verified.

6.7.2.5. Recalculations

Recalculations of 88 kt in 2019 occurred in this source category from the addition of the Muskrat Falls and Keeyask reservoirs and from the indirect impact on the estimate of quantities of C stocks in lands deforested for hydro-reservoirs after revisions to Forest Land methodologies (see section 6.3.1.5 for more details).

6.7.2.6. Planned Improvements

Further refining estimates of CO_2 emissions from the surface of reservoirs will partly depend on the ability to quantify lateral transfers of DOC from watersheds to reservoir systems. The monitoring of DOC as it travels through the landscape to the point of emission or long-term storage is beyond current scientific capabilities and will require long-term investments in research. Efforts to ensure that activity data are updated and validated will continue on an ongoing basis.

Continuous improvements will focus on the development of knowledge, updated activity data, parameters and emission factors to estimate CH_4 emissions from flooded lands.

6.8. Settlements (CRF Category 4.E)

The Settlements category is very diverse and includes: all roads and transportation infrastructure; rights-of-way for power transmission and pipeline corridors; residential, recreational, commercial and industrial lands in urban and rural settings; and land used for resource extraction other than forestry (e.g., oil and gas, mining).

For the purpose of this inventory, the Settlements category is divided into Settlements Remaining Settlements (urban trees) and Land Converted to Settlements. Two types of land conversion to settlements were estimated: conversion from forested lands reported under Forest Land Converted to Settlements and conversion from non-forested lands in the Canadian North reported under Grassland Converted to Settlements. In 2020, 0.59 Mha of Land Converted to Settlements accounted for emissions of 6.6 Mt.

6.8.1. Settlements Remaining Settlements (CRF Category 4.E.1)

6.8.1.1. Sink Category Description

This category includes estimates of C sequestration by urban trees in Canada. Estimates of CO_2 removals from tree growth on other Settlement subcategories outside of urban areas are not included. Total annual removals from urban trees were relatively stable throughout the time series at around 4.3 Mt. Estimates are reported for nine of the southernmost reporting zones, where major urban centres are situated. The largest removals in 2020 were in the Mixedwood Plains (1.6 Mt) and Pacific Maritime (1.5 Mt) reporting zones, which together accounted for 70% of total removals.

Emissions attributed to urban tree biomass transferred to the HWP pool and used for residential bioenergy accounted for 0.3 Mt per year of the total firewood emissions reported under the Harvested Wood Products category.

6.8.1.2. Methodological Issues

The CO_2 removals from urban trees were estimated using a Tier 2A crown cover methodology 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 and classed into broad categories of tree crown or non-crown, based on digital air photos or high-resolution satellite imagery. The total crown cover area was then estimated using UTC and total urban area estimates for each time period. The estimate of total crown cover area was then multiplied by a crown cover area growth rate (CRW) specific to its reconciliation unit (RU) to yield an annual gross sequestration rate; net sequestration was estimated by applying a factor to the gross value. The CRW values for 18 RUs (see Table A3.5-11) are derived as described in Steenberg et al. (2021). Growth and sequestration rates are applied to the 18 RUs and, as a result, estimates of urban tree crown cover area and the sequestration rate are the main drivers of overall removal estimates. A more detailed description of this estimation methodology can be found in Annex 3.5.7.1.

6.8.1.3. Uncertainty and Time-Series Consistency

The uncertainty of the UTC estimates is assessed on the basis of 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 high number of sampling points used. The uncertainty associated with the total urban area is estimated at 15% in 1990 and 10% in 2012. The uncertainty value for the national scale gross C sequestration (27%) was estimated using a Monte Carlo analysis associated with each RU for the urban tree field data collected in Canada. The total uncertainty associated with the estimates of the net CO_2 sequestration of urban trees is 28% for 1990 and 2012. Annex 3.5.7.1 provides more information.

The same methodology and coefficients are used for the entire time series of emission estimates (1990–2020).

6.8.1.4. Quality Assurance / Quality Control and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures being implemented for Canada's GHG inventory. The same procedures apply to this category as well.

Estimates of regional UTC values used were compared with published UTC values for Canadian cities that were estimated from point-based sampling. In most cases, the UTC estimates correspond closely with an overall coefficient of determination (R_2) of 0.90 from linear regression analysis. In addition, at a national scale, UTC estimates were compared to those derived using a potential natural vegetation approach (IPCC, 2006) and, when weighted on the basis of urban area, were within 2%.

6.8.1.5. Recalculations

There were no recalculations for this sink category.

6.8.1.6. Planned Improvements

Continued work will focus on updating activity data estimates and the coefficients used to estimate gross and net removals. Updates are planned for 2005 and 2015 activity data that involve sampling of digital air photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas around these years.

6.8.2. Land Converted to Settlements (CRF Category 4.E.2)

In 2020, emissions from Land Converted to Settlements amounted to 6.6 Mt. While there are potentially several land categories converted to Settlements, including Forest Land, there are currently insufficient data to quantify areas or associated emissions for 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 1990–2020 period, 26 kha of forest land were 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 under this category. A consistent methodology was developed for all forest conversion and is outlined in section 6.9 and Annex A3.5.2.5.

The remainder of this section covers non-forest land conversion to settlements, which includes land-use changes in the Canadian North reported under Grassland Converted to Settlements as well as land conversion occurring in the agricultural regions of Canada reported under Cropland Converted to Settlements.

6.8.2.1. Cropland Converted to Settlements (CRF Category 4.E.2.2)

6.8.2.1.1. Source Category Description

Urban and industrial expansion for resource extraction has been the main driver of conversion of cropland to settlements in Canada. On average, during the 1990–2000 and 2000–2010 periods, 18 kha and 11 kha of Cropland were converted annually to Settlements, predominantly in the Mixedwood Plains, Subhumid Prairies and Atlantic Maritime reporting zones. Emissions are not estimated at this point, but are part of the improvement plans for this category.

6.8.2.1.2. Methodological Issues

Areas of cropland converted to settlements were estimated from land-use maps from 1990, 2000 and 2010 by Huffman et al. (2015a) using the methods described in Annex 3.5.7.2. Annual conversion rates were estimated by calculating total areas of land converted between these three years and dividing them by the time range, assuming a constant conversion rate from year to year. Annual conversion rates were extrapolated using a constant conversion rate after 2010.

6.8.2.1.3. Uncertainties and Time-Series Consistency

The uncertainty in land-use change areas was quantified using 457 points over the five main census metropolitan areas (i.e., Toronto, Hamilton, Oshawa, Montreal and Edmonton), which encompass over 45% of the total area changed. The overall accuracy in detecting areas of true change was above 80% and concurs with the values found by Huffman et al. (2015a) on the accuracy of each individual land-use map.

6.8.2.1.4. Quality Assurance / Quality Control and Verification

Polygons from the 2011 census were used to define the boundary of each census metropolitan area, and Landsat imagery from the Global Land Survey products from ArcGIS Online was obtained for each area for 1990, 2000 and 2010.[10] 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, 50% on areas of change from cropland to settlements and 50% on areas of no change, separated by a minimum distance of 1 km, to avoid statistical bias.

6.8.2.1.5. Recalculations

There were no recalculations for this source category.

6.8.2.1.6. Planned Improvements

Future efforts to develop estimates for this category will focus on estimating emissions and removals associated with the areas of change.

10 https://www.arcgis.com/home/item.html?id=3db133ce90d548948fef4e9ff244ef8b

6.8.2.2. Grassland Converted to Settlements (CRF Category 4.E.2.3)

6.8.2.2.1. Source Category Description

Resource development is the dominant driver of land-use change in Canada's Arctic and sub-Arctic regions. In 2020, the conversion of grassland to settlements in the Canadian North accounted for emissions of 19 kt, down from 48 kt in 1990. The major source of emissions in this category over the time series is associated with conversion of grassland to settlements in the Taiga Shield East, Taiga Plains and Boreal Cordillera (reporting zones 4, 13 and 16).

6.8.2.2.2. Methodological Issues

An accurate estimation of this direct human impact 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, intersecting 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 based on image interpretation for the years 1990, 2000 and 2010, as described in Annex 3.5.7.2.

Biomass factors were based on field sampling and cross-checked with values in the literature for the Canadian North (Annex 3.5.7.2).

Emissions include only C stock changes in pre-conversion above-ground biomass. In spite of field campaigns and comparison with existing relevant literature, the estimation of actual or average biomass density over such a large area is challenging and remains fraught with uncertainty.

6.8.2.2.3. Uncertainties and Time-Series Consistency

An error propagation approach described in Annex 3.5.7.3 was used to estimate uncertainty for this category. The uncertainty estimate for this category varies between 78% and 87% for the different reporting zones due to the difficulty in the collection of ground data to estimate above-ground biomass and the variability of vegetation and climate conditions over this vast area.

6.8.2.2.4. Quality Assurance / Quality Control and Verification

Section 1.3 of Chapter 1 describes the general QA/QC procedures being implemented for Canada's GHG inventory. The same procedures apply to this category as well.

6.8.2.2.5. Recalculations

There were no recalculations for this source category.

6.8.2.2.6. Planned Improvements

Future efforts to improve estimates for this category will focus on gathering data and compiling domestic science to estimate emissions from the soil pool as well as improving estimates of the pre-conversion above-ground biomass by adjusting the biomass factors used for each reporting zone with image-based vegetation indices and more ground data.

6.9. Forest Conversion

6.9.1. Source Category Description

Forest conversion is not a reporting category, since it overlaps with the Cropland Remaining Cropland, Land Converted to Cropland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Land Converted to Settlements and Harvested Wood Products categories. This section will briefly discuss methodological issues specific to this type of land-use change and outline the general approach taken to estimate its extent, location and impact. A consistent approach was applied for all types of forest conversion, minimizing omissions and overlaps, while maintaining spatial consistency as much as possible.

In 2020, conversion of forest land to cropland, wetlands (flooded lands namely reservoirs, and peat extraction) and settlements resulted in total immediate and residual emissions of 13 Mt, down from 18 Mt in 1990. This decline includes a 4.2-Mt decrease in immediate and residual emissions from forest conversion to cropland and a 1.5-Mt decrease in emissions from forest conversion to wetlands (reservoirs). There was also an increase of 0.5 Mt in immediate and residual emissions from forest conversion to settlements. Note that the above values include residual emissions more than 20 years after conversion (10 years for reservoirs and 1 year for peat extraction) that are reported under the "land remaining" categories, such as Cropland Remaining Cropland or Wetlands Remaining Wetlands. Additional emissions associated with this source include those that result from the use and disposal of HWP manufactured from wood coming from forest conversion activities since 1990, which are included in the estimates of CO_2 reported in CRF Table 4.G and which amounted to 3.4 Mt in 2020, up from 2.7 Mt in 1990 (see section 6.4 for more details).

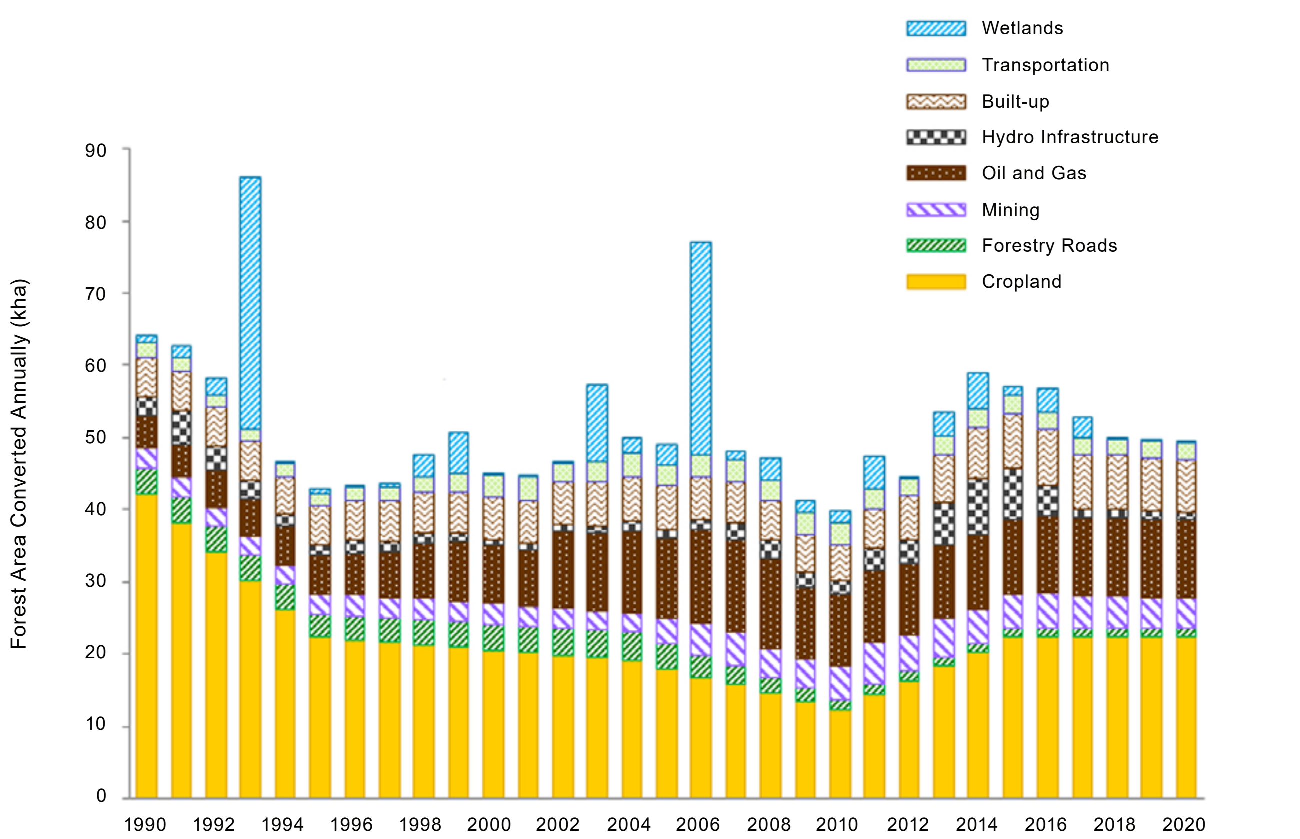
Care should be taken to distinguish annual forest conversion rates (64 kha in 1990 and 49 kha in 2020) from the total area of forest land converted to other land uses as reported in the CRF tables for each inventory year. The values in the CRF encompass all forest land conversion for 20 years, including the current inventory year (10 years for reservoirs and 1 year for peat extraction), and are therefore significantly higher than the annual rates of forest conversion to other land use.

It is also important to note that immediate emissions from forest conversion, which occur at the time of the conversion event, are only a fraction of the total emissions due to current and previous forest conversion activities reported in any inventory year. In 2020, immediate emissions (2.7 Mt) represented only 21% of the total reported land emissions due to forest conversion events; the balance is accounted for by residual emissions due to current and prior events. Decay rates for DOM are such that residual emissions continue beyond 20 years (10 years for reservoirs and 1 year for peat extraction), after which they are reported in the C stock changes in Cropland Remaining Cropland and Wetlands Remaining Wetlands.

