NATIONAL INVENTORY REPORT 1990–2018: GREENHOUSE GAS SOURCES AND SINKS IN CANADA

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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 2020 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 Guidelines for National GHG Inventories by the Intergovernmental Panel on Climate Change (IPCC). 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 2019. Ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce their uncertainties as far as practicable.

April 2020

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Executive Summary

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Overall coordination of Canada's National Inventory Report was led by Lindsay Pratt, with support from Ashton Cunje, Alessia Czerwinski and Raphaëlle Pelland St-Pierre. Centralized data compilation and the generation of comprehensive emission tables was led by Catherine Robert with support from Pegah Baratzadeh. Compilation of uncertainty estimates as well as key category analyses were led by Catherine Robert. Compilation and layout of the National Inventory Report for publication were led by Marida Waters. 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 Common Reporting Format (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 Pomme Arros.

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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

ECCC..... Environment and Climate Change Canada

EF ..... emission factor

GDP ..... gross domestic product

GHG..... greenhouse gas

GHGRP ..... Greenhouse Gas Reporting Program

HFC..... hydrofluorocarbon

HWP..... harvested wood products

IPCC ..... Intergovernmental Panel on Climate Change

IPPU ..... Industrial Proccesses and Product Use

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

MSW ..... municipal solid waste

N/A..... not available

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

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

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

Chemical Formulas

Al ..... aluminium

$Al2O_3$..... alumina

CaC_2 ..... calcium carbide

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

$CaMg(CO_3)_2$ ..... dolomite (also $CaCO_3 \cdot MgCO_3$)

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

$CHCl_3$ ..... chloroform

CO ..... carbon monoxide

CO_2 ..... carbon dioxide

CO_2 eq ..... carbon dioxide equivalent

H_2 ..... hydrogen

H_2O ..... water

H_2S ..... hydrogen sulphide

HCFC ..... hydrochlorofluorocarbon

HCl ..... hydrochloric acid

HF ..... hydrogen fluoride

HNO_3 ..... nitric acid

K_2CO_3 ..... potassium carbonate

Mg ..... magnesium

$MgCO_3$ ..... magnesite; magnesium carbonate

MgO ..... magnesia; dolomitic lime

N ..... nitrogen

N_2 ..... nitrogen gas

Na_2CO_3 ..... sodium carbonate; soda ash

$Na3AlF_6$ ..... cryolite

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 ..... megahectare

mm ..... millimetre

Mt ..... megatonne

MW ..... megawatt

PJ ..... petajoule

t ..... tonne

TWh ..... terrawatt-hour

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ES

EXECUTIVE SUMMARY

ES.1. Key Points

- After hovering between 700 and 720 megatonnes of carbon dioxide equivalent (Mt CO_2 eq) in recent years, in 2018 (the most recent annual dataset in this report) Canada's greenhouse gas (GHG) emissions increased to 729 Mt CO_2 eq. This increase is attributed to higher fuel consumption for transportation, winter heating and oil and gas extraction.
- Over the long term, Canada's economy has grown more rapidly than its GHG emissions: the emissions intensity for the entire economy (GHG per Gross Domestic Product [GDP]) has declined by 36% since 1990 and 20% since 2005.
- Emission trends since 2005 remain consistent, with emission increases in the Oil and Gas and Transportation sectors being offset by decreases in other sectors, notably Electricity and Heavy Industry.
- The Pan-Canadian Framework on Clean Growth and Climate Change (adopted in 2016) puts Canada on the path towards meeting our Paris Agreement GHG emissions reduction target of 30% below 2005 levels by 2030. The Framework is a comprehensive plan to reduce emissions across all sectors of Canada's economy, stimulate clean economic growth and build resilience to the impacts of climate change. Canada is committed to continue implementing the Framework, while working to exceed its 2030 emissions reduction goal, and developing a plan to achieve net-zero emissions by 2050.

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.

To achieve its objective and implement its provisions, the UNFCCC lays 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.[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 National Inventory Report (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), hydrofluorocarbons (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 the preparation of National GHG 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.

In May 2015, Canada indicated its intent to reduce GHG emissions by 30% below 2005 levels by 2030. Canada later confirmed this target in its Nationally Determined Contribution (NDC) to the Paris Agreement. 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.

1 Under the United Nations Environment Programme (UNEP), the Montreal Protocol on Substances that Deplete the Ozone Layer is an international agreement designed to reduce the global consumption and production of ozone-depleting substances.

The Pan-Canadian Framework on Clean Growth and Climate Change

The Pan-Canadian Framework on Clean Growth and Climate Change (PCF) was adopted on December 9, 2016 as Canada's plan to take ambitious action to fight climate change, build resilience to a changing climate, and drive clean economic growth. It is the first climate change plan in Canada's history to include joint and individual commitments by federal, provincial and territorial levels of government, and to have been developed with input from Indigenous Peoples, businesses, non-governmental organizations, and Canadians from across the country. The PCF is built on four pillars: pricing carbon pollution, complementary actions to reduce emissions across the economy, adaptation and climate resilience, and clean technology, innovation, and jobs. It includes more than fifty concrete actions that cover all sectors of the Canadian economy.

Canada's most recent GHG emissions projections[2] estimate that Canada's GHG emissions in 2030 will be 227 million tonnes lower than projected prior to the PCF or 19% below 2005 levels. This improvement, equivalent to approximately a third of Canada's emissions in 2005, is widespread across all economic sectors, reflecting the breadth and the depth of the PCF.

Canada now has a price on carbon pollution across the country. In 2018, the Greenhouse Gas Pollution Pricing Act was passed. Carbon pollution pricing systems are now in place in all provinces and territories across Canada (either provincial/territorial systems or the federal system). Between 2015 and 2019, the Government of Canada invested $60 billion to drive down greenhouse gas emissions, generate clean technologies, help Canadians and communities adapt to a changing climate, and protect the environment.

Other key measures in the PCF include:

- Regulating methane emissions in the oil and gas sector, which will reduce carbon pollution by about 16.5 million tonnes in 2030;
- Accelerating the phase-out of coal-fired electricity generation by 2030, as part of our efforts to have 90 percent of electricity from non-emitting sources, and supporting workers and communities in the transition to a low-carbon economy;
- Investing in zero-emission vehicle purchase incentives to make it easier for Canadians to reduce their transportation emissions;
- Developing net-zero energy ready building codes to ensure new homes are ready for a low-carbon future;
- Adopting a Climate Lens to ensure that future climate impacts are considered and addressed in all federally funded infrastructure projects; and
- Establishing a new Canadian Centre for Climate Services, giving Canadians better access to climate science and information.

Canada is committed to exceeding its 2030 emissions reduction target, putting Canada on a path to a prosperous net-zero emissions future. This involves continued implementation of the PCF, while strengthening existing measures and introducing new GHG reducing measures. Canada also committed to develop a plan to achieve a net-zero emissions economy by 2050. This includes setting legally-binding, five-year emissions-reduction milestones based on advice of experts and consultations with Canadians. These ambitious goals will be supported by a continued commitment to ensuring a price on carbon pollution is in place everywhere in Canada, as well as prioritization of measures including green buildings and communities, support for zero-emission vehicles, clean electricity, clean technology, and nature-based climate solutions including a commitment to planting 2 billion trees in the coming years.

Canada's National Inventory Report, along with other reports such as Canada's National Communications and Biennial Reports, and the Greenhouse Gas and Air pollutant Emissions Projections (also submitted to the UNFCCC) and the annual synthesis reports on the status of implementation of the PCF, allows Canada to assess its progress in reducing emissions and combatting climate change.

2 BR4 https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/fourth-biennial-report-climate-change.html

Section ES.3 of this Executive Summary summarizes the latest information on Canada's net anthropogenic (i.e. human-induced) GHG emissions over the 2005–2018 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 by the following economic sectors: Oil and Gas, Electricity, Transportation, Heavy Industry, Buildings, Agriculture and Waste & Others. 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.