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—the levels observed in mid-1990s—due to a more recent agricultural expansion mostly in the Boreal Plains, Subhumid Prairies and Mixedwood Plains (Figure 6–8).

By contrast, annual rates of forest land conversion to settlements for a range of end land uses, including forestry roads, mining, oil and gas, hydro infrastructure, transportation and built-up lands, increased from 21 kha in 1990 to peaks of 31 kha in 2007 and 34 kha in 2014 and then dropped to 27 kha in 2020 (Figure 6–8). Since 2000, the settlements land use has become the main driver of forest conversion, accounting on average for 57% of the total area converted annually, except for the years 2003 and 2006, when forest was cleared for important hydro development projects (Figure 6–8). This trend is reflective of resource development (e.g., forestry roads, hydro infrastructure, mining, oil and gas, and transportation),

Figure 6–8 **Annual Forest Conversion Areas per End Land Use**



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, but still contributes to 28% of the total forest area lost nationally in 2020.

The occasional impoundment of large reservoirs (e.g., La Forge-1 in 1993 and Eastmain-1 in 2006) may also convert large forest areas to Wetlands (Figure 6–8). However, because much of the pre-conversion C stocks are flooded, these episodic events may not release commensurate quantities of greenhouse gases.

Forest conversion affects both managed and unmanaged forests. Losses of unmanaged forests occur mainly in reporting zones 4 (Taiga Shield East) and 5 (Boreal Shield East) and are caused mostly by reservoir impoundment. They also occur to a lesser extent in reporting zones 9 (Boreal Shield West) and 8 (Hudson Plains).

6.9.2. Methodological Issues

Forest conversion to other land categories has occurred in the past at high rates, 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; they 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 integrates a large variety of information sources to capture the various forest conversion patterns across the Canadian landscape, while maintaining a consistent approach in order to minimize omissions and overlap.

The approach adopted for estimating forest areas converted to other uses is based on three main information sources: (1) systematic or representative sampling of remote sensing imagery, (2) records, and (3) expert judgement (Dyk et al., 2011, 2015). The core method involves mapping of forest conversion on samples from remotely sensed Landsat images dated circa 1975, 1990, 2000, 2008, 2013 and 2018. For implementation purposes, all permanent forest removal wider than 20 m from tree base to tree base and at least 1 ha in area was considered forest conversion. This convention was adopted as a guide to consistently label linear patterns on the landscape. The other main information sources consist 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 among records and remote sensing information and to resolve apparent discrepancies across the 1975–1990, 1990–2000, 2000–2008, 2008–2013 and 2013–2018 area estimates. A more detailed description of the approach and data sources is provided in Annex 3.5.2.5.

All estimates of emissions from biomass and DOM pools due to forest conversion were generated using the CBM-CFS3 (section 6.3.1.2), except when forests were flooded without prior clearing or cleared for peat extraction (see section 6.7 and Annex A3.5.6). Emissions from the soil pool were estimated in different modelling frameworks, except for the Land Converted to Settlements subcategory, for which CBM-CFS3 decay rates were used. Hence, methods are generally consistent with those used in the Forest Land Remaining Forest Land subcategory. Annex 3.5.2 summarizes the estimation procedures.

6.9.3. Uncertainties and Time-Series Consistency

An overall uncertainty estimate of ±30% bounds the estimate of the total forest area converted annually in Canada (Leckie, 2011), placing with 95% confidence the true value of this annual area in 1990 between 45 kha and 83 kha, and in 2020 between 34 kha and 64 kha. Care should be taken not to apply the 30% range to the cumulative area reported in the CRF tables for Forest Land converted to another land category over the last 20 years (10 years for reservoirs). Annex 3.5.2.5 describes the main sources of uncertainty associated with area estimates derived from remote sensing.

6.9.4. Quality Assurance / Quality Control and Verification

General QA/QC procedures are implemented 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 detailed examination of results (Dyk et al., 2011, 2015). The calculations, use of records data and expert judgement are traceable through the compilation system and documented. More information is available in Annex 3.5.2.5.

Environment and Climate Change Canada, while maintaining its own QA/QC procedures for estimates developed internally (refer to section 1.3, Chapter 1), has implemented specific procedures for estimates obtained from data partners, as well as for all estimates and activity data contained in the LULUCF data warehouse (Blondel, 2018) and entered into the CRF Reporter.

6.9.5. Recalculations

There were changes in the estimated annual areas of forest conversion to cropland, to wetlands (reservoirs) and to settlements as a result of the completion of the northern deforestation mapping and the addition of three hydro-related large events: Site-C in British Columbia, which is not yet flooded and only hydro infrastructure is reported in this submission, Muskrat Falls in Newfoundland and Labrador and Keeyask in Manitoba. These changes resulted in adjustments of forest conversion estimates across the time series, in particular an increase of 0.2 Mt (+0.8%) in 1990 and 0.3 Mt (+2.6%) in 2020 and a decrease of 0.1 Mt (-0.5%) in 2005, for immediate and residual emissions. The associated HWP pool emissions increased by 0.2 Mt (9.9%) in 1990 and decreased by 0.1 Mt (-40%) in 2005, with very small recalculations in 2019 that are negligible.

6.9.6. Planned Improvements

The development of new mapping data, parameters and processes for forest conversion is part of the continuous improvements of LULUCF estimates. In the medium-term, improvements include: (1) revision of 1970 to 2010s deforestation activity data used that will lead to improved estimates for earlier time periods; and (2) update assumptions of proportions of types of forest that existed previous to deforestation events.

WASTE (CRF SECTOR 5)

7.1. Overview

The Waste sector in Canada includes emissions from the treatment and disposal of wastes, including Solid Waste Disposal (Landfills), Composting and Biological Treatment of Solid Waste, Incineration and Open Burning of Waste, and Wastewater Treatment and Discharge.

7.1.1. Emissions Summary

Sources and gases from the Waste sector include methane (CH_4) from Solid Waste Disposal (Landfills) and Industrial Wood Waste Landfills; CH_4 and nitrous oxide (N_2O) from the Biological Treatment of Solid Waste; carbon dioxide (CO_2), CH_4 and N_2O from Incineration and Open Burning of Waste; and, CH_4 and N_2O from Wastewater Treatment and Discharge.

In 2020, greenhouse gas (GHG) emissions from the Waste sector accounted for 27.3 Mt of total national emissions, compared with 24.4 Mt for 1990—an increase of 2.9 Mt or 12% (Table 7–1). The emissions from this sector represented 4.11% and 4.07% of total Canadian GHG emissions in 1990 and 2020, respectively.

The chief contributor to the Waste sector emissions was Solid Waste Disposal (Landfills) which, in 2020, accounted for 22.1 Mt CO_2 eq or 81% of the Waste sector emissions (Table 7–1).

When the waste treated or disposed of is derived from biomass, CO_2 emissions attributable to such waste are reported in the inventory as a memo item. CO_2 emissions of biogenic origin are not reported if they are reported elsewhere in the inventory or if the corresponding CO_2 uptake is not reported in the inventory (e.g., annual crops). In this latter case, emissions are not included in the inventory emission totals, since the absorption of CO_2 by the harvested vegetation is not estimated and thus the inclusion of these emissions in the Waste sector would result in an imbalance. Also, CO_2 emissions from wood and wood products are reported in the Land Use, Land-use Change and Forestry (LULUCF) sector. In contrast, CH_4 emissions from anaerobic decomposition of wastes are included in the inventory totals as part of the Waste sector.

The majority of changes relative to previous inventory submissions are from recalculations and updates to activity data (Table 7–2). Detailed descriptions of the recalculations and activity data updates are provided in the recalculation section for each source in this chapter and in Chapter 8.

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

GHG Source Category	GHG Emissions (Mt CO_2 eq)						
	1990	2005	2016	2017	2018	2019	2020
Waste	24.4	28.7	26.3	26.7	27.0	27.1	27.3
Solid Waste Disposal (Landfills)	19.6	23.0	20.9	21.4	21.7	21.9	22.1
Biological Treatment of Solid Waste	0.1	0.2	0.3	0.3	0.4	0.4	0.4
Wastewater Treatment and Discharge	1.6	1.9	2.4	2.5	2.5	2.5	2.5
Incineration and Open Burning of Waste	0.3	0.3	0.2	0.2	0.2	0.2	0.2
Industrial Wood Waste Landfills	2.9	3.3	2.4	2.4	2.3	2.2	2.2

Note: Totals may not add up due to rounding.

Table 7–2 **Summary of Recalculations in the Waste Sector for Selected Years (Mt CO_2 eq)**								
Sector	1990	2000	2005	2015	2016	2017	2018	2019
Biological Treatment of Solid Waste								
Previous (2021) inventory submission	0.07	0.19	0.24	0.31	0.31	0.32	0.37	0.38
Current (2022) inventory submission	0.07	0.20	0.24	0.31	0.32	0.33	0.36	0.36
Net change in emissions	0.00	0.01	0.01	0.01	0.01	0.01	-0.01	-0.02
Incineration and Open Burning of Waste								
Previous (2021) inventory submission	0.27	0.37	0.34	0.20	0.20	0.19	0.18	0.19
Current (2022) inventory submission	0.27	0.37	0.35	0.20	0.20	0.19	0.18	0.18
Net change in emissions	0.00	0.00	0.01	0.00	0.00	0.00	0.00	-0.01
Industrial Wood Waste Landfills								
Previous (2021) inventory submission	3.85	4.53	4.37	3.37	3.27	3.18	3.09	3.00
Current (2022) inventory submission	2.87	3.38	3.26	2.50	2.43	2.36	2.30	2.24
Net change in emissions	-0.98	-1.15	-1.11	-0.87	-0.84	-0.81	-0.79	-0.77
Solid Waste Disposal (Landfills)								
Previous (2021) inventory submission	20.98	24.69	25.09	21.83	21.89	22.22	22.54	22.99
Current (2022) inventory submission	19.59	22.46	22.97	20.61	20.86	21.39	21.68	21.91
Net change in emissions	-1.39	-2.23	-2.12	-1.22	-1.03	-0.83	-0.86	-1.08
Wastewater Treatment and Discharge								
Previous (2021) inventory submission	0.83	0.89	0.94	1.00	1.00	1.00	1.01	1.02
Current (2022) inventory submission	1.61	1.88	1.90	2.59	2.44	2.45	2.47	2.47
Net change in emissions	0.78	0.98	0.96	1.58	1.44	1.45	1.47	1.44

Note: Totals may not add up due to rounding.

7.2. Solid Waste Disposal (Landfills) (CRF Category 5.A)

7.2.1. Source Category Description

The Solid Waste Disposal (Landfills) category provides a quantification of CH_4 emissions resulting from the decay of waste deposited in municipal landfills. Municipal solid waste (MSW) encompasses waste from the Residential sector, the Industrial, Commercial and Institutional (ICI) sector and the Construction and Demolition (C&D) sector, as well as sewage sludge.

Industrial wood waste (i.e., waste from sawmill operations, pulp and paper production and other forest industry processes) is often deposited in small landfills at or near the originating facility. Because of the unique composition (wood) and distinct locations and practices of wood waste landfills, they are reported as a separate category (section 7.3).

In Canada, most waste disposal occurs in managed municipal landfills. Few, if any, unmanaged waste disposal sites still exist in Canada. The disposal of MSW is regulated by provinces and territories, but is typically managed by municipal or regional authorities. While regulations vary across the country, common regulatory requirements include landfill gas capture and landfill covers. Furthermore, many provinces are implementing, or already have in place, specific waste reduction targets, such as organic bans on landfilled waste, or per capita waste generation goals.

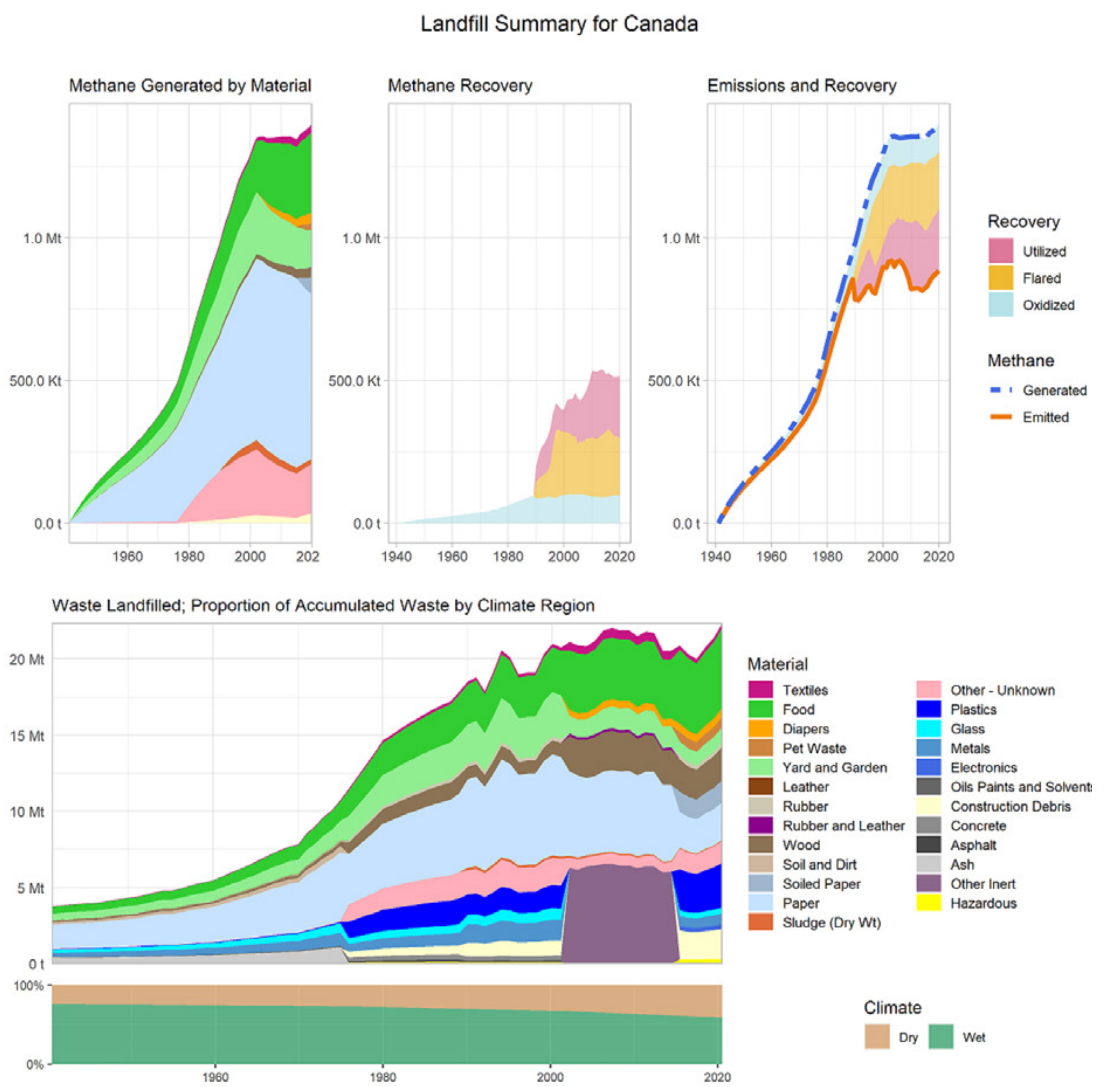
Emissions from waste disposal are generated by the anaerobic decomposition of buried organic waste in the landfill. While CO_2 is also produced, it is of biogenic origin from the same year as emission and is therefore not reported as part of the total emissions of this sector. Emissions of N_2O are considered negligible.