ES.3. Overview, National GHG Emissions

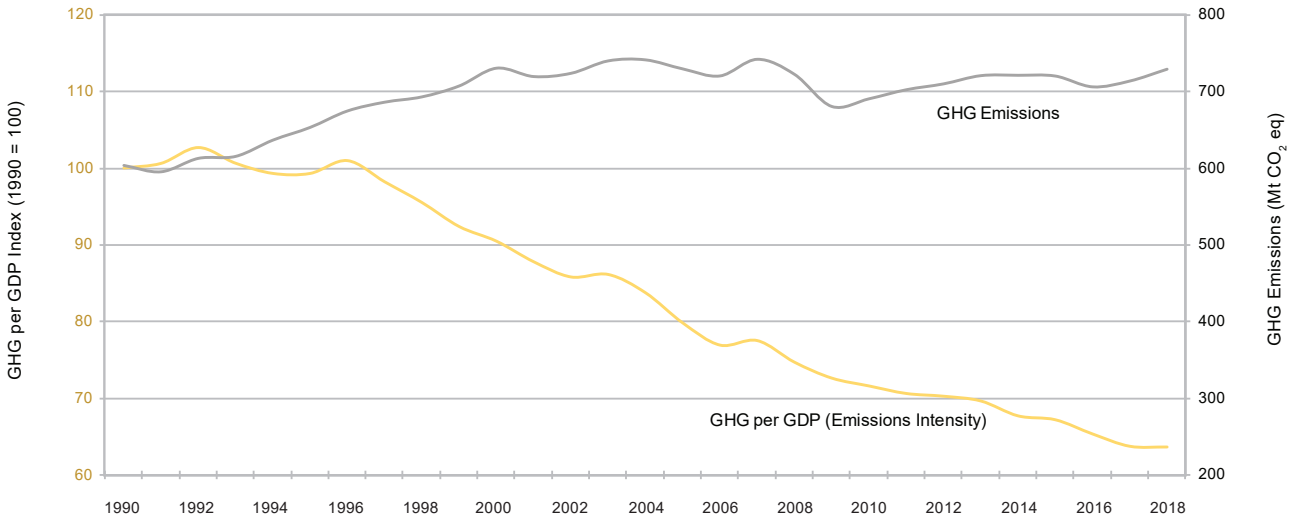
After hovering for several years between 700 and 720 megatonnes of carbon dioxide equivalent (Mt CO_2 eq)[3], in 2018 (the most recent annual dataset in this report) Canada's greenhouse gas (GHG) emissions increased to 729 Mt CO_2 eq (Figure ES–1).[4]

The 15 Mt increase in 2018 is due to the combined effect of multiple factors, including: an increase in fuel consumption by vehicles on and off-road (+7.8 Mt between 2017 and 2018); colder winter weather, which influences emissions related to heating (+5.1 Mt between 2017 and 2018); increased production of oil and gas in 2018 (+4.1 Mt between 2017 and 2018); variations in production levels and a rise in the use of fossil fuels in industrial sectors (+2.0 Mt between 2017 and 2018); and an increase in import and stocks of HFCs (+1 Mt between 2017 and 2018). These emission increases were partially offset by a reduction of coal in the mix of fuels combusted to produce electricity and heat (-6 Mt between 2017 and 2018).

3 Unless explicitly stated otherwise, all emission 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 percentages) have been performed using unrounded data.

Figure ES–1 **Canadian GHG Emissions and Indexed Trend Emission Intensity (excluding LULUCF)**



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 a

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 has grown more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (GHG per GDP) has declined by 36% since 1990 and 20% 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.

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

In 2018, the Energy sector (consisting of Stationary Combustion, Transport and Fugitive Sources) emitted 596 Mt of greenhouse gases, or 82% of Canada's total GHG emissions (Figure ES–2). The remaining emissions were largely generated by the Agriculture and IPPU sectors (approximately 8% each), with minor contributions from the Waste sector (2%). In 2018, the LULUCF sector removed 13 Mt of CO_2 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 80% of total emissions in 2018 (Figure ES–3). The majority of the CO_2 emissions in Canada result from the combustion of fossil fuels. CH_4 emissions in 2018 amounted to 91 Mt or 13% 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 transport, and accounted for 38 Mt or 5.2% of Canada's emissions in 2018. Emissions of synthetic gases (HFCs, PFCs, SF_6 and NF_3) constituted slightly less than 2% of national emissions.

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

Year	2005	2013	2014	2015	2016	2017	2018
Total GHG (Mt)	**730**	**721**	**721**	**720**	**706**	**714**	**729**
Change since 2005 (%)	NA	-1.2%	-1.2%	-1.3%	-3.2%	-2.2%	-0.1%
GDP (Billion 2012$)	**1 654**	**1 871**	**1 926**	**1 938**	**1 953**	**2 024**	**2 071**
Change since 2005 (%)	NA	13%	16%	17%	18%	22%	25%
GHG Intensity (Mt/$B GDP)	**0.44**	**0.39**	**0.37**	**0.37**	**0.36**	**0.35**	**0.35**
Change since 2005 (%)	NA	-13%	-15%	-16%	-18%	-20%	-20%

Notes:
GDP data source: StatCan a
NA not applicable

Figure ES–2 **Breakdown of Canada's Emissions by IPCC Sector (2018)**

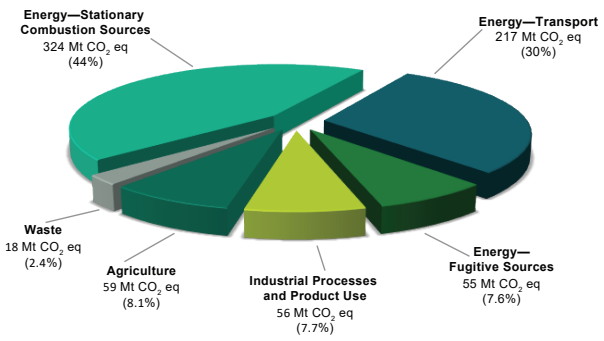
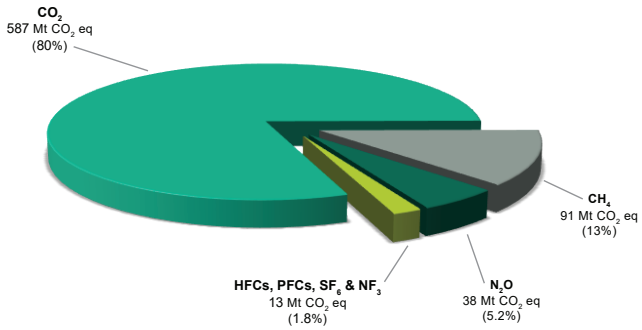


Figure ES–3 **Breakdown of Canada's Emissions by GHG (2018)**



Total: 729 Mt CO_2 eq

*Note: Totals may not add up to due to rounding.

Canada represented approximately 1.6% of global GHG emissions in 2016 (CAIT 2017), although it is one of the highest per capita emitters. Canada's per capita emissions have dropped since 2005, when this indicator was 22.6 t CO_2 eq/capita, reaching new lows between 19.5–19.7 t CO_2 eq/capita since 2016 (Figure ES–4).

ES.4. Emissions and Trends by IPCC Sectors

Trends in Emissions

Over the 2005–2018 period, total emissions decreased by 0.4 Mt or 0.1% (Figure ES–5). Two sources of the Energy sector dominated this trend, with emission decreases of 18 Mt (5%) in Stationary Combustion Sources and 5.4 Mt (9%) in Fugitive Sources (Table ES–2). Over the same period, emissions also decreased by 0.2 Mt (0.4%) in the IPPU sector and 2.2 Mt (11%) in the Waste sector. However, emissions from Transport (also in the Energy sector) increased by 26 Mt (14%) partially offsetting the decreases from the other categories (Figure ES–6).