MSW disposal is the dominant contributor of emissions from the Waste sector. This category accounts for 80% of the Waste sector emissions (Table 7–1).

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

7

Figure 7–1 **Waste Landfilled, Methane Generated (by Source Material), Recovered and Emitted**



7.2.2. Methodological Issues

Waste disposal emissions in Canada are estimated using the first-order decay methodology from the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), with parameters from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019). The same methodology—but with different parameters—is used for Solid Waste Disposal and Industrial Wood Waste Landfills (discussed in section 7.3.2).

Landfill gas, which is composed mainly of CH_4 and CO_2, is produced by the anaerobic decomposition of organic wastes. The decomposition process typically begins after waste has been in a landfill for 10 to 50 days. Although the majority of the CH_4 and CO_2 gases are generated within 20 years of landfilling, emissions can continue for 100 years or more (Levelton, 1991).

A consistent source of data on the amount of waste landfilled is not currently available. Instead, the total amount of waste disposed (landfilled, exported and incinerated) in each province forms the basis of the emission calculations. Data are available on the amount of waste exported and incinerated and so are used to derive the amount of waste landfilled.

A number of factors contribute to the generation of gases within a landfill. One of the most important factors is the composition of the waste entering the landfill. As consumer habits and waste management practices change over time, so do the types of waste disposed of in MSW landfills. Another important factor influencing the production of CH_4 emissions within a landfill is moisture content. Moisture is considered to be a limiting factor in CH_4 generation. It is assumed that it is the major factor affecting moisture content within the landfill, and it is captured by climate region (wet or dry). While there are a number of other factors affecting CH_4 generation in landfills, such as pH and nutrient availability, they are not represented in the model.

Not all CH_4 generated within a landfill will be released into the atmosphere. To determine the amount of CH_4 released, the amount captured through landfill gas capture technology and the proportion of CH_4 oxidized in landfill covers are accounted for. Landfill gas capture on managed landfill sites is an increasingly popular activity in Canada. CH_4 from landfill gas can be used to generate electricity or heat or is flared to reduce the GHG potential of emitted gases.

Oxidation of CH_4 into CO_2 by methanotrophic bacteria in landfill covers is accounted for by applying an oxidation factor to the emissions estimated to be generated in the landfill, after landfill gas capture is accounted for. Every province/territory in Canada requires managed landfills of a certain size to have daily cover material in place to bury waste. There are also annual cover requirements, as well as more robust cover material for closed landfills.

7.2.3. Uncertainties and Time Series Consistency

The level of uncertainty associated with CH_4 emissions from Solid Waste Disposal was estimated to be ±76% for CH_4 based on defaults available in the IPCC 2006 Guidelines (IPCC, 2006).

7.2.4. QA/QC and Verification

The annual quality control process consisted in verifying that all activity data and methodological updates had been incorporated into the model. Expected changes in emission estimates from individual methodological updates and regular data updates were compared against the total actual changes in emissions to verify that all recalculations had been incorporated correctly. Inter-annual emissions were compared to identify any unexpected changes in emissions at the regional and national level. Standard quality assurance checks were run, such as confirming that records for all years and regions had been included in final estimates and that national totals matched the sum of regional totals.

7.2.5. Recalculations

An accounting error in the previous inventory has been corrected. In the previous inventory, waste incinerated after 1990 was included in the totals of waste landfilled, resulting in an over-estimate of landfill emissions. The correction of this error has reduced emissions by 0.17 (1990), to 1.2 (2019) Mt compared to the previous inventory (varying by year, generally increasing over time).

The carbon content and degradability (DOC and DOCf) for three material types have been updated. What was formerly labelled "other organics" is now known to be soiled paper and packaging. The name and parameters have been updated to match those of paper. The carbon content of soil has been updated to an estimated 3% carbon (formerly 50%, which is the default 'bulk' waste value). The degradability of generic construction debris has been updated to that of wood (less decomposable materials). The impact of this update is a reduction in estimates by 0.28 Mt, 0.49 Mt and 1.41 Mt in 1990, 2006 and 2019.

7.2.6. Planned Improvements

Opportunities for more refined data on amounts and types of waste landfilled in provinces are being investigated. Increased collaboration with provincial and other regional authorities may result in higher quality data that can be integrated directly into the waste model or used to verify current estimates.

7.3. Industrial Wood Waste Landfills (CRF Category 5.A.2)

7.3.1. Source Category Description

Industrial Wood Waste Landfills are mostly privately owned and operated by forest industries, such as sawmills and pulp and paper mills. These industries use landfills to dispose of surplus wood residue, including sawdust, wood shavings, bark and sludge. Some industries have shown increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes. In recent years, residual wood previously regarded as waste is now being processed as a value-added product—e.g., wood pellets for residential and commercial pellet stoves and furnaces, and hardboard, fibreboard and particleboard.

Wood waste landfills are reported as unmanaged landfills in the CRF. Industrial wood waste disposal accounts for 12% (2.9 Mt CO_2 eq) of the emissions from waste in 1990, 11% (3.3 Mt) in 2005, and 8% (2.2 Mt) in 2019.

7.3.2. Methodological Issues

Industrial Wood Waste Landfills are dedicated lots for the disposal of wood waste from the pulp and paper and solid wood industries. There is limited data available on the amount of waste sent to these lots. It is assumed that the amount of waste disposed of in wood waste landfills is rapidly decreasing as repurposing of wood waste becomes increasingly popular. As of 2010, landfilling of sawmill residues in private lots is believed to be negligible. In contrast, several pulp and paper facilities are continuing to landfill process waste.

It is assumed that no LFG recovery (flaring or use for energy) occurs at wood waste landfills. Wood waste landfills are assumed to be unmanaged. It is unknown whether landfill covers are installed. However, shallow wood waste is assumed to be an appropriate medium for the methanotrophic bacteria that oxidize CH_4 generated deeper in the landfill.

7.3.3. Recalculations

Emissions from wood waste landfills come from two different industries: the solid wood industry and the pulp and paper industry. The oxidation and DOCf parameters have been updated. The oxidation factor has been updated for both industries, and the DOCf value for the solid wood industry has been updated. The recalculation using the updated parameters has resulted in an overall reduction of emissions by 25% for all years, compared to the previous inventory.

7.3.4. Uncertainties and Time Series Consistency

The level of uncertainty associated with CH_4 emissions from MSW landfills and wood waste landfills combined was estimated to be in the range of ± 190% for CH_4.

7.3.5. Planned Improvements

The DOCf value used for the pulp and paper industry is under review.

7.4. Biological Treatment of Solid Waste (CRF Category 5.B)

7.4.1. Source Category Description

This source category includes emissions from composting and anaerobic digestion at biogas facilities. Many municipalities in Canada utilize centralized composting facilities and some are establishing centralized anaerobic digestion facilities to reduce the quantity of organics sent to landfill. Additionally, a number of municipalities across Canada are considering or have already established organic waste bans on landfills in their jurisdiction to further divert organic waste to biological treatment. These practices have contributed to a large increase in the quantity of organic waste diverted in Canada since 1990.

GHG emissions from composting are affected by the moisture content and composition of the waste and the ability to maintain aerobic decomposition conditions. Anaerobic digestion of organic waste accelerates the natural decomposition of organic material without oxygen by maintaining optimal conditions for the process. Both biological treatment processes result in the production of CO_2, CH_4 and N_2O emissions. However, CO_2 emissions are not included in the national inventory total as the carbon is considered to be of biogenic origin and accounted for under the Agriculture, Forestry and Other Land Use (AFOLU) sector (IPCC, 2006).

In 2019, the Biological Treatment of Solid Waste category contributed 381 kt of CO_2 eq or 1% of total emissions to the Waste sector and 0.05% to Canada's total. Emissions were 308 kt (421%) above the 1990 levels of 73 kt.

7.4.2. Methodological Issues

The estimation of CH_4 and N_2O emissions from the biological treatment of waste in Canada is carried out by using a Tier 3 method. Facility-level data is available for both anaerobic digestion and composting facilities in Canada. This data has been collected with industry associations, online literature searches and annual reports as well as other in-house contracts led by Environment and Climate Change Canada. Composting emissions are calculated based on the waste type accepted in wet tonnes at the facility-level in Canada. The emission factors by waste type have been developed through a in-house literature review that compiled information from primary literature sources (ECCC, 2020a).

Under the Biological Treatment of Solid Waste category, anaerobic digestion emissions are only calculated for industrial or municipal facilities. Emissions are calculated as the percent of CH_4 lost from the total biogas produced at the facility level. This percentage was developed based on primary literature and/or facility-based insight and compiled through an in-house literature review (ECCC, 2020b). Some gaps exist in the activity data for both composting and anaerobic digestion, including a lack of data prior to the year 1992 for composting. In order to fill the data gaps throughout the time series, the earliest available data point is carried back to 1990 for facilities that were known to be open at that time. Otherwise, the last available data point is carried forward to the next available data point through time. For anaerobic digestion, there were no facilities in the industrial/municipal sector that were in operation in 1990. Therefore, the earliest data point available for the facility is carried back to its opening year and is also carried forward until the next data point for the facility becomes available. For additional quality assurance, composting and anaerobic digestion activity data totals were compared against Statistics Canada's Waste Management Industry Survey: Business and Government Sectors (Statistics Canada, n.d.[b]). The Statistics Canada data set includes waste diverted as a single tonnage to both composting and anaerobic digestion.

7.4.3. Uncertainties and Time Series Consistency

The combined uncertainties for emissions of CH_4 and N_2O from composting and anaerobic digestion were calculated by waste type for composting and by the fugitive loss percentage for CH_4 for anaerobic digestion. Uncertainty range is from a high of ±176% down to ±99% for CH_4 and ±136% down to ±65% for N_2O based on waste type for composting and ±79% for CH_4 for anaerobic digestion fugitive loss. This is based on emission factors collected through primary literature and compiled in an in-house literature review. Activity data uncertainty was not calculated, given that it is based on direct facility data.

7.4.4. QA/QC and Verification

The quality control process for the Biological Treatment of Solid Waste category consisted of verifying all aspects of the emission estimate calculations, including:

- downloaded and manually inputted activity data
- calculations to carry forward or backward activity data to bridge data gaps in the time series
- inputted emission factors
- unit conversions and emission calculations

The final activity data and emission trends were plotted to identify any outliers. The recalculated emission estimates were also compared with the previous inventory's estimates to ensure that the changes in emission levels made sense.

7.4.5. Recalculations

The recalculations made for this category are based on applying a new methodology and including a new source of activity data for this source category. Please note that prior to the 2021 inventory, anaerobic digestion emissions for municipal and industrial facilities were not included.

7.4.6. Planned Improvements

Opportunities for acquiring more refined data on the amounts of waste being composted and/or anaerobically digested in the provinces and territories will continue to be investigated. Increased collaboration with provincial and other regional authorities may result in a more complete data set and higher quality data that could be used to improve or verify the current emission estimates.

7.5. Incineration and Open Burning of Waste (CRF Category 5.C)

7.5.1. Source Category Description

This category includes emissions from the incineration of waste. There are 33 incinerators currently in operation in Canada. Incinerators are classified by the source of their primary feed material: MSW, hazardous waste, sewage sludge or clinical waste. Some municipalities in Canada use incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application. Incineration can also be used for energy recovery from waste, and emissions from these facilities are reported in the Energy sector. GHG emissions from open burning of waste are assumed to be negligible, representing less than the reporting threshold of 500 kt CO_2 eq and 0.05% of national GHG total emissions.

Emissions from waste incineration include CO_2, CH_4 and N_2O. In accordance with the 2006 IPCC Guidelines, CO_2 emissions from biomass waste combustion are not included in the inventory totals. The only CO_2 emissions detailed in this section are from fossil fuel-based carbon waste, such as in the form of plastics, rubber, inorganics, and fossil liquids. CH_4 and N_2O emissions are estimated from all incinerated waste.

GHG emissions from incinerators vary with the amount of waste incinerated, the composition of the waste, the carbon content of the non-biomass waste and the facilities' operating conditions. Emissions are derived from the quantities of waste incinerated that were provided directly by facilities in a series of surveys conducted by Environment and Climate Change Canada (ECCC, 2020c), as well as additional reports which provide quantities of clinical waste incinerated for the early years in the time series (Chandler, 2006; Sawell, 1996; RWDI AIR Inc., 2014).

Incineration of MSW is not a common practice across most of Canada. Approximately 5% of Canada's total MSW is incinerated, mostly in energy-from-waste facilities. The vast majority of Canada's incinerated MSW is processed in large, highly regulated facilities. However, there are still a small number of remote communities that rely on rudimentary incinerators to dispose of their MSW. There are currently three incinerators in operation in Canada that are classified as hazardous waste incinerators, all located in Ontario and Alberta. Two different types of sewage sludge incinerators exist in Canada: multiple hearth and fluidized bed. In both types of incinerators, the sewage sludge is partially dewatered prior to incineration. The dewatering is typically done using a centrifuge or a filter press. There are currently two major centralized clinical waste incinerators in Canada, one in Ontario and the other in Alberta. They accounted for nearly 80% of the GHG emissions from clinical waste incineration. The remaining 20% of GHG emissions are from a number of small hospital-based incinerators and incinerators operated by the Government of Canada.

The Incineration and Open Burning of Waste category contributed 165 kt CO_2 eq (0.60%) of total emissions to the Waste sector or 0.02% of Canada's total emissions in 2020. Emissions from this category are 39% below the 1990 level of 273 kt CO_2 eq.

7.5.2. Methodological Issues

The emission estimation methodology depends on type of waste incinerated and gas emitted. A more detailed discussion of the methodologies is presented in Annex 3.6.

Given the relatively small number of incinerators in Canada, emissions from incineration can be estimated at the facility level. Facilities that emit greater than 10 kt CO_2 eq per year are required to report emissions to Environment and Climate Change Canada on an annual basis through the Greenhouse Gas Reporting Program (GHGRP). These publicly available data represent a significant portion of emissions from this sector.

In-house estimates for smaller facilities that are not required to report to the GHGRP are generated by ECCC using Tier 3 methodology and activity data from a biennial survey of incinerators across Canada. Please see Annex 3.6 for details. In-house estimates are also derived for historical emissions for those facilities operating before the GHGRP was put in place in 2004. This includes currently operating facilities that operated prior to 2004 and those that closed before the program began.

The in-house estimates are developed using the IPCC default values for carbon content of waste and fossil carbon as a percentage of total carbon (IPCC, 2006). N_2O and CH_4 emissions are estimated based on the type of waste being incinerated as well as the facilities specific incineration technology. IPCC default factors were used, except for hazardous waste, for which emission factors were derived from site-specific data provided by a facility, which were deemed more representative than IPCC default values. As the IPCC 2006 Guidelines do not contain default emission factors for clinical waste incineration, the IPCC 2006 Guidelines default emission factors for MSW incineration were used in accordance with the IPCC 2000 Good Practice Guidance, which recommends using MSW emission factors when specific clinical emission factors are not available.

Facilities are distinguished as either energy-from-waste (EFW) facilities or non-EFW facilities, depending on whether they produce energy and/or heat from the incineration process. Emissions from EFW facilities are reported under the Energy sector, while emissions from non-EFW facilities are reported under the Waste sector. See Annex 3.6 for details.

7.5.3. Uncertainties and Time Series Consistency

IPCC default values are used to quantify uncertainty for the incineration sector. The activity data uncertainty is ±5%, while the CO_2, CH_4 and N_2O emission factor uncertainties are ±40%, ±100%, and ±100%, 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

This year the amounts of waste incinerated at each facility have been reviewed and several corrections have been made.

7.5.6. Planned Improvements

No planned improvements are scheduled for the Incineration and Open Burning of Waste category.

7.6. Wastewater Treatment and Discharge (CRF Category 5.D)

7.6.1. Source Category Description

In Canada, most wastewater from domestic and industrial sources is treated in centralized municipal wastewater treatment plants. However wastewater can also be treated by private and occasionally communal septic systems, notably in rural areas. In some coastal areas, untreated wastewater is discharged directly to the sea. Most industrial facilities discharge their wastewater to municipal treatment systems. Several large industrial facilities treat or pre-treat their wastewater on-site before discharging it to the environment or to municipal wastewater treatment systems for further treatment.

Wastewater treatment involves the removal of organics, measured as biological oxygen demand, or BOD_5, and nutrients. The treatment process results in emissions of CO_2, CH_4 and N_2O.

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

The most common types of treatment systems in Canada are primary and secondary centralized treatment systems, aerobic and facultative lagoons, and septic systems. Discharge of untreated sewage to sea has been declining, but is still carried out in some coastal regions. Wetland treatment systems, sequence batch reactors, anaerobic lagoons and some other treatment types are also in use in Canada. Many of the largest systems in Canada have tertiary level treatment.

Wastewater treatment produces varying amounts of CH_4, depending on the organic load (BOD_5)—determined by the population—and treatment type. CH_4 is produced from certain treatment processes, steps, or areas in the treatment systems that are anaerobic. For example, primary and secondary treatment and aerobic lagoons produce little or no CH_4 emissions, whereas anaerobic steps in sequence batch reactors, anaerobic lagoons and septic systems produce relatively higher amounts of CH_4. Facultative lagoons have both naturally aerated and anaerobic layers and produce CH_4, but less than a fully anaerobic lagoon.

Centralized wastewater treatment plants with secondary or tertiary levels of treatment often include anaerobic sludge digestion, which produces CH_4 in the form of biogas or digester gas. The CH_4 generated in these systems is typically contained and combusted.

Wastewater treatment generates N_2O through the nitrification and denitrification of sewage nitrogen at treatment facilities. N_2O emissions are also considered to occur from the receiving body of discharged effluent, whether treated or untreated.

CO_2 is also a product of aerobic and anaerobic wastewater treatment. However, as detailed in section 7.1, CO_2 emissions originating from the decomposition of organic matter are not included with the national total estimates in the Waste sector.

The Wastewater Treatment and Discharge category accounted for 1021 kt CO_2 eq, or 3.7%, of the total emissions of the Waste sector and 0.14% of Canada's total in 2019. Wastewater Treatment and Discharge emissions in 2019 were 194 kt CO_2 eq (23%) above the 1990 level of 827 kt.

Emissions from wastewater treatment show an increasing trend over time that roughly follows the trend in population growth. Changes in treatment technology have impacts on emission trends at the provincial level. For example, the growing percentage of the population using septic systems in several provinces results in increases in total emissions, whereas upgrades of several major wastewater systems from untreated discharge to sea to primary treatment in other provinces decreases emissions. On the whole, the increasing trend in emissions is fairly steady, with a slight acceleration in 2010 and 2011, largely due to an increase in the estimated population using septic systems in many provinces around that time. Overall, population growth is the most important factor in the emissions trend for Wastewater Treatment and Discharge. In part, this is because of assumed constant per-capita organics loading (BOD_5) and reasonably steady per-capita protein consumption rates (increasing from 66.17 g per person per day in 1991 to 69.85 g per person per day in 2009, the earliest and latest data points available) (Statistics Canada, 2009).

7.6.2. Methodological Issues

Annex 3.6 provides additional information on the methodologies used for various categories covered by this category.

The approach used to estimate CH_4 emissions from municipal wastewater treatment is based on the amount of organic matter generated per person in Canada and the conversion of organic matter to CH_4 in anaerobic treatment systems, according to IPCC 2006 Guidelines (IPCC, 2006; AECOM Canada, 2011).

Emission factors are treatment-type specific. These are obtained from the 2006 IPCC Guidelines (IPCC, 2006) and 2019 Refinement (IPCC, 2019), with a few exceptions for treatment types not detailed in the Guidelines. A methodological challenge is determining the number of people serviced by each wastewater treatment system type (e.g., septic, lagoon, untreated). The population served by septic systems was determined from an analysis of Statistics Canada's Households and the Environment Survey (Statistics Canada, n.d.[a]). The population served by each of the more than 3000 wastewater treatment or discharge systems in Canada was estimated on the basis of the relative regional volumes of wastewater treated by (or discharged through) that facility or system and the regional population, at the census metropolitan area level. A more complete description of the methodology is provided in Annex 3.6.

Emissions from on-site industrial wastewater treatment are estimated on a Tier 3, facility-by-facility basis. Environment and Climate Canada conducts facility-level surveys on a biennial basis to obtain CH_4 emissions from industrial facilities that treat their effluent anaerobically on-site. The facilities surveyed were those identified by industry associations as having anaerobic wastewater treatment systems. Facility data have been updated (new data appended, existing data revised and corrected) with each successive biennial survey. The latest survey was conducted in 2016. Where actual measured facility data were not provided, design specifications particular to that site were used to estimate maximum emissions expected. A complete description of the methodology is provided in Annex 3.6. Currently estimates are based on 19 industrial facilities across the country. Expanding the list of facilities to survey and include in the industrial emissions estimates is a planned improvement.

The N_2O emissions are estimated based on nitrogen in the wastewater in accordance with the IPCC 2006 Guidelines (IPCC, 2006). The amount of nitrogen introduced to wastewater is estimated based on per-capita protein consumption. Protein consumption estimates, in kg/person/year, were obtained from an annual Food Statistics report published by Statistics Canada, adjusted to account for retail, household and cooking plate loss (Statistics Canada, 2009; AECOM Canada, 2012). A complete description of the methodology is provided in Annex 3.6.

7.6.3. Uncertainties and Time Series Consistency

The overall level of uncertainty associated with the Wastewater Treatment and Discharge category was estimated to be in the range of ±55% for CH_4 and ± 51% for N_2O based on IPCC 2006 default uncertainties and an estimated 20% uncertainty for the degree of utilization of each treatment type.

The updated activity data for municipal wastewater treatment and discharge will necessitate an updated uncertainty assessment. This is in progress and planned for the following inventory.

7.6.4. QA/QC and Verification

The quality control process consisted of following calculations step by step to ensure that equations, parameters and unit conversions were appropriate and that links were accurate. Emissions were plotted to observe trends for any unusual jumps or patterns that were inconsistent with changes in activity data over time. Recalculated estimation values were compared to the previous submission, and a comparison was made of changes from one year to the next along the time series to identify unsupported significant changes that may point to a data manipulation error.

7.6.5. Recalculations

The recalculations for Municipal Wastewater include a method change to include N_2O emissions from treatment per the IPCC 2019 Refinement, an error correction, and general updates of activity data.

In the previous year's inventory, the emission from effluent (CH_4 and N_2O) and from anaerobic digestion of sludge (CH_4) were missed. The error has been corrected for this inventory submission. All emission sources are included. In addition, a small error where some population was missed in regions early in the time series if they only had one facility and that facility had not yet been constructed has been corrected.

The method change introduced brings the inclusion of N_2O emissions from treatment to the inventory. The estimates are based on the 2019 IPCC Refinement.

The activity data, specifically details of the wastewater treatment technology used, and volumes treated—which is used to determine the populations served—at numerous facilities have been updated, particularly for smaller facilities. The impact of this refinement is minor, but is part of continuous data gathering and refinement for this sector.

Recalculations for industrial wastewater include addition of new data sources: facility reported wastewater treatment emissions from the GHGRP, and discharges of nitrogen in wastewater for effluent-based emissions. With these new data sources, the inventory has better coverage in terms of the number of facilities reporting. Emissions of N_2O from treatment and from effluent are also now included.

7.6.6. Planned Improvements

Efforts are underway to characterize the types of receiving waterbodies for all wastewater treatment systems in Canada, to apply waterbody specific effluent emission factors.

RECALCULATIONS AND IMPROVEMENTS

Canada's greenhouse gas (GHG) inventory undergoes a continuous process of updates, revisions and improvements to maintain and enhance the completeness, consistency and accuracy of the reported information. Section 8.1 of this chapter provides an overview of the recalculations performed in this year's GHG inventory, including analyses by sector to facilitate an integrated view of changes in, and impacts on, emission levels and trends. A summary of the major inventory improvements implemented this year can be found in section 8.2 and planned improvements for future inventories are described in section 8.3.

Further details on recalculations and improvements can be found in the individual chapters for each sector (chapters 3 to 7).

8.1. Impact of Recalculations on Emission Levels and Trends

Continuous improvement is good inventory preparation practice. Environment and Climate Change Canada consults and works with key federal, provincial and territorial partners, along with industry stakeholders, research centres and consultants, on an ongoing basis to improve the quality of the underlying variables and scientific information used to compile the national inventory. As new information and data become available and more accurate methods are developed, previous estimates are updated to provide a consistent and comparable trend in emissions and removals.

Recalculations occur annually for a number of reasons, including the following:

- correction of errors detected by quality control procedures
- incorporation of updates to activity data, including changes in data sources
- reallocation of activities to different categories (this only affects subtotals)
- refinements of methodologies and emission factors (EF)
- inclusion of categories previously not estimated (which improves inventory completeness)
- recommendations from United Nations Framework Convention on Climate Change (UNFCCC) reviews

8.1.1. Estimated Impacts on Emission Levels and Trends

In this year's GHG inventory, total emissions were revised for all years as shown in Figure 8–1. Overall, recalculations of previously reported 1990–2019 estimates have resulted in a decrease of between one and two percent (7 to 12 Mt) of the emissions for 1990 to 2000 and an increase of a comparable amount of emissions for 2010 to 2019. There are relatively small revisions to national totals for 2001 to 2009 (≤ 5 Mt).

The trend between 1990 and 2019 is now reported as a 24.1% increase in total GHG emissions since 1990, compared with a 21.4% increase reported in last year's National Inventory Report (NIR). There is a net upward recalculation of 2.5 Mt for the base year 2005 (Table 8–1).

8.1.2. Recalculations by Sector

As previously noted, good inventory preparation practice requires that methodological improvements and updates be applied across the time series (i.e., from 1990 to the most recent year reported). Methodological consistency across the time series avoids confounding a methodological change with an actual change in GHG emissions or removals.

Recalculations conducted this year have resulted in changes to previously reported emissions/removals for all Intergovernmental Panel on Climate Change (IPCC) sectors (Energy; Industrial Processes and Product Use [IPPU]; Agriculture; Land Use, Land-Use Change and Forestry [LULUCF]; and Waste) and Energy subsectors (Stationary Combustion, Transport and Fugitive Sources) and for all applicable years in the time series (1990–2019).

These revisions are largely due to improved estimation methodologies as well as updated energy data. As reflected in Table 8–2, for 2019, the revisions made resulted in the most significant changes in Fugitive (+12.4 Mt), Agriculture (-5.8 Mt) and Stationary Combustion (+3.0 Mt). Revisions for selected years of the time series are presented in Table 8–3.