Since 2009, when emissions were at their lowest in the latest decade, emission increases are driven by growth in Oil and Gas Extraction (34 Mt); in the number of light-duty gasoline trucks (12 Mt) and heavy-duty diesel vehicles in operation (12 Mt); in the production and consumption of halocarbons, SF_6 and NF_3 (5.6 Mt); and in the application of inorganic nitrogen fertilizers (3.6 Mt). During the same period, there was a 30 Mt decrease in emissions from electricity generation, which partly offset the growth in emissions.

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

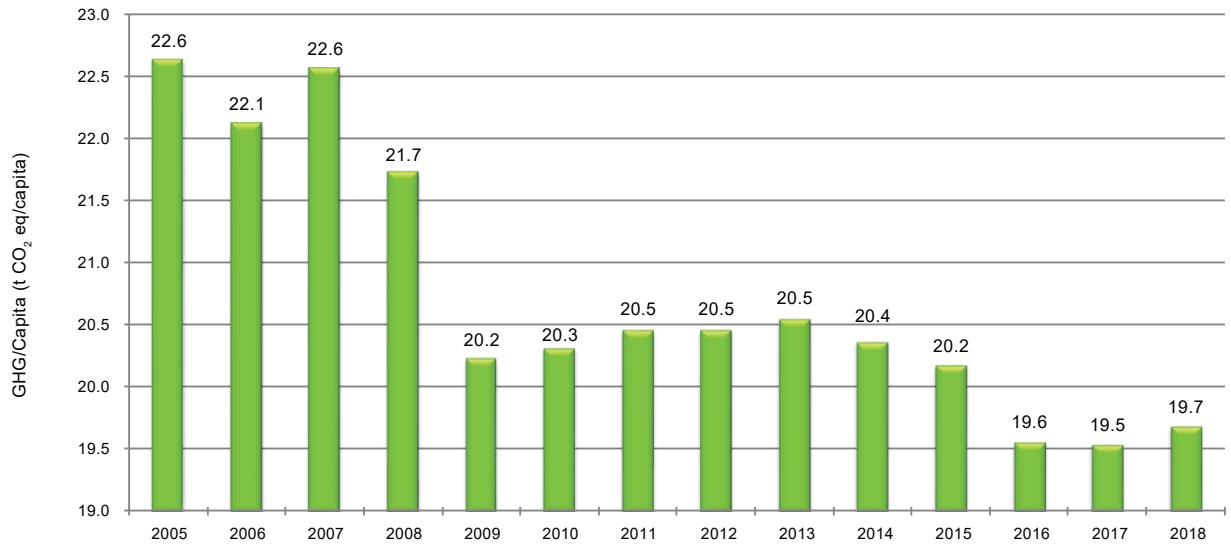
The following describes the emissions and trends of each IPCC sector since 2005 in further detail.

Energy—2018 GHG Emissions (596 Mt)

In 2018, GHG emissions from the IPCC Energy sector (596 Mt) were 0.4% higher than in 2005 (593 Mt). Within the Energy sector, a 43 Mt increase in combustion emissions from Oil and Gas Extraction and a 24 Mt growth in Road Transport emissions were largely offset by a 55 Mt decrease in emissions from Public Electricity and Heat Production and a 4 Mt drop in emissions from Manufacturing.

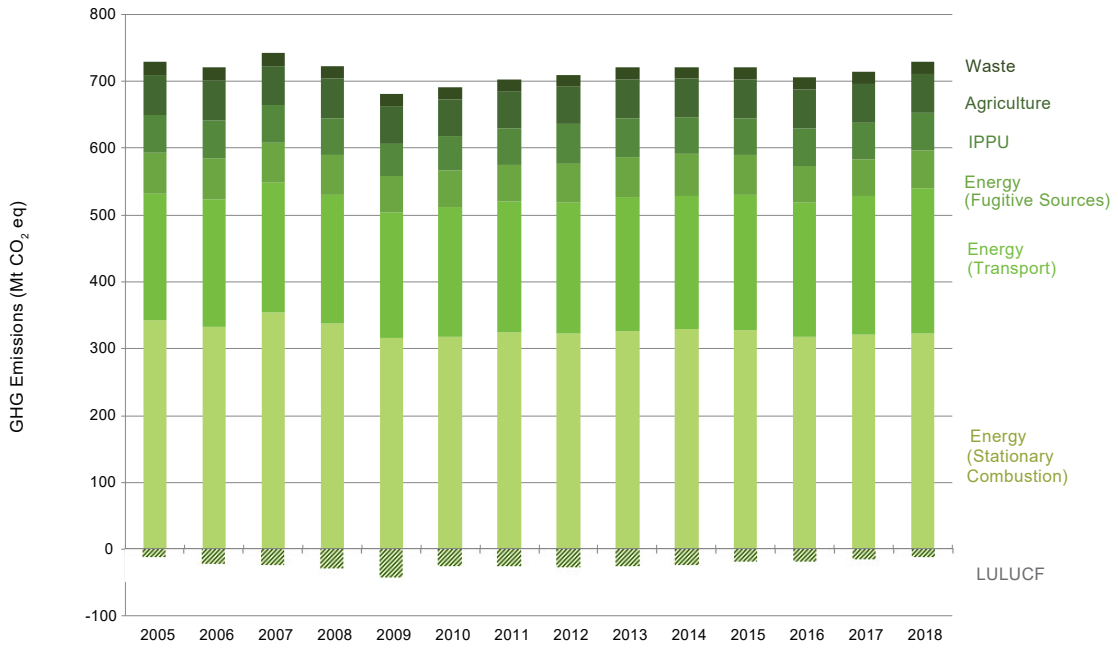
5 The complete NIR can be accessed here: http://www.publications.gc.ca/site/eng/9.506002/publication.html

Figure ES–4 **Canadian per Capita GHG Emissions (2005–2018)**



Note: Population data source: StatCan b

Figure ES–5 **Trends in Canadian GHG Emissions by IPCC Sector (2005–2018)**



Stationary Combustion (324 Mt)

Decreasing electricity generation from coal and oil (50% and 73% decrease, respectively) was a large driver of the 55 Mt decrease in emissions associated with Electricity and Heat Production between 2005 and 2018. The permanent closure of all coal generating stations in Ontario by 2014 contributed 50% of the decreased coal consumption,[6] and reduced coal consumption in Alberta contributed an additional 43%. Reduced coal consumption also occurred in Nova Scotia (15%), New Brunswick (24%), Manitoba (98%) and Saskatchewan (10%). Decreased oil consumption for electricity generation in New Brunswick (89%) and Nova Scotia (88%), offset by increased consumption in Newfoundland and Labrador (40%) accounts for 99% of the reduced oil consumption. Minor emission fluctuations over the period reflect variations in the mix of electricity generation sources.[7]

The 43 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.

GHG emissions from Manufacturing Industries decreased by 4.0 Mt between 2005 and 2018, consistent with both a 12% decrease in energy use and an observed decline in output[8] in these industries.

Transport (217 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 transport emissions is largely due to more driving, exemplified by increases in the supply of diesel, in gasoline retail pump sales as well as in the number of vehicles on and off-road. Despite a reduction in kilometres driven per vehicle, the total vehicle fleet has increased by 40% since 2005, most notably for trucks (both light- and heavy-duty), leading to more kilometres driven overall.

6 Ontario Power Generation News, April 15, 2014; http://www.opg.com/news-and-media/news-releases/Pages/news-releases.aspx?year=2014, accessed 2018 January).

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

8 See, for example, Table 25-10-0025-01 Manufacturing industries, total annual energy fuel consumption in gigajoules, 31-33; https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510002501 (accessed 2019 December 16).