Figure 8–1 **Comparison of Emission Trends (2021 NIR vs 2022 NIR)**

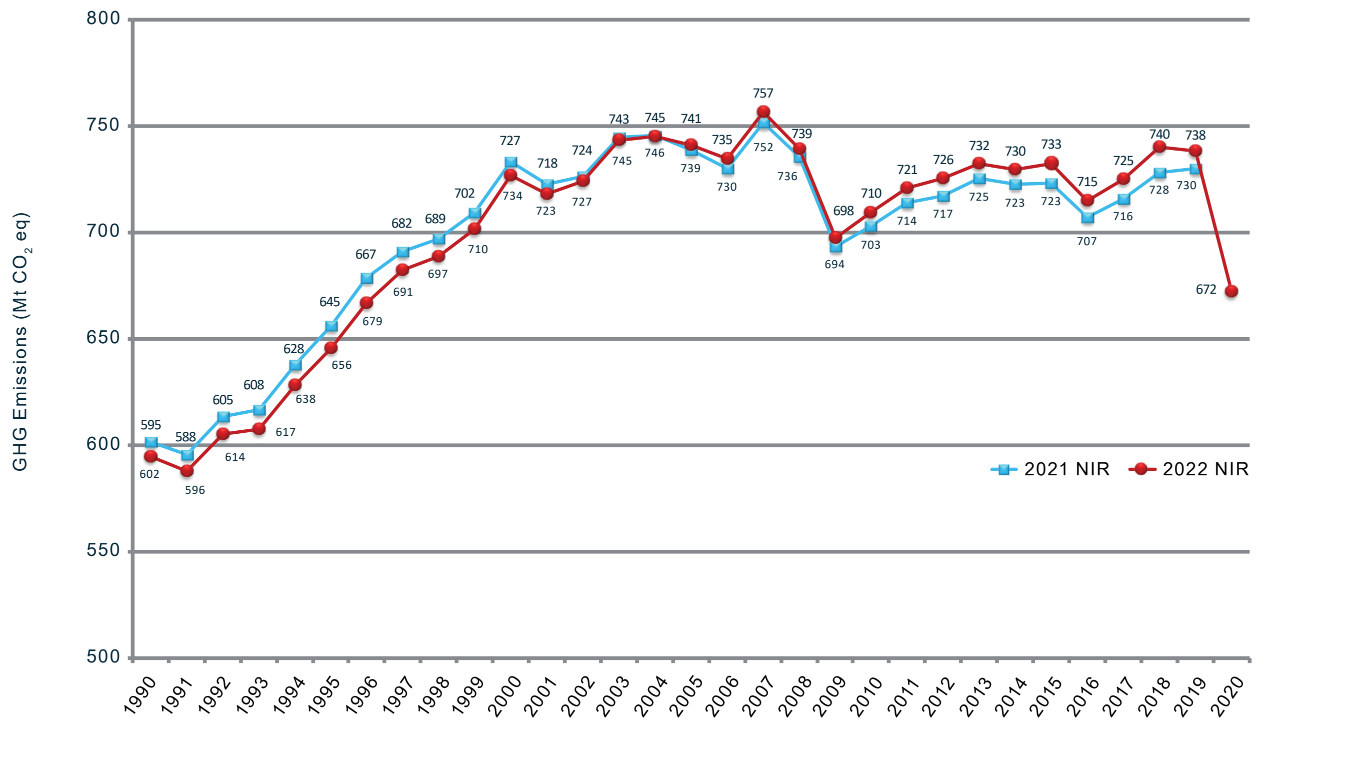


Table 8–1 **Summary of Recalculations in the 2022 National Inventory (Excluding Land Use, Land-Use Change and Forestry)**

National Total	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2015	2016	2017	2018	2019	(1990–2019)	(2005–2019)
Previous Submission (2021 NIR)	601 524	733 511	738 717	723 094	706 932	716 090	728 475	730 245	21.4%	-1.1%
Current Submission (2022 NIR)	594 722	726 987	741 182	732 535	715 094	725 014	740 005	738 283	24.1%	-0.4%
Change in Total Emissions	**-6 801**	**-6 524**	**2 464**	**9 441**	**8 162**	**8 924**	**11 530**	**8 039**	-	-
	-1.13%	**-0.89%**	**0.33%**	**1.31%**	**1.15%**	**1.25%**	**1.58%**	**1.10%**	-	-

Table 8–2 **Changes in Canada's GHG Emissions from 730 Mt (for 2019, Previous Submission) to 672 Mt (for 2020, Current Submission)**

Sector	2019 to 2020 Change (Mt CO_2 eq)	2019 Change Due to Recalculations (Mt CO_2 eq)
Energy (Stationary Combustion)	-21.8	3.0
Energy (Transport)	-26.4	-0.3
Energy (Fugitive)	-16.6	12.4
Industrial Processes and Product Use	-3.1	-0.8
Agriculture	1.9	-5.8
Waste	0.2	-0.4
Total Change	**-65.9**	**8.0**

Note: Totals may not add up due to rounding.

Energy (Stationary Combustion)

With respect to Stationary Combustion emissions, most of the recalculations for 2019 occurred in Commercial/Institutional (+3.1 Mt), Residential (-1.5 Mt), Oil and Gas Extraction (-1.1 Mt), Petroleum Refining Industries (+1.1 Mt), Public Electricity and Heat Production (+0.9 Mt), and Manufacturing Industries (+0.7 Mt). Recalculations also occurred throughout the time series, with the major source being updates to the marketable natural gas EFs. These updates caused downward revisions between 2000–2011 (as much as -1.6 Mt) in 2006 and upward revisions from 2012–2019 (as much as +3.9 Mt in 2019). See section 3.1 for further details on this change in methodology.

Recalculations in the Commercial/Institutional category occurred for the entire time series, with significant revisions from 2016 to 2019. These significant revisions are caused by decreased volumes of natural gas, partially offset by the revised natural gas EFs. Prior to 2016, the recalculations are a result of revised marketable natural gas EFs and revised quantities of municipal solid waste used for energy purposes.

Recalculations in the Residential category occurred for the entire time series, with significant revisions from 2016 to 2019. These significant revisions are caused by decreased volumes of natural gas partially offset by the revised marketable natural gas EFs. Prior to 2016, the recalculations are a result of the revised natural gas EFs.

Recalculations to the Oil and Gas Extraction category occurred for the entire time series with significant revisions from 2000–2019. Revisions to producer consumed natural gas volumes in British Columbia caused downward revisions from 2001–2019 ranging from -0.2 Mt in 2016 to -1.9 Mt in 2009. Updates to the marketable natural gas EFs caused downward revisions from 2000–2011 and upward revisions from 2012–2019.

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

Recalculations in the Public Electricity and Heat Production sector occurred between 1999 and 2019. The largest revision occurred in 2007 (+1.8 Mt) due to corrected natural gas consumption in Quebec in the RESD, offset partially by the revised marketable natural gas EFs. Recalculations between 2010-2019 are a result of a method change that revised coal EFs, and was based on facility-level data on the carbon content of the coal consumed. This was combined with the revised natural gas EFs and resulted in recalculations ranging from -0.4 Mt to 1 Mt. Recalculations prior to 2010, excluding 2007, are a result of the revised natural gas EFs and range from -0.01 Mt to -0.1 Mt.

Energy (Transport)

Recalculations for the Transport sector were applied to the entire time series. The most notable is an emissions change of approximately -0.8 Mt (-0.4%) in 2016. This downward revision is largely the result of updated natural gas consumption volumes for the Pipeline Transport sub-category. Revisions to Pipeline Transport emissions in other years are a result of the updated marketable natural gas EFs. Other notable revisions were observed in the On/Off Road Transport sub-categories as result of updates to motor gasoline and diesel fuel volume data used for the Northwest Territories. The updates to the rail model did not significantly affect national values but rather reallocated fuel between provinces resulting in significant provincial recalculations. For additional information on updates to activity data, please refer to section 3.1.

Energy (Fugitives)

Revisions occurred in the Oil and Natural Gas category of the Fugitives subsector for the entire time series, with significant revisions from 2000–2019. Overall, emissions were revised upwards from 1990–1991 and 1999–2019, ranging from +0.8 Mt (1%) in 1999 to +17.0 Mt (30%) in 2011. From 1992–1998 emissions were revised downwards ranging from -0.018 Mt (0.02%) in 1997 to -0.5 Mt (0.7%) in 1996. These recalculations resulted from three methodological updates:

1. Fugitive Emissions Model (FEM): The FEM is used to estimate emissions from pneumatics, compressor seals and equipment leaks at upstream oil and gas facilities in Manitoba, Saskatchewan, Alberta and British Columbia for the entire time series using facility counts, average number of components per facility subtype, component-level emission factors and gas composition data. Emissions from pneumatics and compressor seals are allocated to the Venting sub-category, while equipment leak emissions are allocated to the Oil and Natural Gas sub-categories, depending on the facility type. See Annex 3.2, section A3.2.2.1.3 for more details about this method. Implementation of the FEM resulted in downward revisions to emissions from 1990–1998 ranging from -0.8 Mt in 1990 to -1.8 Mt in 1996. Upward revisions in emissions occurred from 1999 to 2019 ranging from +0.4 Mt in 1999 to +19 Mt in 2011.
2. Surface casing vent flow (SCVF): A new methodology for estimating SCVF emissions for Alberta and British Columbia based on facility reported data collected by the provinces resulted in both upward and downward revisions to emissions during the time series. Emissions were revised upwards from 1990–1993 ranging from +0.1 Mt in 1993 to +0.3 Mt in 1990. Conversely, emissions were revised downwards from 1994–2019 ranging -0.002 Mt in 1994 to -2.9 Mt in 2012. See Annex 3.2, section A3.2.2.1.4 for more detail on this method. Besides causing revisions to overall SCVF emissions, the new method improves the allocation of SCVF emissions to specific sub-categories. Whereas all SCVF emissions were previously allocated to the Natural Gas sub-category due to lack of data granularity, the new method allocates significant SCVF emissions to the Oil sub-category since the SCVF are known to occur at oil wells. Therefore, not only are SCVF emissions revised downward overall, but the recalculation is more substantial in the Natural Gas sub-category as SCVF emissions are also reallocated to the Oil sub-category.
3. Saskatchewan reported venting and flaring: More information on the new method for estimating emissions from reported venting and flaring in Saskatchewan can be seen in Annex 3.2, section A3.2.2.1.2. This methodology uses gas composition data provided by the province and facility reported flare and vent volumes. Emissions were revised up from 1990–2019 ranging from +0.4 Mt in 2010 to +1.7 Mt in 1998.

Industrial Processes and Product Use

There were recalculations for the IPPU sector for the whole time series (1990–2019), ranging from -0.84 Mt to +0.052 Mt. A significant contributor was from the Product Uses as Substitutes for ozone-depleting substances (ODS) category, specifically the consumption of hydrofluorocarbons (HFCs). There were updates in the gross output data used in the data extrapolation process for 2011 to 2019, updated activity data for 2017 to 2019, and a correction to exclude reclaimed, recycled and used HFC exports in the net consumption equation. These resulted in recalculations for 2011 to 2019, ranging from -0.40 Mt in 2017 to +0.023 Mt in 2016.

Revisions to Statistics Canada's RESD data have resulted in recalculations for the Non-Energy Products from Fuels and Solvent Use category for the years 2013 to 2019, with 2019 observing the largest change of -0.38 Mt. For the Iron and Steel Production category, a small recalculation for 2013–2019 was due to a correction to the EF for Basic Oxygen Furnaces and the carbon content for scrap steel, ranging from +0.0008 Mt in 2013 to +0.014 Mt in 2019. For the Cement Production category, there were updates to the EF for total organic carbon in raw meal and the correction factor for cement kiln dust (CKD) for 2015 and 2016, updates to the facility-reported data for 2017 to 2019, as well as a correction to the Tier 3 calculation methodology to subtract CO_2 emissions from CKD not recycled to the kiln for 2017–2019. These resulted in recalculations for 2015 to 2019, ranging from -0.065 Mt in 2017 to -0.026 Mt in 2018.

Emission values for the Ammonia Production category have undergone recalculations, ranging from -0.047 to +0.064 Mt, for 1990 to 2019 due to a methodological change that includes: the application of facility-specific natural gas carbon content values voluntarily provided/confirmed by the facility (annual and province specific carbon content values were used in instances where facility-specific values were not available) for years 1990 to 2017; and the direct use of facility-specific natural gas feedstock values, carbon content, and CO_2 recovered for Urea Production from the GHGRP for 2018 and 2019.

Other Uses of Urea emissions estimates were recalculated for 2008 to 2019. These recalculations range from -0.045 Mt to 0.00012 Mt due to revised Statistic Canada's estimates of urea and used as fertilizer for 2019, revised urea and urea-ammonium-nitrate fertilizer mix import and export data for 2019, revised urea production data for 2018 and 2019, and revised estimates for urea used as diesel exhaust fluid in selective catalytic reduction (SCR) vehicles for 2008 to 2019.

Agriculture

Recalculations in the Agriculture sector were primarily driven by revisions to the Tier 2 emission factors used to estimate direct N_2O emissions from agricultural soils. Other important recalculations resulted from (i) changes in nitrogen mineralization from loss of soil organic carbon due to revisions to the cropland soil organic carbon estimation approach, (ii) the implementation of climate-specific N_2O emission factors for volatilized nitrogen (EF_4) from the 2019 IPCC Refinement, (iii) implementation of a correction to the Swine nitrogen excretion rate contained in the latest corrigenda to Volume 4, Chapter 10 of the 2006 IPCC Guidelines, and (iv) revised inorganic nitrogen fertilizer activity data from Statistics Canada for the year 2019.

As a result of these recalculations, agricultural emissions were revised downward by 5.8 Mt in 1990, 5.7 Mt in 2005, and 5.8 Mt in 2019.

Refer to Table 8–4 for more details on implemented improvements.

Waste

Recalculations in the Waste sector resulted in a decrease in emission estimates of 1.6, 2.6 and 1.6 Mt CO_2 eq in 1990, 2005 and 2019, respectively. The recalculations include: four method changes, occurring in the Municipal and Industrial Wastewater, Industrial Wood Waste Landfills and Solid Waste Disposal (Landfills) subsectors; two error corrections, one for Municipal Solid Waste Landfills, the other for Municipal Wastewater; and, numerous activity data updates.

The largest recalculation in the Waste sector was due to an error correction in the Solid Waste Disposal (Landfills) subsector. In the previous inventory, quantities of waste incinerated was erroneously included as waste landfilled, resulting in an over-estimate of landfill emissions in provinces where waste incineration occurs. This correction decreases emission estimates by 0 Mt in 1990, -1.1 Mt in 2005 and -1.2 Mt CO_2 eq in 2019, compared to the previous inventory. In addition, a few waste material parameters (carbon content and degradability) were refined, which yielded an additional downward revision in emission estimates of 0.28, 0.49 and 1.41 Mt CO_2 eq in 1990, 2005 and 2019.

Industrial wood waste landfills emissions were recalculated based on a new oxidation factor and DOCf parameter for the solid wood industry, resulting in downward revisions in emission estimates of 1.0, 1.1, and 0.8 Mt CO_2 eq in 1990, 2005 and 2019, respectively.

The Wastewater subsector had a method change, and N_2O emissions from the treatment process are now included for both municipal and industrial wastewater treatment. The total recalculation for Municipal Wastewater yields an increase 0.63 Mt, 0.85 Mt and 1.11 Mt CO_2 eq in 1990, 2005 and 2019. The method change for Industrial Wastewater treatment included addition of new data-sources, expanded the facility-coverage and introduced N_2O emissions from treatment and effluent, yielding a further increase of 0.15, 0.10 and 0.33 Mt CO_2 eq in 1990, 2005 and 2019, respectively. Lastly, there was a correction in Municipal Wastewater Treatment and Discharge as emissions from effluent and anaerobic digestion of sludge were missed in the previous inventory.

Land Use, Land-Use Change and Forestry

Recalculations also occurred in the estimates of emissions and removals from the LULUCF sector, notably in the Forest Land, Cropland, and Harvested Wood Products categories. The most important recalculations were due to (i) revisions to forest harvest and HWP activity data from the National Forestry Database (NFD), based on provincial input, replacing previously reported value projected from 2018 activity data, (ii) updated model parameters based on latest forest product statistics from the Food and Agriculture Organization (FAO), (iii) updated method to estimate changes in soil organic carbon impacted by crop productivity changes and manure application, and (iv) updates to residential bioenergy activity data based on the 2019 Households and the Environment Survey (HES) carried out by Statistics Canada. Other less significant recalculations occurred in Forest Land due to retroactive updates of wildfire and insects activity data. Additional recalculations occurred in land categories associated with forest conversion as a result of the completion of the northern deforestation mapping and the addition of three hydro-related large events.

The combined impact of these and other minor recalculations in the LULUCF sector increased the estimates of net removals by 6.7 Mt (+12%) for 1990 and switched the previously reported net sources of emissions of 8.2 Mt in 2005 and 9.9 Mt in 2019 to net sinks of 4.2 Mt and 16 Mt, i.e. net changes of 12 Mt (-152%) and 26 Mt (-261%), respectively.

Refer to Table 8–4 for more details on implemented improvements.

Table 8–3 **Summary of Recalculations by Sector**										
	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2015	2016	2017	2018	2019	(1990–2019)	(2005–2019)
ENERGY (Stationary Combustion)										
Previous Submission (2021 NIR)	277 722	344 748	340 523	323 997	311 116	315 717	317 502	318 670	14.7%	-6.4%
Current Submission (2022 NIR)	277 706	344 409	339 046	325 198	313 005	318 102	322 706	321 686	15.8%	-5.1%
Change in Emissions	**-16**	**-339**	**-1 477**	**1 201**	**1 890**	**2 385**	**5 204**	**3 016**	-	-
	0.0%	**-0.1%**	**-0.4%**	**0.4%**	**0.6%**	**0.8%**	**1.6%**	**0.9%**	-	-
ENERGY (Transport)										
Previous Submission (2021 NIR)	144 881	177 464	189 820	201 163	201 167	207 322	215 214	216 770	49.6%	14.2%
Current Submission (2022 NIR)	144 881	177 448	189 858	201 112	200 333	207 546	215 020	216 440	49.4%	14.0%
Change in Emissions	**0**	**-16**	**37**	**-51**	**-834**	**224**	**-194**	**-330**	-	-
	0.0%	**0.0%**	**0.0%**	**0.0%**	**-0.4%**	**0.1%**	**-0.1%**	**-0.2%**	-	-
ENERGY (Fugitive)										
Previous Submission (2021 NIR)	48 956	69 495	60 904	59 484	54 133	54 767	54 799	53 846	10.0%	-11.6%
Current Submission (2022 NIR)	49 575	71 753	72 793	74 113	67 929	67 920	68 215	66 249	33.6%	-9.0%
Change in Emissions	**618**	**2 258**	**11 889**	**14 629**	**13 796**	**13 154**	**13 416**	**12 403**	-	-
	1.3%	**3.2%**	**19.5%**	**24.6%**	**25.5%**	**24.0%**	**24.5%**	**23.0%**	-	-
IPPU										
Previous Submission (2021 NIR)	57 020	54 114	56 612	53 491	54 473	53 041	54 345	54 318	-4.7%	-4.1%
Current Submission (2022 NIR)	56 961	54 080	56 591	53 532	54 515	52 680	53 895	53 478	-6.1%	-5.5%
Change in Emissions	**-59**	**-34**	**-21**	**41**	**42**	**-361**	**-449**	**-840**	-	-
	-0.1%	**-0.1%**	**0.0%**	**0.1%**	**0.1%**	**-0.7%**	**-0.8%**	**-1.5%**	-	-
AGRICULTURE										
Previous Submission (2021 NIR)	46 940	57 021	59 884	58 257	59 366	58 341	59 427	59 058	25.8%	-1.4%
Current Submission (2022 NIR)	41 183	51 013	54 176	52 375	53 054	52 043	53 178	53 280	29.4%	-1.7%
Change in Emissions	**-5 757**	**-6 008**	**-5 708**	**-5 882**	**-6 312**	**-6 297**	**-6 249**	**-5 778**	-	-
	-12.3%	**-10.5%**	**-9.5%**	**-10.1%**	**-10.6%**	**-10.8%**	**-10.5%**	**-9.8%**	-	-
WASTE										
Previous Submission (2021 NIR)	26 004	30 669	30 972	26 702	26 677	26 903	27 188	27 581	6.1%	-10.9%
Current Submission (2022 NIR)	24 417	28 284	28 717	26 205	26 257	26 722	26 990	27 150	11.2%	-5.5%
Change in Emissions	**-1 587**	**-2 385**	**-2 255**	**-497**	**-421**	**-181**	**-198**	**-431**	-	-
	-6.1%	**-7.8%**	**-7.3%**	**-1.9%**	**-1.6%**	**-0.7%**	**-0.7%**	**-1.6%**	-	-
LULUCF										
Previous Submission (2021 NIR)	-56 816	-21 741	8 189	4 014	95	696	8 411	9 878	-117.4%	20.6%
Current Submission (2022 NIR)	-63 537	-36 496	-4 228	-78	-10 606	-17 020	-8 468	-15 935	-74.9%	276.9%
Change in Emissions	**-6 721**	**-14 755**	**-12 417**	**-4 092**	**-10 702**	**-17 716**	**-16 879**	**-25 813**	-	-
	11.8%	**67.9%**	**-151.6%**	**-101.9%**	**-11 215.3%**	**-2 544.0%**	**-200.7%**	**-261.3%**	-	-

8.2. Inventory Improvements

Inventory improvements aim to improve the accuracy of GHG estimates or enhance components of the inventory preparation process, including the supporting institutional, legal and procedural arrangements. Improvements that involve a methodological change or refinement must be documented and reviewed prior to implementation. Improvements that lead to recalculations of estimates must be applied across the time series to maintain consistency.

This year, improvements to Canada's inventory resulted from recommendations from expert review teams (ERTs), continued implementation of the *2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories* (2006 IPCC Guidelines) and internal continuous improvement activities.

Table 8–4 provides additional information about the improvements implemented this year presented by IPCC sectors and Common Reporting Format (CRF) categories.

8.2.1. Expert Review Team Recommendations

Canada's inventory submission is typically reviewed annually by an ERT following agreed-upon UNFCCC review guidelines[1] as adopted in Decision 13/CP.20 at COP 20 in Lima in 2014. Reviews are coordinated by the UNFCCC Secretariat, and the ERT is composed of inventory experts from developed and developing countries. The purpose of the review is to provide a thorough and comprehensive technical assessment of the implementation of the Convention and adherence to the UNFCCC Reporting Guidelines. At the end of the review, the ERT provides technical feedback on any methodological and procedural issues encountered. The ERT will focus 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 reflected in an annual review report that is provided to the country under review and made public by the UNFCCC.

The recommendations from ERTs were taken into consideration when identifying potential improvements for this year. The latest review by the ERT can be found on the UNFCCC website.[2]

Methodological changes made this year that addressed ERTs recommendations include the following:

- updated CO_2 EFs for marketable natural gas combustion
- revision of 2008 to 2019 perfluorocarbon (PFC) data in Product Uses as Substitutes for ODS applications
- reallocation of 2014 to 2018 PFC data in the Other Contained Product Use category to the Refrigeration and Air Conditioning category
- revision of the nitrogen excretion rate for Swine
- update of oxidation factor for unmanaged solid waste landfills

8.2.2. 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories

The 2006 IPCC Guidelines contain internationally agreed-upon methodologies for use by countries to estimate GHG emissions and to report to the UNFCCC (IPCC, 2006). These guidelines were developed by the IPCC at the invitation of the UNFCCC. The 2006 IPCC Guidelines encourage the use of country-specific refined methodologies for estimating emissions, including complex modelling approaches at higher tiers.

The 2006 IPCC Guidelines became the methodological reference in 2015, in accordance with the revised UNFCCC Reporting Guidelines on Annual Inventories for Annex I Parties (UNFCCC Reporting Guidelines), as adopted in Decision 24/CP.19 at COP 19 in Warsaw in 2013. Methodological changes made this year for consistency with the 2006 IPCC Guidelines include the following:

- use of 2006 IPCC Guidelines default CH_4 EF for Ethylene Dichloride (EDC)

8.2.3. Continuous Improvements

The GHG inventory team also identifies improvements based on evolving science, quality assurance / quality control (QA/QC) and verification activities (in accordance with the QA/QC Plan), and new and innovative modelling approaches or new sources of activity data. Implementation of the improvements is prioritized by taking into consideration the outcomes of the key category and uncertainty analysis, the level of effort and the significance of the improvements. Examples of continuous improvement activities implemented in this year's inventory include:

- updated EF and energy content for sub-bituminous coal from the public electricity and heat production sector
- updated provincial activity data for the railway model
- updated method to calculate emissions from surface casing vent flows in Alberta and British Columbia
- implementation of a new fugitive emissions model to calculate emissions from pneumatics, compressor seals and equipment leaks in the oil and gas industry in British Columbia, Alberta, Saskatchewan and Manitoba
- partial integration of facility-reported data for the ammonia production category

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

2 https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports-2021

- updated wildfire area burned estimates in Forest Land
- updated EF and energy content for marketable natural gas
- updated forest conversion activity data including the addition of three new reservoirs and northern land-use change mapping
- updates to industrial wastewater for N_2O in municipal wastewater
- continued implementation of a landfill waste model with waste-specific parameters
- revisions to the methodology used to estimate N_2O emissions from agricultural soils
- implementation of an IPCC Tier 2 model for estimating change in soil organic carbon impacted by crop productivity
- elimination of summerfallow reduction as a reporting sub-category that overlapped with the implementation of an IPCC Tier 2 model for estimating change in soil organic carbon impacted by crop productivity
- implementation of a country specific method for estimating change in soil organic carbon impacted by manure application

8.3. Planned Inventory Improvements

Canada's planned improvements to the national GHG inventory are contained in an *Inventory Improvement Plan* that identifies and tracks planned improvements to emission estimates (including underlying activity data, EFs and methodologies). The planned improvements are based on recommendations from internal sources and external review processes and on collaborative work between inventory sector experts and industry, other government departments and academia.

Planned improvement activities (Table 8–5) are prioritized by taking into consideration key category analysis, QA/QC activities, uncertainty assessments, the level of effort and the significance of the improvements. Although the quantification of uncertainty for the emission estimates (Annex 2) helps prioritize improvement activities for future inventories, uncertainty itself is not an indicator of potential future changes resulting from continuous improvement activities. The *Inventory Improvement Plan* is updated annually to track progress in implementing improvements to the inventory. Table 8–4 and Table 8–5 are updated as planned improvements are implemented each year.

Table 8–4 **Improvements to Canada's 2022 NIR**

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Energy (Transport)	Railways (CRF 1.A.3.c)	Updated provincial activity data for the rail model.	The provincial activity data has been updated to reflect the amount of fuel consumed within a geographical region whereas the previous model was based on fuel supplied to a geographical region. Update does not affect the national emissions total.	Continuous improvement	Annex 3.1.4.2.4
Energy (Combustion)	Public Electricity and Heat Production (CRF 1.A.1.a)	Updated CO_2 EFs and energy content for sub-bituminous coal.	This update improves the accuracy of the sub-bituminous coal CO_2 EF with new detailed facility-level information. Analytical information about the coal consumed was provided back to 2010, which has allowed Environment and Climate Change Canada (ECCC) to develop industry specific CO_2 EFs and corresponding energy content.	Continuous improvement	Annex 6.1.3
	All CRF combustion categories from 1.A.1 to 1.A.4	Gaseous fuel: Updated CO_2 EF for marketable natural gas.	This improvement better captures the variation in carbon content of marketable natural gas consumed across Canada. Revised CO_2 EFs are based on data provided by the natural gas industry at key transmission and distribution points including regional transferred and imported volumes. Information such as fuel composition, higher heating values and volumetric flow were used to develop representative carbon composition over time by regions. Refer to Chapter 3 for a description of this update and Annex 6 for revised CO_2 EFs.	Continuous improvement and UNFCCC ERT recommendation	Annex 6.1

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Table 8–4 **Improvements to Canada's 2022 NIR** (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Energy (Fugitive Emissions)	Fugitive Emissions from Fuels – Oil and Natural Gas – Venting and Flaring (CRF 1.B.2.c)	Updated method for estimating flaring and reported venting emissions in Saskatchewan and Alberta.	Saskatchewan (SK) reported venting and flaring emissions from the upstream oil and gas (UOG) industry were based on the 2014 UOG study completed by Clearstone Engineering Ltd. for the 2011 data year and extrapolated based on annual reported venting and flaring volumes from the SK Ministry of Energy and Resources (SK MER). This assumes a static gas composition based on the flaring and venting that occurred in the 2011 data year. Additionally, Clearstone applied generic speciation profiles derived from Alberta data when calculating SK reported venting and flaring emissions as SK specific data was not available. Using annual fuel, flare and vent data by facility available from SK MER, reported venting and flaring emissions are now calculated directly using SK specific gas composition data provided by SK MER. Alberta (AB) reported venting and flaring emissions are currently estimated using facility reported public Petrinex data and gas composition data by Alberta township. However, the public Petrinex data does not include confidential facilities. ST60B: Upstream Petroleum Industry Flaring and Venting Report is published annually by the Alberta Energy Regulator (AER) and summarizes reported venting and flaring volumes including those volumes reported by facilities not available in the public Petrinex data. In the new method, gas volumes and associated emissions are adjusted so that volumes match those reported in ST60B.	Continuous improvement	Annex 3.2.2.1.2
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Updated method for estimating emissions from pneumatics, compressor seals and equipment leaks in the oil and gas sector.	Emissions from pneumatics, compressor seals and equipment leaks were based on the 2014 UOG study completed by Clearstone Engineering Ltd. for the 2011 data year and extrapolated based on annual production volumes. This method assumes a static emission intensity based on 2011 data and cannot capture the impact of regulations, changes in technology or changes in industry practices. The new method utilizes well and facility counts by subtype, average number of components per facility subtype (asset ratios), previously published and new EFs by component, and gas composition data to estimate emissions for the entire time series. The new method eliminates the need for extrapolations and provides the necessary flexibility to incorporate new science and reflect the impacts of regulations and changes to technology and industry practices over time. This method utilizes recent provincial field studies to derive asset ratios and new EFs.	Continuous improvement	Annex 3.2.2.1.3
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Updated method for estimating surface casing vent flow (SCVF) emissions in British Columbia and Alberta.	SCVF emissions were based on the number of producing oil and gas wells in each province and territory and a constant EF (1731 m^3/yr) developed by Clearstone Engineering using Alberta SCVF data from 2000. The new method estimates CH_4 and CO_2 emissions from crude oil and natural gas wells in Alberta (AB) and British Columbia (BC) by utilizing reported SCVF data from AB and BC, including well IDs, location, magnitude, and duration of these leaks. As the data is not complete for every reported SCVF, various assumptions are required. Location-specific natural gas composition data is also used for AB estimates.	Continuous improvement	Annex 3.2.2.1.4
IPPU	Cement Production (CRF 2.A.1)	Update of Tier 3 methodology.	The Tier 3 methodology has been updated to comply with the 2006 IPCC Guidelines. Previously, the CO_2 emissions from cement kiln dust (CKD) not recycled to the kiln was added in the calculation of the total process CO_2 emissions from cement production. The Tier 3 methodology has been updated so the CO_2 emissions from CKD not recycled to the kiln are subtracted in the calculation of the total process CO_2 emissions from cement production.	IPCC 2006 Guidelines	Chapter 4
	Ammonia Production (CRF 2.B.1)	Partial integration of facility- reported data collected under the Greenhouse Gas Reporting Program (GHGRP) for 2018 to 2020. In addition, carbon contents of natural gas used as feedstock for the years 1990 to 2017 have been updated to facility-specific, where possible.	For 2018 onwards, the method used has been improved from a Tier 2 to a Tier 3 type. In the Tier 3 method, facility-level data, such as total fuel requirement, carbon content, and CO_2 consumed in the production of urea, are directly used in the quantification of ammonia production emissions. In the previously used Tier 2 method, total fuel requirement and CO_2 consumed in the production of urea were derived from ammonia and urea production quantities, respectively, and province-specific carbon contents were used. For the years 1990 to 2017, natural gas carbon content values obtained and confirmed by facilities (not province-specific) have been used to develop emission estimates.	Continuous improvement	Chapter 4