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

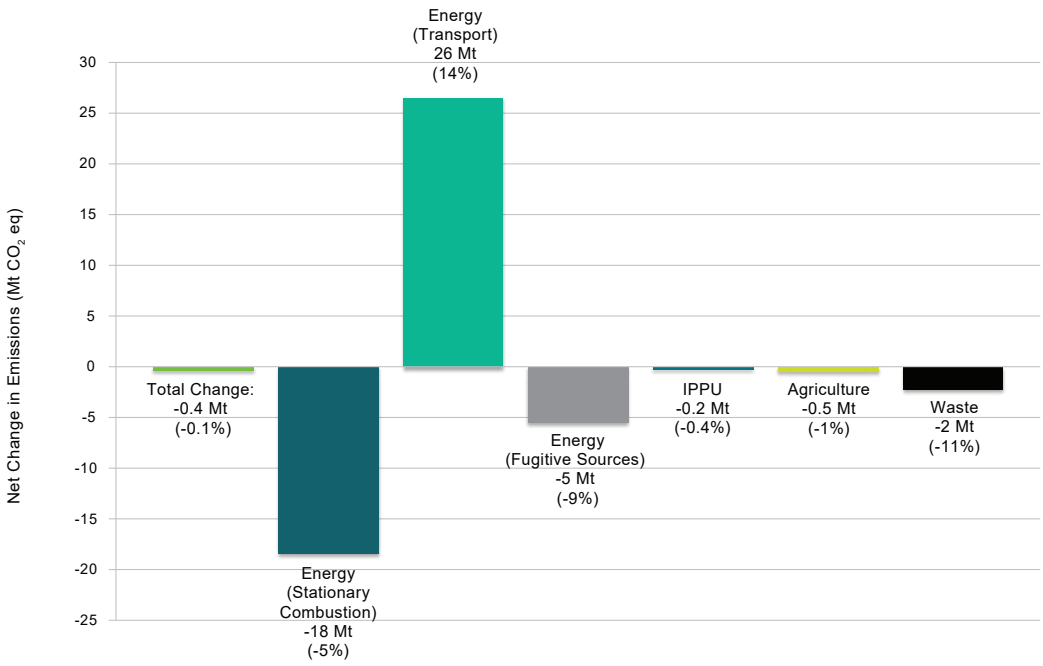
Greenhouse Gas Categories		2005	2013	2014	2015	2016	2017	2018
		Mt CO_2 Equivalent						
TOTAL[a, b]		**730**	**721**	**721**	**720**	**706**	**714**	**729**
ENERGY		**593**	**587**	**591**	**590**	**574**	**584**	**596**
a.	Stationary Combustion Sources	342	326	329	328	318	321	324
	Public Electricity and Heat Production	125	88	84	87	81	78	70
	Petroleum Refining Industries	20	18	18	18	18	16	16
	Oil and Gas Extraction	63	91	96	97	99	102	106
	Mining	4.3	5.4	5.1	4.6	4.3	4.7	4.9
	Manufacturing Industries	48	45	45	44	42	42	44
	Construction	1.5	1.3	1.3	1.3	1.3	1.3	1.4
	Commercial and Institutional	33	30	31	30	30	32	33
	Residential	46	44	46	43	39	41	45
	Agriculture and Forestry	2.2	3.8	3.8	3.6	3.8	3.7	3.8
b.	Transport	191	201	199	201	201	207	217
	Domestic Aviation	7.6	7.6	7.2	7.1	7.1	7.4	8.0
	Road Transportation	130	144	142	143	145	148	154
	Railways	6.6	7.3	7.5	7.1	6.5	7.5	7.6
	Domestic Navigation	4.8	4.3	4.1	3.9	3.9	4.0	4.0
	Other Transportation	42	38	39	40	39	40	44
c.	Fugitive Sources	61	61	63	60	55	55	55
	Coal Mining	1.4	1.5	1.3	1.1	1.3	1.2	1.3
	Oil and Natural Gas	60	59	62	59	54	54	54
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**	**55**	**54**	**55**	**54**	**56**
a.	Mineral Products	10	7.8	7.8	8.1	7.9	8.5	8.9
b.	Chemical Industry	10	7.3	7.2	7.6	7.7	6.9	7.7
c.	Metal Production	20	15	15	14	15	15	15
d.	Production and Consumption of Halocarbons, SF_6 and NF_3	5.1	10	11	11	11	12	13
e.	Non-Energy Products from Fuels and Solvent Use	10	16	13	13	12	11	12
f.	Other Product Manufacture and Use	0.54	0.56	0.48	0.57	0.63	0.66	0.74
AGRICULTURE		**60**	**59**	**58**	**58**	**59**	**58**	**59**
a.	Enteric Fermentation	31	25	24	24	24	24	24
b.	Manure Management	8.8	7.8	7.7	7.8	7.9	7.9	7.9
c.	Agricultural Soils	19	24	23	24	25	24	25
d.	Field Burning of Agricultural Residues	<0.05	0.05	0.05	0.06	0.05	0.05	0.05
e.	Liming, Urea Application and Other Carbon-containing Fertilizers	1.4	2.7	2.5	2.6	2.5	2.5	2.6
WASTE		**20**	**17**	**17**	**18**	**18**	**18**	**18**
a.	Solid Waste Disposal	14	12	12	12	12	12	12
b.	Biological Treatment of Solid Waste	0.29	0.44	0.46	0.45	0.45	0.45	0.45
c.	Wastewater Treatment and Discharge	1.0	1.1	1.2	1.2	1.1	1.1	1.1
d.	Incineration and Open Burning of Waste	0.58	0.32	0.36	0.40	0.39	0.39	0.39
e.	Industrial Wood Waste Landfills	4.3	3.8	3.7	3.6	3.5	3.5	3.4
LAND USE, LAND-USE CHANGE AND FORESTRY		**- 13**	**- 25**	**- 25**	**- 18**	**- 19**	**- 16**	**- 13**
a.	Forest Land	- 145	- 150	- 150	- 143	- 144	- 143	- 140
b.	Cropland	- 11	- 10	- 9.5	- 8.6	- 7.7	- 6.8	- 6.2
c.	Grassland	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
d.	Wetlands	3.1	3.1	3.1	2.9	2.9	3.0	2.6
e.	Settlements	2.1	2.3	2.3	2.2	2.1	1.9	1.8
f.	Harvested Wood Products	139	130	129	128	128	129	129

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 ES–6 **Changes in Emissions by IPCC Sector (2005–2018)**



Fugitive Sources (55 Mt)

Since 2005, fugitive GHG emissions from fossil fuel production (coal, oil and natural gas) have decreased by 5.4 Mt, largely the result of provincial regulations to increase conservation of natural gas which is mainly comprised of methane (CH_4).

Industrial Processes and Product Use—2018 GHG Emissions (56 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 56 Mt (7.7%) to Canada's 2018 emissions.

Between 2005 and 2018, process emissions from most IPPU categories decreased. A notable exception is the 7.4 Mt (146%) increase in emissions from the use of HFCs.

The aluminium industry has decreased its process emissions by 3.2 Mt (-37%) since 2005, largely due to implementation of technological improvements to mitigate PFC emissions and shutting down of older smelters using Søderberg technology. For example, the last Søderberg smelter was closed in 2015. Closure of primary magnesium plants in 2007 and 2008 also contributed to 1.0 Mt of the overall process emission drop (-5.3 Mt or -26%) seen in Metal Production between 2005 and 2018.

The overall decrease in GHG emissions from chemical industries since 2005 is primarily the result of the closure in 2009 of the sole Canadian adipic acid plant located in Ontario. 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 the noted increase in ethylene production in 2016.

Agriculture—2018 GHG Emissions (59 Mt)

The Agriculture sector covers non-energy GHG emissions relating to the production of crops and livestock. Emissions from Agriculture accounted for 59 Mt, or 8.1% of total GHG emissions for Canada in 2018.

In 2018, Agriculture accounted for 31% of national CH_4 emissions and 76% 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 72%, while major livestock populations peaked in 2005, then decreased sharply until 2011. In 2018, emissions from livestock digestion (enteric fermentation) accounted for 41% of total agricultural emissions, and the application of inorganic nitrogen fertilizers accounted for 23% of total agricultural emissions.

Waste—2018 GHG Emissions (18 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from Waste contributed 18 Mt (2.4%) to Canada's total emissions in 2018 and 20 Mt (2.7%) in 2005.

The primary sources of emissions in the Waste sector are municipal solid waste (MSW) disposal in landfills (12 Mt in 2018) and Industrial Wood Waste Landfills (3.4 Mt in 2018). In 2018, 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 contributed the remaining 11%.

CH_4 emissions from MSW landfills make up 63% of emissions from SWD; these emissions decreased by 11% between 2005 and 2018. Of the 26 Mt CO_2 eq of CH_4 generated by MSW landfills in 2018, only 12 Mt CO_2 eq (48%) were actually emitted to the atmosphere. A significant portion (46% or 11 Mt CO_2 eq) of the generated CH_4 was captured by landfill gas collection facilities and flared or used for energy—compared with 36% in 2005.

Land Use, Land-Use Change and Forestry—2018 (Net GHG Removals of 13 Mt)

The Land Use, Land-Use Change and Forestry (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 2018, this net flux amounted to net removals of 13 Mt.

Net removals from the LULUCF sector have fluctuated over recent years, increasing from 13 Mt in 2005 to 42 Mt in 2009 and have since again decreased to 13 Mt in 2018. Fluctuations are driven mainly by variations in emissions from HWP and removals from Forest Land that are closely tied to harvest rates.

The Forest Land estimates are split between emissions and removals resulting from significant natural disturbances on managed forests (wildfires and insects), and anthropogenic emissions and removals associated with forest management activities. Net anthropogenic removals in Forest Land have fluctuated between 150 Mt and 140 Mt over the period between 2005 and 2018, as forests recover from peak harvest rates and low-level insect disturbances occurring in the early 2000s. Over this same period, emissions from HWP originating from domestic harvest declined from 140 Mt in 2005 to 130 Mt in 2018. Approximately 30% of HWP emissions result from long-lived wood products reaching the end of their economic life decades after the wood was harvested. Hence emission and removal patterns in both HWP and Forest Land are influenced by recent forest management trends and by the long-term impact of forest management that occurred in past decades.

After peaking in the years 2006-2011, current net removals from Cropland are 6.2 Mt, 5 Mt lower than in 2005, mainly as a result of increased conversion of perennial to annual crops on the Prairies and the declining effect of the adoption of conservation tillage on cropland.

The conversion of forests[9] to other land uses is a prevalent, yet declining, practice in Canada and is mainly due to forest conversion for resource extraction and cropland expansion. Emissions due to forest conversion fell from 16 Mt in 2005 to 14 Mt in 2018.

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 the emissions 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 recategorizes emissions under different headings and does not change the overall magnitude of Canadian emissions estimates.

GHG emissions trends in Canada's economic sectors are consistent with those described for IPCC sectors, with the Oil and Gas and Transportation economic

9 Forest conversion emissions are incorporated within sums of emissions of other land-use categories; therefore, the values of 14 and 16 Mt reported here are included in the sums associated with the other land-use category totals.

sectors showing emission increases of 22% and 16% respectively since 2005 (Figure ES–7 and Table ES–3). These increases have been more than offset by emission decreases in Electricity (46%), Heavy Industry (10%) and Waste & Others (9.3%).

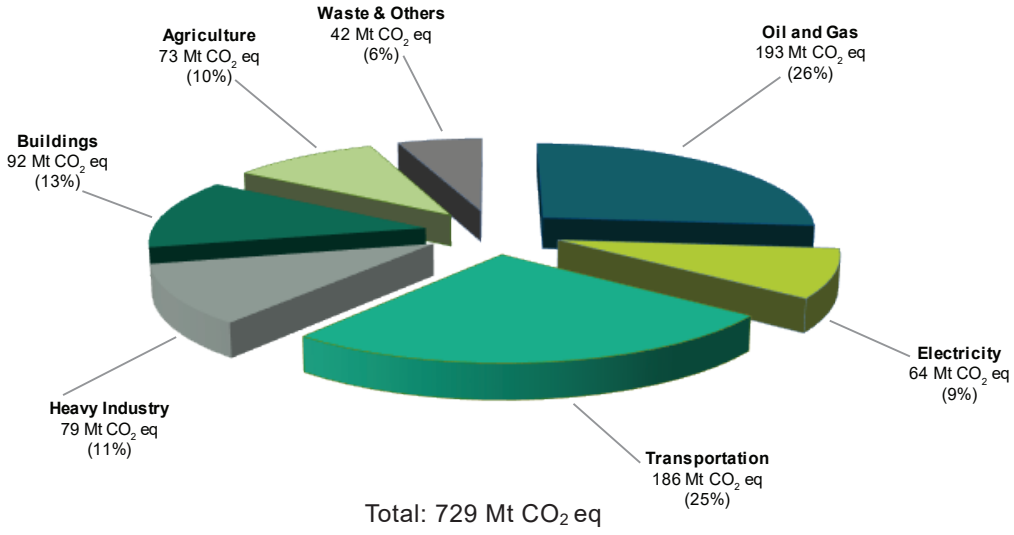
Further information on economic sector trends can be found in Chapter 2. Additional information on the IPCC and economic sector definitions, as well as a detailed crosswalk table between IPCC and economic sector categories can be found in Part 3 of this report.

ES.6. Provincial and Territorial GHG Emissions

Emissions vary significantly by province as a result of factors like 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 their electricity generation emit relatively more greenhouse gases 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 increased

Figure ES–7 **Breakdown of Canada's Emissions by Economic Sector (2018)**



Note: Totals may not add up due to rounding.

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

	1990	2005	2013	2014	2015	2016	2017	2018
	Mt CO_2 equivalent							
NATIONAL GHG TOTAL	**603**	**730**	**721**	**721**	**720**	**706**	**714**	**729**
Oil and Gas	106	158	185	191	191	187	188	193
Electricity	95	119	81	77	81	75	73	64
Transportation	121	161	174	172	172	174	179	186
Heavy Industry[a]	97	87	79	80	79	77	76	78
Buildings	74	86	86	89	86	82	85	92
Agriculture[b]	57	72	73	71	71	72	71	73
Waste & Others[c]	53	46	43	41	41	41	42	42

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 assoicated with the production of fertilizer are reported in the Heavy Industry sector.

c. "Others" includes Coal Production, Light Manufacturing, Construction & Forest Resources.

by 41 Mt (18%) 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 38 Mt (19%) since 2005, owing primarily to the closure of coal-fired electricity generation plants.

Saskatchewan's emissions increased by 8.4 Mt (12%) between 2005 and 2018 and those in British Columbia increased by 3.5 Mt (5.6%) over the same time period. Emissions in Manitoba as well as Newfoundland and Labrador have also increased since 2005, but to a lesser extent (1.7 Mt or 8.3% and 0.6 Mt or 5.3%, respectively). Provinces that have seen significant decreases in emissions include New Brunswick (6.7 Mt or a 34% reduction), Nova Scotia (6.1 Mt or a 26% reduction), Quebec (3.5 Mt or a 4.1% reduction) and Prince Edward Island (0.4 Mt or a 19% reduction).