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Table 8–4 **Improvements to Canada's 2022 NIR** (cont'd)					
Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
IPPU (cont'd)	Ethylene Dichloride Production (CRF 2.B.8.c)	Update of CH_4 EF.	The Ethylene Dichloride (EDC) model has been updated to comply with the default EFs available from the 2006 IPCC Guidelines.	IPCC 2006 Guidelines	Chapter 4
	Semiconductor Manufacturing (CRF 2.E.1)	Collection of more exact 2014 to 2019 NF_3, SF_6 and PFC use data.	The largest known semiconductor manufacturer was surveyed to provide exact use quantities of NF_3, SF_6, and PFCs (based on weighing cylinders before and after use) instead of using import data to estimate activity data. This information was provided for years 2014 to 2020 and is incorporated into the inventory estimates.	Continuous improvement	Chapter 4
	Product Uses as Substitutes for ODS – PFCs (CRF 2.F)	Revision of 2008 to 2019 activity data.	PFC activity data in mixtures of HFCs and PFCs for 2008 to 2019 was disaggregated and included in the reported PFC estimates for 2.F categories. In addition, 2014 to 2018 PFC activity data voluntarily collected from a gas distributor contributing to the "Heat Transfer Medium" CRF category 2.G.4 has been confirmed to be for intended use as a refrigerant. This activity data was reallocated to CRF category 2.F.1.	UNFCCC ERT recommendation	Chapter 4
	PFC Emissions from Other Contained Product Uses (CRF 2.G.4)	Reallocation of 2014 to 2018 PFC activity data to Product Uses as Substitutes for ODS (CRF 2.F) categories.	2014 to 2018 PFC activity data voluntarily collected from a gas distributor contributing to the "Heat Transfer Medium" CRF category 2.G.4 has been confirmed to be for intended use as a refrigerant. This activity data was reallocated to CRF category 2.F.1.	UNFCCC ERT recommendation	Chapter 4
Agriculture	Agricultural Soils (CRF 3.D)	Revised N_2O EFs for Agricultural Soils.	New EFs for direct N_2O emissions from managed soils were developed based on Canadian publications. A new exponential relationship was developed between growing season precipitation and N_2O, and ratio factors were applied to this relationship to account for impacts to emissions from nitrogen sources, cropping systems, non-growing season emissions, topography, soil texture, tillage, and irrigation. The $Frac_{GASM}$ and EF_4 factors were also updated to match those in the 2019 refinement to the 2006 IPCC Guidelines, leading to recalculations in indirect N_2O emissions from managed soils.	Continuous improvement	Chapter 5.4 Annex 3.4.5
	Manure Management – Swine (3.B.2.3) Direct N_2O Emissions from Managed Soils (3.D.1) Indirect N_2O Emissions from Managed Soils (3.D.2)	Revision to Nitrogen Excretion Rate for Swine.	A correction to the nitrogen excretion rate for swine was required in response to the publication of corrigenda to Volume 4 Chapter 10 of the 2006 IPCC guidelines.	UNFCCC ERT recommendation	Chapter 5.3 Chapter 5.4 Annex 3.4.4 Annex 3.4.5
LULUCF	Forest Land Remaining Forest Land (CRF 4.A.1)	Update of 1990-2003 wildfire area burned estimates.	Temporal coverage of the National Burned Composite fire mapping product was retroactively updated to include the 1990-2003 period that was previously drawn from the Canadian Large Fires Database.	Continuous improvement	Annex 3.5.2.3
	Cropland Remaining Cropland (CRF 4.B.1)	Increase in crop productivity/crop residue C input enhances soil organic carbon sink.	The 2019 Refinement to the 2006 IPCC Guidelines provides IPCC Tier 2 approach for estimating the change in soil organic carbon as impacted by crop productivity in Cropland Remaining Cropland (CLCL) of LULUCF. This method generates soil C change factors based on crop production/crop residue C input that is consistent with the methodology that is currently used for calculating nitrogen and N_2O emissions from crop residue input to agricultural soils. The implementation of this method overlaps with summerfallow reduction as a reporting category that needs to be eliminated.	Continuous improvement	Chapter 6.5 Annex 3.5
	Cropland Remaining Cropland (CRF 4.B.1)	Manure application on soil organic C storage.	The application of animal manure on agricultural soils increases soil organic carbon storage. The average retention factor of animal manure as a fraction of carbon input from various manure types was established through measurements of long-term manure studies. A country-specific method using manure-induced carbon retention factors (MCRs) is used to estimate soil organic carbon change as a result of manure application in CLCL.	Continuous improvement	Chapter 6.5 Annex 3.5
	Land Converted to Cropland (CRF 4.B.2) Land Converted to Wetlands (CRF 4.D.2) Land Converted to Settlements (CRF 4.E.2) Harvested Wood Products (CRF 4.G)	Inclusion of deforestation mapping.	Inclusion of the Northern Taiga Plains deforestation mapping, and addition of three hydro-related large events (Site-C in British Columbia, Muskrat Falls in Newfoundland and Labrador and Keesyak in Manitoba).	Continuous improvement	Chapter 6.9 Annex 3.5.2.6

Table 8–4 **Improvements to Canada's 2022 NIR** (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Waste	Solid Waste Disposal (CRF 5.A)	Continued updates from the previous inventory to enable emissions calculations based on waste subcomponents, whereas previously emissions were calculated using bulk waste (averaged waste content).	Parameter updates include: Other Organics: discovered to be mostly soiled paper and degradable packaging. Dissolved organic carbon (DOC) 0.5 changed to 0.4 (in line with paper), DOCf: 0.7 changed to 0.5 (highly to moderately decomposable, in line with paper). This material first appears in the ECCC 2020 waste characterization, applied to the waste disposed from 2015 onwards. Soil and Dirt: DOC 0.5 changed to 0.03, DOCf: unchanged (0.1). Construction Debris: DOC estimate is based on an estimated 50% of debris being wood and the other 50% assumed inert (concrete, asphalt, metal, etc.). DOC: 0.22 (unchanged), DOCf 0.5 (IPCC bulk default) changed to 0.1 (IPCC 2019 Refinement value for wood / less decomposable waste).	Continuous improvement	Chapter 7.2.5
	Solid Waste Disposal (CRF 5.A.2)	Update to model parameters data.	Changing the oxidation factor from 0.1 to 0.0 for industrial wood waste landfills, and within this category, changing the DOCf parameter from 0.5 to 0.1 for the solid wood industry.	Continuous improvement	Annex 3.6.1.3
	Municipal Wastewater Treatment/Discharge (CRF 5.D)	A number of updates focusing on an update of N_2O emissions and use of the 2019 IPCC refinement.	A number of updates were made to the wastewater sector, notably including new directly facility N_2O emissions; a new method to calculate protein consumption; the inclusion of N_2O based on household products; and, accounting for nitrogen removed by treatment when estimating nitrogen remaining in effluent (previously, all nitrogen was effectively assumed to be discharged with the effluent).	Continuous improvement	Annex 3.6.4
	Industrial Wastewater Treatment (CRF 5.D)	An overhaul of the industrial wastewater method to include ECCC facility reporting programs, NPRI and GHGRP.	This method changes includes the following: • The incorporation of GHGRP facility-reported wastewater emissions for industrial facilities. • A correction; the recalculation of old and voluntary survey based on estimates; the removal of estimates supplanted by GHGRP reported values. • The incorporation of National Pollutant Release Inventory (NPRI) discharges of nitrogen to wastewater as activity data to calculate N_2O emissions from effluent. • The completion of time series by interpolating and extrapolating earliest and last values, by industry category and province/territory. It was completed using simple linear interpolation and constant extrapolation.	Continuous improvement	Annex 3.6.4.2

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Table 8–5 **Summary of Canada's Inventory Improvement Plan**

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Energy	General	Conversion of volumes of natural gas to energy units.	An investigation is underway to obtain current and historical activity data to allow volumes of natural gas to be converted to energy units by the province in which they are consumed.	UNFCCC ERT recommendation	Data collection and analysis underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Analyze and incorporate raw gas composition data for the province of British Columbia into emission estimates.	The British Columbia Oil and Gas Commission (BCOGC) collects measured raw gas composition data for oil and gas wells drilled in the province and makes the data available on their website. The data will be analyzed to improve fugitive emission estimates from oil and gas facilities and the CO_2 EFs used to estimate emissions from raw gas combustion at oil and gas facilities.	Continuous improvement	Data collection underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Develop Canadian-specific EFs from measurement data to improve estimates for abandoned oil and gas wells.	Canada currently estimates emissions from abandoned oil and gas wells using IPCC default EFs based on measurements taken in the United States. Recent measurements of abandoned and suspended wells in Canada will be used to develop Canadian specific EFs.	Continuous improvement	Data collection underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Storage tank emissions.	Incorporate storage tank emission estimates into the Fugitive Emissions Model (FEM) previously developed to estimate emissions for pneumatics, compressor seals and equipment leaks in the oil and gas industry.	Continuous improvement	Data collection and analysis underway
	Fugitive Emissions from Fuels – Oil and Natural Gas (CRF 1.B.2)	Analysis of aircraft measurement data to improve CH_4 estimates in the oil and gas industry.	Atmospheric measurements of CH_4 emissions from the oil and gas industry have identified a gap between bottom-up inventory estimates and top-down estimates using aircraft measurements, stationary towers and vehicles. Recent field campaigns in British Columbia (2019, 2021), Alberta (2021) and Saskatchewan (2020, 2021) using low-altitude LiDAR measurement technology and ground-level truck-based measurements will be analysed to determine how the results can be used to improve CH_4 estimates from the oil and gas industry. The results of the analysis may be used to validate bottom-up models or, where the measurement data allows, be used to improve model parameters and estimates.	Continuous improvement	Data collection and analysis underway
	Oil and Natural Gas – Fugitive (CRF 1.B.2)	Refine method used to estimate emissions from SCVFs.	Continuous improvements to SCVF emission estimates using provincial data and available measurements, where available.	Continuous improvement	Data analysis underway
	Off-Road Transportation (General)	Revamp of off-road emissions model inputs.	Work is underway to incorporate several major updates to off-road model inputs. These updates include implementing new off-road equipment population data for all reported calendar years, modifying the geographical distributions assigned to off-road equipment, and updating the annual hours-of-use parameter for select off-road equipment types.	Continuous improvement	Data collection and analysis underway
	Off-Road Transportation (General)	Off-road emissions model update.	Work is underway to improve the already modified version of the United States Environmental Protection Agency's off-road emissions model NONROAD. As per an ERT recommendation, the improved model will include consumption and emissions of lube oils used in two-stroke gasoline engines. In addition, the improved model will have updated reference tables to ensure the inclusion of new off-road equipment types introduced since the last model update.	UNFCCC ERT recommendation	Verification and finalization of improvement
	Road Transportation (CRF 1.A.3.b)	Revamp of on-road emissions model inputs.	Work is underway to incorporate several major updates to on-road model inputs. These updates include implementing new on-road vehicle population data and utilizing more recent kilometre accumulation rates.	Continuous improvement	Data collection and analysis underway
	Road Transportation (CRF 1.A.3.b)	Transition to an improved on-road emissions model.	Subject to review, ECCC intends to adopt the United States Environmental Protection Agency's most recent motor vehicle emission simulator MOVES3. Some benefits of transitioning from MOVES2014b to MOVES3 are updated emission rates and adjusted modelling to better account for vehicle starts and long-haul truck hoteling.	Continuous improvement	Model review underway