Figure ES–8 **Emissions by Province and Territory in 2005, 2010 and 2018**

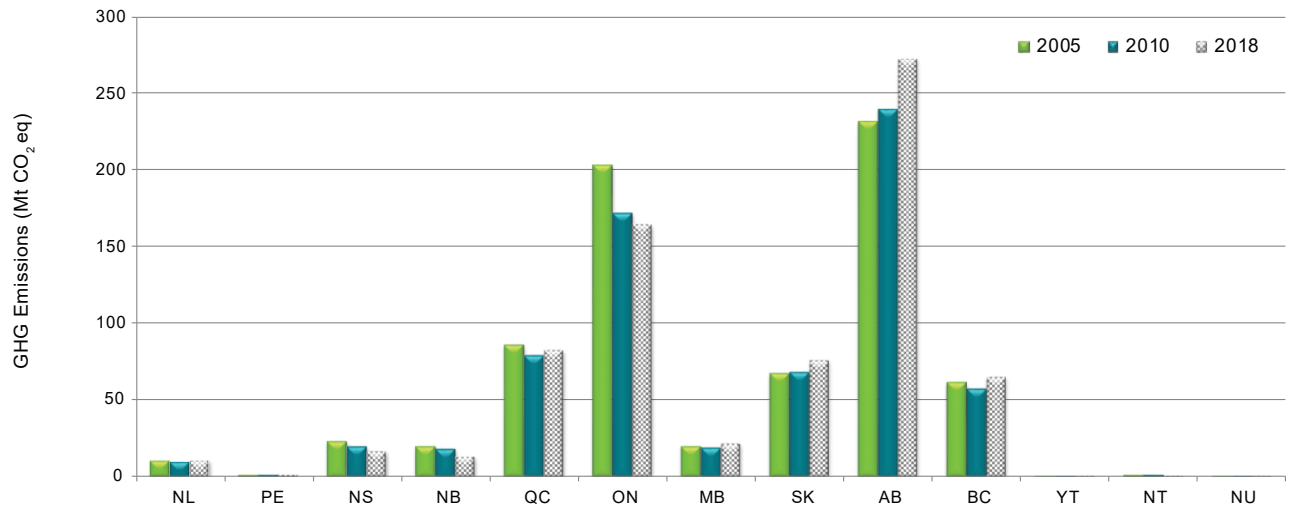


Table ES–4 **GHG Emissions by Province/Territory, Selected Years**

	GHG Emissions (Mt CO_2 eq)								Change (%)
Year	1990	2005	2013	2014	2015	2016	2017	2018	2005–2018
GHG Total (Canada)	**603**	**730**	**721**	**721**	**720**	**706**	**714**	**729**	**-0.1%**
NL	9.8	10	10	11	11	11	11	11	5.3%
PE	2.0	2.1	1.8	1.7	1.6	1.7	1.7	1.7	-19%
NS	20	23	18	17	17	16	16	17	-26%
NB	16	20	15	14	14	14	14	13	-34%
QC	87	86	80	78	79	78	80	83	-4.1%
ON	179	203	167	165	163	160	155	165	-19%
MB	18	20	21	21	21	21	21	22	8.3%
SK	44	68	72	75	77	75	77	76	12%
AB	173	232	272	277	276	265	272	273	18%
BC	52	62	60	60	59	62	63	66	5.6%
YT	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.6	14%
NT	NA	1.6	1.3	1.5	1.7	1.6	1.3	1.2	-22%
NU	NA	0.6	0.8	0.7	0.6	0.7	0.7	0.7	24%

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

ES.7. National Inventory Arrangements

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

The institutional arrangements for the preparation of the inventory include formal agreements on data collection and estimate development; a quality management plan, including an improvement plan; the ability to identify key categories and generate 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 on annual inventories (see Chapter 1, section 1.2).

Structure of Submission

The UNFCCC requirements include the annual compilation and submission of both the National Inventory Report (NIR) and the Common Reporting Format (CRF) tables. The CRF tables are a series of standardized data tables, containing mainly numerical information, which 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 as well as 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, as well as 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 is also available on the Government of Canada's Open Data website: at open.canada.ca.

Executive Summary References

[CAIT] Climate Analysis Indicators Tool. 2017. Washington (DC):World Resources Institute. Available online at: https://www.wri.org/our-work/project/cait-climate-data-explorer.

[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). (accessed December 05, 2019). 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.* (accessed December 05, 2019). Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000501.

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 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 greenhouse gases (GHGs) have grown significantly since pre-industrial times. Since 1750, the concentration of atmospheric CO_2 has increased by 147%, CH_4 by 259% and nitrous oxide (N_2O) by 123% (WMO 2019). These increases are caused by the use of fossil fuels as a source of energy and by land use and land use changes, in particular agriculture (IPCC 2013).

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 2018 was 0.6°C above normal (see Figure 1–1). Averaged annual temperatures in Canada have remained above normal since 1996, with a warming trend of 1.7°C over the past 72 years (ECCC 2019).

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. In its actions to achieve its objective and to implement its provisions, the UNFCCC lays 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 adaptating to those impacts. Specifically, Articles 4 and 12 and Decision 24/CP.19 of the Convention commit all Parties to develop, periodically update,[1] publish and make available to the COP national inventories of anthropogenic[2] emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol[3] that use comparable methodologies.

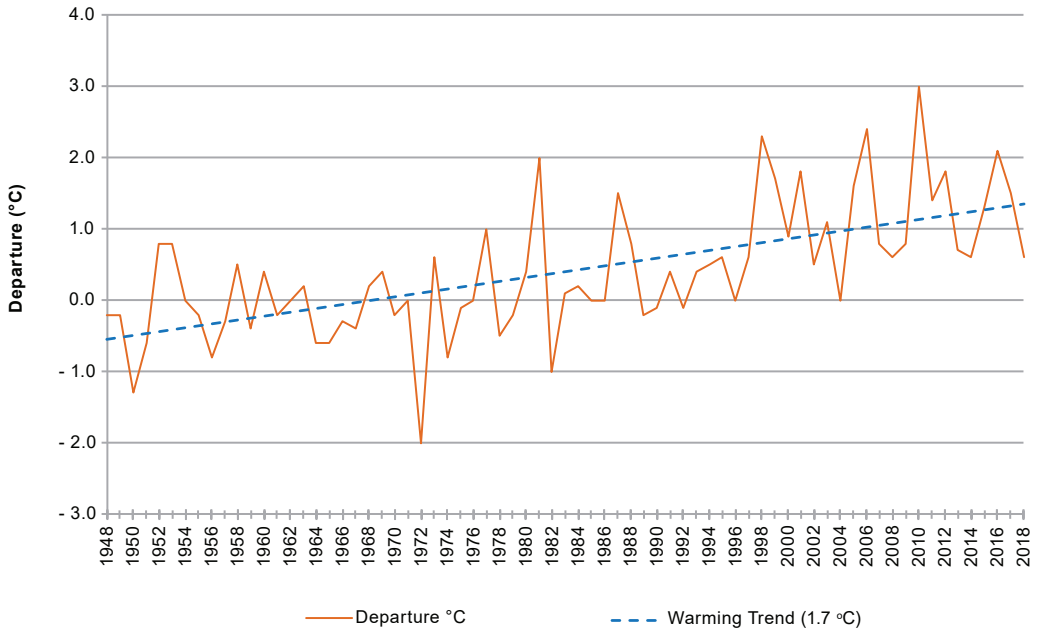
This National Inventory Report (NIR) documents Canada's annual GHG emissions estimates for the period 1990−2018. The NIR, along with the Common Reporting Format (CRF) tables, comprise Canada's 2020 submission to the UNFCCC. The NIR

1 Annex I Parties (or developed countries) 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 Under the United Nations Environment Programme (UNEP), the Montreal Protocol on Substances that Deplete the Ozone Layer is an international agreement designed to reduce the global consumption and production of ozone-depleting substances.

Figure 1–1 **Annual Canadian Temperature Departures and Long-term Trend, 1948–2018**



Data source: ECCC (2019)

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, PFCs, HFCs, sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). In addition, and in keeping with the UNFCCC reporting guidelines, Annex 7 provides the online location 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)

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 carbon dioxide 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 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)

CH_4 is a colourless, odourless, flammable gas that 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 plant or organic matter in the absence of oxygen, as well as 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 garbage decomposition in landfills.

Nitrous Oxide (N_2O)

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)

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)

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 chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and halons in various applications including refrigeration, fire-extinguishing, semiconductor manufacturing and foam blowing.

Sulphur hexafluoride (SF_6)

SF_6 is a synthetic gas that is colourless, odourless, and non-toxic (except when exposed to extreme temperatures), and 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 also as a tracer gas for gas dispersion studies in industrial and laboratory settings.

Nitrogen Trifluoride (NF_3)

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, which is 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.

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 global warming potential (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 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 1–5) are used in this report. For example, the 100-year GWP for methane (CH_4) used in this inventory is 25; as such, an emission of one hundred kilotonnes (100 kt) of methane is equivalent to 25 x 100 kt = 2500 kt CO_2 eq.

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).

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

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

Notes:

a. Data source: IPCC's *Fourth Assessment Report—Errata* (IPCC 2012).

b. 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. The National Inventory Focal Point is:

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

A detailed description of the functions 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, Environment and Climate Change Canada (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. As such, ECCC 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.

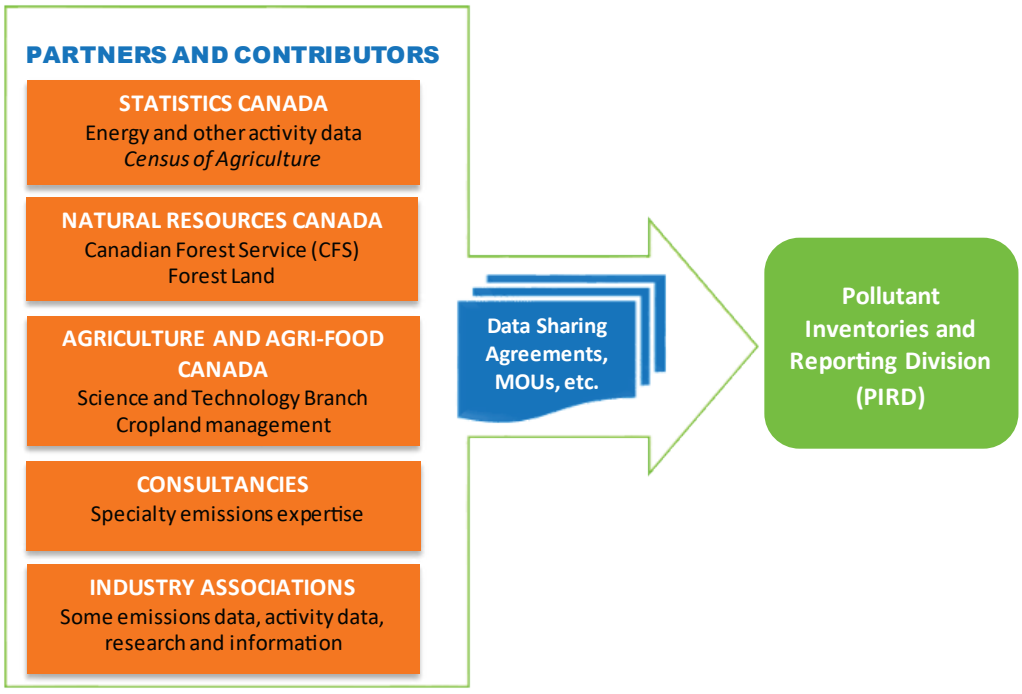
Figure 1–2 identifies the various partners and contributors to the inventory agency and their contribution to the development of Canada's national inventory.

1.2.1.1. Statistics Canada

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 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 established 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, Natural Resources Canada (NRCan) and the Canadian Energy and Emissions Data Centre (CEEDC) of Simon Fraser University review the 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.

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



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, the statistics agency collects agricultural activity data (related to crops, crop production and management practices) through the *Census of Agriculture* and provides animal population data.

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

ECCC has officially designated responsibilities to Agriculture and Agri-Food Canada and the Canadian Forest Service of Natural Resources Canada (NRCan/CFS) for the development of key components of the Land Use, Land-use Change and Forestry (LULUCF) sector. 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. The Earth Science Sector of NRCan has, in the past, also supported the development of Earth observation products to improve land information used in the estimation of GHG emissions/removals from LULUCF.

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 directly emit large amounts of GHGs under its GHG Reporting Program (GHGRP). The facility-level GHG data are used 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 agreement with the Aluminium Association of Canada (AAC) has been signed, under which process-related emission estimates for CO_2, PFCs and SF_6 are to be provided annually to ECCC. A similar agreement has been negotiated 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.

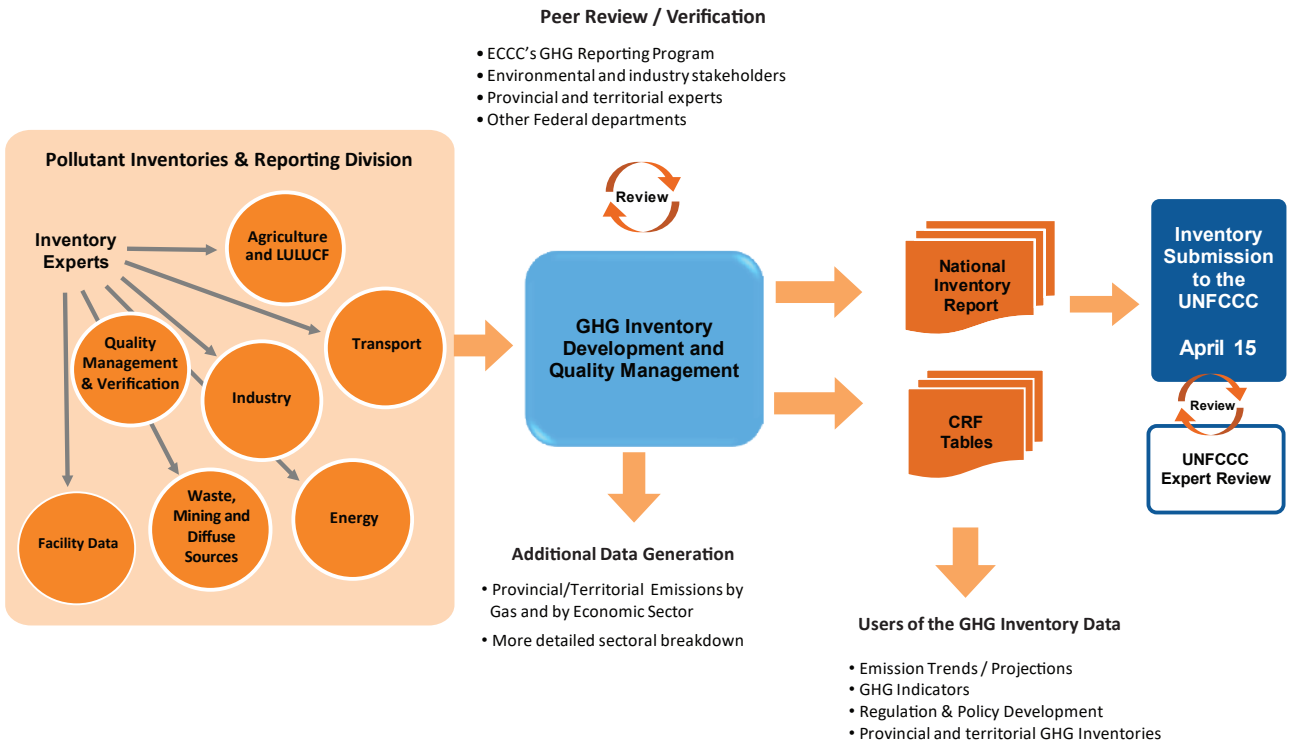
1.2.2. Process for Inventory Preparation

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

The inventory builds from a continuous process of methodological improvements, refinements and review, according to the quality management and improvement plans. The Quality Management and Verification Section is responsible for preparing the inventory development schedule; the schedule may be adjusted each year based on the results of the lessons-learned review of the previous inventory cycle, QA/QC follow-up, the UNFCCC review report, and collaboration with provincial and territorial governments. Based on these outcomes, methodologies and emission factors are reviewed, developed and/or refined. QA reviews of methodologies and emission factors 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.