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Oil and Gas (economic sector)	Natural Gas Production and Processing Conventional Light Oil Production Conventional Heavy Oil Production Oil Sands (Mining, In-Situ, Upgrading)	Refine allocation of emissions to the various oil and gas industry segments, i.e., Conventional Light Oil Production, Conventional Heavy Oil Production, Natural Gas Production and Processing, Oil Sands (Mining, In-situ and Upgrading), etc.	Statistics Canada reports fuel consumption data in the aggregated category "Total Mining and Oil and Gas Extraction" which includes all mining sectors (i.e., coal, metal mining, non-metal mining and quarrying, oil sands mining) and oil and gas extraction. Work is underway to refine the model used to allocate fuel consumption and the subsequent emissions from the aggregated category to more discrete categories and subcategories.	Continuous improvement	Data analysis
IPPU	Methanol Production (CRF 2.B.8.a)	Validate the applicability of EFs used.	The EFs used to estimate emissions from methanol production came from the 2010 Cheminfo study. The improvement plan is to assess the applicability of such EFs for years post-2010.	UNFCCC ERT recommendation	No significant progress made
	Iron and Steel Production (CRF 2.C.1)	Allocate natural gas and coal emissions associated with manufacturing with iron and steel manufacturing to Iron and Steel Production instead of the Energy sector's Manufacturing, and the IPPU sector's Non-Energy Products from Fuels and Solvent Use, respectively.	A part of the process, CO_2 emissions associated with Iron and Steel Production originate from the use of reductants other than metallurgical coke, specifically natural gas and coal. Natural gas is used as a reductant in the direct reduced iron (DRI) method of iron manufacturing and is currently reported as part of the Energy sector's CO_2 emissions associated with Iron and Steel Production. A fraction of coal, shown in the RESD's non-energy line, is used in iron and steel making and is currently reported under the Non-energy Products from Fuels and Solvent Use subcategory. It is planned to allocate the aforementioned emissions to the Iron and Steel Production Category.	UNFCCC ERT recommendation	Data analysis underway
	Non-Energy Products from Fuels and Solvent Use (CRF 2.D)	Update EFs for various non-energy petroleum products and natural gas.	EFs for various non-energy petroleum products and natural gas were developed based on studies conducted in 1992 and 2005, respectively. There is a plan to evaluate whether these emissions factors are still valid and to update if necessary.	UNFCCC ERT recommendation	No significant progress made
	Product Uses as Substitutes for ODS (HFCs, CRF 2.F)	Develop means to annually update in-item HFC use.	A data gap exists with the in-item data that are available up to 2010. To fill this gap, statistics and import/export data will be examined to determine a method to arrive at HFC quantities.	Continuous improvement	No significant progress made
	Electrical Equipment (CRF 2.G.1)	Reporting of CF_4 emissions.	SF_6 is used as an insulating and arc-quenching medium in electrical transmission and distribution equipment. To enhance performance in cold weather, SF_6 gas can be mixed with CF_4 gas. Currently, Canada only reports SF_6 from this source category and it is planned to report CF_4 emissions as well.	Continuous improvement	Initiated data collection / study
	Hydrogen Production	Include CO_2 emissions resulting from stand-alone hydrogen production facilities in Canada.	Collection of hydrogen production activity data and estimation of CO_2 emissions from this source using methods presented in the 2019 Refinement to the 2006 IPCC Guidelines.	Continuous improvement	Data collection underway
	Other Limestone and Dolomite Use (CRF 2.A.4.d)	Resolve 2017–2019 activity data discrepancies and identify new activity data source (as necessary).	Potential discrepancies were observed in 2017–2019 data on limestone and dolomite use in various sectors, particularly for the iron and steel and ferrous foundry sectors. Investigations have been started and will be continued to determine whether corrections are needed and whether a new data source is needed.	Continuous improvement	Data analysis underway
	Product Uses as Substitutes for ODS – HFCs (CRF 2.F)	Update end-of-life EFs for HFCs in refrigeration and air conditioning applications.	End-of-life EFs for HFCs in refrigeration and air conditioning applications are currently from the 2006 IPCC Guidelines. Information and data on HFC recovery at the end-of-life for refrigeration and air conditioning applications will be collected (e.g., from industry associations) and assessed to determine the feasibility of developing country-specific end-of-life EFs.	Continuous improvement	Data collection underway
	Semiconductor Manufacturing – NF_3, SF_6, PFCs (CRF 2.E.1)	Collection of 2014–2020 activity data and EF information from end users.	The largest known semiconductor manufacturer in Canada was surveyed and provided use data on NF_3, SF_6, and PFCs (replacing sales data from voluntary gas distributor surveys). The company also provided information on the emissions abatement technology utilization and efficiency for each gas used. Other known semiconductor manufacturers, who are also purchasers of NF_3, SF_6, and PFCs, will be contacted to provide more accurate use quantities and to collect data that can be used to develop facility-specific EFs (where possible).	Continuous improvement	Data collection underway

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
IPPU (cont'd)	SF_6 and PFCs from other product use – SF_6 (CRF 2.G.2)	Data collection and significance assessment.	2014–2020 sales data collected from gas distributors through voluntary data surveys indicate that some end-users may use SF_6 and PFCs for applications mentioned in the 2006 IPCC Guidelines (vol.3, chap. 8.3, pp.8.23–8.34). Identified end-users and relevant national agencies for certain applications (such as those knowledgeable on particle accelerators and ophthalmology uses) have been sent surveys for recent years. Once data is collected, a Tier 1 emission estimation will be performed for these years to assess the significance of emissions coming from this category. If the category is determined to be significant, efforts will be made to develop emission estimates for the whole time series.	UNFCCC ERT recommendation	Data collection underway
	N_2O Emissions from Medical Applications (CRF 2.G.3.a) and Propellant Usage (CRF 2.G.3.b)	Update N_2O sales patterns by application.	The N_2O sales pattern by application is based on 2005 data and has been assumed to be the same since. Work is underway to update the sales pattern by application.	Continuous improvement	Data collection underway
	PFC Emissions from Other Contained Product Uses (CRF 2.G.4)	Reallocation of all activity data to other CRF categories, such as applications in CRF 2.E.1, 2.F, or 2.G.2.	Activity data for 2014 to 2018 that was originally attributed for use as a "heat transfer medium" was re-allocated to CRF category 2.F.1 following confirmation from the activity data provider that the intended use was as a refrigerant. Older activity data contributing to CRF 2.G.4 are under review and legacy data sources are being investigated in order to re-allocate activity data to the correct categories.	UNFCCC ERT recommendation	Data analysis underway
	Ammonia Production (CRF 2.B.1)	Integrate data on carbon capture and storage in emission estimates.	Data collected as part of the national GHGRP indicate that there are ammonia facilities involved in carbon capture and storage activities. Review of this reported data is underway. Additionally, there are plans to obtain additional confirmation with facilities to ensure consistency in the carbon capture and storage data reported.	Continuous improvement	Data analysis underway
Agriculture	Enteric Fermentation/ Manure Management (CRF 3.A/3.B)/ Agricultural Soils (CRF 3.D)	Integrate new information on animal nutrition.	Continued improvements to animal nutrition time series are being carried out based on the review and compilation of multiple data sources. Although priority is on the beef sector, minor refinements to the dairy and swine sectors will be carried out as required. Data have been collected and analyzed, but model development is not complete. Approval and alignment with AAFC methodologies, specifically methodologies used in the estimation of ammonia volatilization, are required, to be followed by database implementation.	Continuous improvement	Developing new parameters
	Enteric Fermentation/ Manure Management (CRF 3.A/3.B)/ Agricultural Soils (CRF 3.D)	Update dairy nutrition parameters.	A dairy nutrition time series is currently used to track changes in animal feed and characteristics for dairy cattle. Updates to the nutrition data for dairy cattle are being derived for years after 2010. Data have been acquired and are undergoing analysis. Approval and alignment with AAFC methodologies will be followed by database implementation.	Continuous improvement	Data analysis underway
	Manure Management (CRF 3.B)	Integrate new information on manure management systems.	Integrate information from multiple surveys to attempt to develop a consistent representation of the changes in manure storage systems for beef over the reporting period, better capture changes in farm practices and improve the accuracy of emission estimates. Data have been collected and analyzed, but require approval and alignment with AAFC methodologies, specifically methodologies used in the estimation of ammonia volatilization, followed by database implementation.	Continuous improvement	Developing new parameters
	Manure Management (CRF 3.B)	Revise methane conversion factors (MCFs).	Methane conversion factors (MCFs) obtained from the 2006 IPCC Guidelines are currently used in the calculation of manure management methane emissions. For certain manure management systems, the default MCF is selected based on a relationship with the average annual temperature of the manure systems. An updated methodology has been provided in the 2019 Refinement to the 2006 Guidelines that uses monthly temperatures and retention time as predictors of methane loss, rather than an averaged annual temperature. Canada plans to implement the 2019 refinement approach as both a continuous improvement and to address an ERT recommendation to regarding the current averaged MCFs used.	UNFCCC ERT recommendation	Data collection underway

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Agriculture (cont'd)	Agricultural Soils (CRF 3.D)	Integrate estimates of N_2O emissions from land application of compost.	Canada currently does not report N_2O emissions from the application of compost to agricultural soils because of a lack of activity data. A contract was carried out to collect information on land application of compost in Canada, and the resulting data is under analysis, for future alignment and integration with the existing organic nitrogen fertilizer methodology.	UNFCCC ERT recommendation	Data analysis underway
	Agricultural Soils (CRF 3.D)	Revision of methodologies for estimating soil nitrous oxide emissions from cultivation of histosols.	Revise estimates for Cropland on drainage of organic soils considering guidance from the IPCC Wetlands Supplement.	Continuous improvement	Data analysis underway
	Field Burning of Agricultural Residues (CRF 3.F)	Improve estimates of crop residue burning.	Data on crop residue burning are available from the Farm Environmental Management Survey (2011), but these data have not been updated for estimating emissions of GHGs. Survey data on field burning of agricultural residues will be extracted and incorporated into the database.	Continuous improvement	Data analysis underway
LULUCF	Cross-cutting	Address completeness of LULUCF subcategories with estimates reported as not estimated (NE).	Improve the completeness of reporting of pools in mandatory categories currently reported as NE.	UNFCCC ERT recommendation	Data collection underway
	Cross-cutting	Development of a plan and time frame for estimating and reporting uncertainties for all LULUCF subcategories.	Canada provides detailed uncertainty analysis for most LULUCF subcategories. However, uncertainty analysis for all subcategories has not been undertaken due to resource limitations. Uncertainty estimates for new and updated categories have been included in recent submissions. Canada aims to develop a plan for estimating, updating and reporting uncertainties for all LULUCF subcategories.	UNFCCC ERT recommendation	Alternative methods being considered
	General: Land Transition Matrix (CRF 4.1)	Revise and improve the consistency and completeness of the land transition matrix.	Include in the next NIR any update on the status of implementation of the project to revise and improve the consistency and completeness of the land transition matrix.	UNFCCC ERT recommendation	Data analysis underway
	Forest Conversion (it may impact Forest Land Converted to Cropland, Wetlands, Settlements land categories and Harvested Wood Products, i.e. CRF 4.B.2, 4.D.2, 4.E.2 and 4.G respectively)	Land-use change improvements – Update and improve forest conversion activity data, parameters and processes.	In the medium-term, improvements to: i) 1970 to 201X deforestation activity data used by $CBM\text{-}CFS_3$ and others, and ii) Updates to deforestation pre-type proportion assumptions.	Continuous improvement	Developing new parameters
	Forest Land (CRF 4.A)	Updates to baseline data/processes/ parameters as input into the Carbon Budget Model.	Updates in the short-term include: i) Improved identification of the stand initiating disturbance in stands that were disturbed prior to 1990 disturbances; ii) Refinements to forest management activity data time series; and in the medium-term include: iii) Improvements to the spatial distribution of harvest; iv) Refinements to wildfire emissions estimates, incorporating variable fire intensity; v) Refinements to regional estimates of slashburning activity; vi) Updates to volume-to-biomass coefficients for the province of Ontario; vii) Further updates to insect disturbance activity data in certain provinces; and viii) Improvements to nationwide estimates of controlled biomass burning.	Continuous improvement	Data analysis underway
	Forest Land (CRF 4.A)	Science improvements.	Improve the representation of partial harvesting in CBM through explicit modelling of uneven-aged stands using the LANDIS-II / For CS simulation platform.	Continuous improvement	Data analysis
	Forest Land (CRF 4.A)	Validation analysis.	Independent EO-based validation dataset of forest carbon stocks for NIR in hardwood forests of Eastern Canada.	Continuous improvement	Data analysis underway
	Forest Land (CRF 4.A) Cropland (CRF 4.B) Grassland (CRF 4.C) Biomass burning (CRF 4(V))	Biomass burning improvements.	Refine estimates of C loss associated with controlled biomass burning activities that occur on managed lands. Integrate estimates into NIR, APEI and Black Carbon Inventories.	Continuous improvement	No significant progress made

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
LULUCF (cont'd)	Cropland (CRF 4.B.1)	Woody Biomass improvements.	Improve the woody biomass time series transition between the two 1990–2000 and 2000–2010 activity data sampling periods of digital air photos by applying an extrapolation method.	Continuous improvement	Data analysis underway
	Wetlands Converted to Cropland (CRF 4.B.2)	Address completeness of LULUCF subcategories with estimates reported as NE.	Improve the completeness of reporting of pools in mandatory categories currently reported as NE. Carbon loss resulting from agricultural drainage of inland mineral wetland in the Prairie Potholes Region.	UNFCCC ERT recommendation	Data collection underway
	Flooded Land Remaining Flooded Land (CRF 4.D.1.1)	Improvements to peat extraction activity data.	Improvements to activity data from a new data agreement with Statistics Canada and addition of a new sampling point for 2020 to estimate extent of peatland areas disturbed by peat extraction with high-resolution satellite imagery.	Continuous improvement	Data collection underway
	Flooded Land Remaining Flooded Land (CRF 4.D.1.2) Land Converted to Flooded Land (CRF 4.D.2.2)	Development of activity data, parameters and EFs for methane in flooded lands.	Improved knowledge of methane emissions in flooded lands with updated activity data and EFs.	Continuous improvement	Data collection underway
	Settlements Remaining Settlements (CRF 4.E.1.1)	Development of a new time series data point for 2005 and 2015–2020 for urban trees.	Update sampling point is planned for 2005 and 2015 activity data that involves sampling of digital air photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas.	Continuous improvement	Data collection underway
	Land Converted to Settlements (CRF 4.E.2)	Address completeness of LULUCF subcategories with estimates reported as "NE."	Improve the completeness of reporting of pools in mandatory categories currently reported as "NE". Carbon loss resulting from the conversion of forest land and wetlands to settlements in the oil sands region and the North.	UNFCCC ERT recommendation	Data collection underway
	Cropland Converted to Settlements (CRF 4.E.2.2)	Address completeness of LULUCF subcategories with estimates reported as "NE."	Improve the completeness of reporting of pools in mandatory categories currently reported as "NE".	UNFCCC ERT recommendation	Data analysis underway
	Harvested Wood Products (CRF 4.G)	Improve uncertainty estimates, development of country-specific half-lives and expansion of temporal coverage.	Improvements are planned to enhance the uncertainty analysis of HWP estimates by considering the uncertainty inherent to the C inputs.	Continuous improvement	Developing new parameters
	Harvested Wood Products (CRF 4.G)	Development of country-specific half-lives.	Research is ongoing to 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.	Continuous improvement	No significant progress made
	Harvested Wood Products (CRF 4.G)	Develop and implement HWP production and trade parameters for each province.	Research is ongoing to improve the regional differentiation of HWP production and trade, so that provincial/territorial summaries more accurately reflect regional conditions.	Continuous improvement	No significant progress made
	Harvested Wood Products (CRF 4.G)	Improve EFs for residential firewood.	Research is ongoing to improve the accuracy of residential biomass burning EFs.	Continuous improvement	No significant progress made
	Harvested Wood Products (CRF 4.G)	Improve knowledge and characterization of industrial fuelwood.	Improve knowledge of industrial bioenergy chain (where the wood is coming from) and develop a better characterization of wood feedstock serving as wood fuel for the industry sector.	Continuous improvement	No significant progress made
Waste	Solid Waste Disposal (CRF 5.A.2)	Review model parameters specific to industrial wood waste.	The project will review and update the model to be more specific to industrial wood waste landfilling, in particular for the pulp and paper sector.	Continuous improvement	Initiated data collection / study
	Multiple waste and wastewater sectors	Further integration of waste sectors with energy and agriculture sectors.	A project to properly account for waste materials (e.g., sludge, compost or digestate) used in agriculture or other land applications as well as a review of biogas production and use from waste facilities such as landfills, wastewater treatment plants and other waste-related anaerobic digesters.	Continuous improvement	Initiated data collection / study
	Wastewater Treatment and Discharge (CRF 5.D)	Update to industrial on-site wastewater treatment.	Building on this year's update, continuation of reviewing of key industrial sectors for continued refinement of emissions, including determination of key parameters (e.g., BOD/COD, methane recovery, etc.)	Continuous improvement	Initiated data collection / study

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