During the early stages of the inventory cycle (May to October), collection of the required data begins while the inventory publication schedule and roles and responsibilities are finalized. Methodologies are finalized by the end of September and the data collection process is completed by the end of October. The data used to compile the national inventory are generally from published sources. Data are collected either electronically or manually (hard copies) from the source agencies, controlled for quality and entered into emission quantification tools: spreadsheets, databases and other

Figure 1–3 **Inventory Preparation Process**



forms of models. In November and December, draft estimates are developed by designated inventory experts and internally reviewed. NIR text and CRF tables are then prepared 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, uncertainty calculation and documentation preparation.

Between January and March, the compiled inventory is first reviewed internally and components of it are externally reviewed 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 normally submitted to the UNFCCC electronically prior to April 15 of each year. Once finalized, the NIR is then translated and made available in French.

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 are briefed on several occasions prior to the report being sent to the Minister. 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 l to protect confidential data. These procedures are documented and confidential source data is protected and archived accordingly.

Specific to data received from Statistics Canada used to estimate GHG emissions in the Energy and Industrial Processes and Product Use 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.

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

Quality assurance, quality control (QA/QC) and verification procedures are an integral part of the inventory development and submission processes. 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 (QC) 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 Common Reporting Format (CRF) online tool by the CRF coordinators, in addition to the review of the tables 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, emission factors (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 emission factor 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, emission factors 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

Verification activities 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, emission factors 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 3-7.

1.3.4.1. The GHG Reporting Program

In March 2004, the Government of Canada established the Greenhouse Gas Reporting Program (GHGRP) to collect Greenhouse Gas (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*[5]. 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.

5 The *Canada Gazette* can be found at: http://gazette.gc.ca/rp-pr/p1/2019/2019-01-19/html/notice-avis-eng.html

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 Canada's 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 50kt to 10kt 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 provide additional detailed data and use prescribed methods to determine their emissions. The 2018 reporting cycle represented Phase 2 of the expansion where facilities in nine additional industry sectors were required to report more detailed emissions information and use prescribed quantification methods. These nine 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.

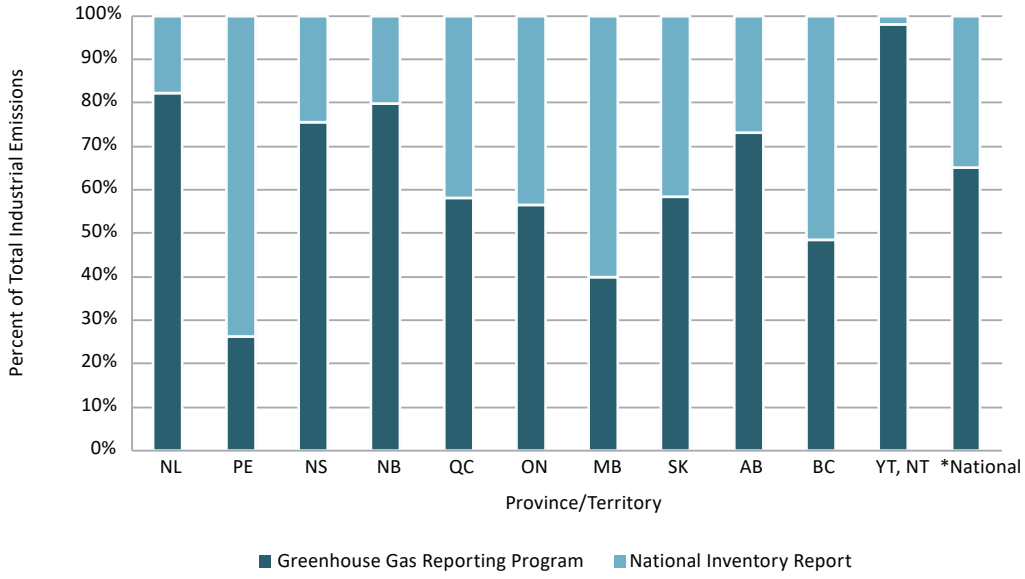
Facilities not covered by the expansion can choose the quantification methodologies most appropriate for their particular industry or application. However, these reporting facilities must use methods for estimating emissions that are consistent with the guidelines developed by the IPCC and adopted by the UNFCCC for the preparation of national GHG inventories. Voluntary submissions from facilities with GHG emissions below the 10kt 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 2018. In 2018, a total of 1706 facilities (mostly industrial) reported their GHG emissions to the program. Environment and Climate Change Canada's GHGRP website[6] 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 2018, the total facility-reported GHG emissions represents 40% of Canada's total GHG emissions (729 Mt) and 65% 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

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

Figure 1–4 **2018 Facility-Reported Emissions as a Percentage of Industrial GHG Emissions by Province/Territory**



Notes:
In this overview report, Canada's industrial GHG emissions include the following GHG categories from the *National Inventory Report, Greenhouse Gas Sources and Sinks in Canada 1990–2018*: 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

province, depending on the size and number of industrial facilities in each province that have emissions above the 10kt reporting threshold (Figure 1–4).

Facility-level GHG emission data are currently used, where appropriate, to confirm the reasonableness of emission estimates in the NIR, developed largely from national and provincial statistics and in accordance with UNFCCC reporting requirements. Information gathered from facilities is shared with provincial and territorial jurisdictions. The GHGRP provides Canadians with consistent information about the GHG emissions reported by facilities. The enhanced facility data collected as part of the expansion will be reviewed, with the intent to directly integrate it over time into the NIR, to the extent possible. Additional information on how this data is used to verify emission estimates for the various source categories can be found in Chapters 3 to 7 of the NIR.

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 2018 Reported Emissions* (Environment and Climate Change Canada 2020).

1.4. Annual Inventory Review

Since 2003, except 2018, Canada's national GHG inventory has been reviewed annually by independent expert review teams 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.[7] Review reports are posted on-line by the UNFCCC Secretariat once finalized.[8]

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, Industrial Processes and Product Use, 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.[9]

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 or 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 emission factors 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

7 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.

8 Annual Inventory Review Reports are available online at https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports/inventory-review-reports-2019.

9 Information on Canada's ozone and aerosol precursors, including carbon monoxide (CO), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SOx) can be found in Canada's Air Pollutant Emission Inventory which is available online at www.canada.ca/APEI.

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 emission factors (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 emission factors 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) defines 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 1990–2018 GHG inventory, level and trend key category assessments were performed according to the recommended IPCC 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 and the LULUCF CRF; however, they have been aggregated in some cases and are specific to the Canadian inventory.

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

- Stationary Fuel Combustion—Energy Industries;
- Stationary Fuel Combustion—Manufacturing Industries and Construction;
- Stationary Fuel Combustion—Other Sectors;
- Fuel Combustion—Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery; and
- Fuel Combustion—Road Transportation.

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

- Fuel Combustion—Road Transportation;
- LULUCF—Forest Land remaining Forest Land;
- Stationary Fuel Combustion—Manufacturing Industries and Construction; and
- LULUCF—Harvest Wood Products;
- Stationary Fuel Combustion—Energy Industries.

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

1.7. Inventory Uncertainty

While national GHG inventories should be accurate, complete, comparable, transparent and consistent, estimates will always inherently carry some uncertainty. Uncertainties[10] 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 emission factors and other model parameters. In a limited number of cases, uncertainty may be reduced based on a validation exercise with an independent data set, such as the total emissions reported by individual facilities in a given industry sector. 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.

10 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).

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. While more complex (Approach 2) methods 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 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 ±2%,. The Energy sector had the lowest uncertainty, at ±2%, while the Waste sector had the highest uncertainty, at ±46%. The Industrial Processes and Product Use and Agriculture sectors had uncertainties of ±12% and ±17%, respectively.

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

- Agriculture—Direct Agriculture Soils, N_2O;
- Waste—Solid Waste Disposal – UnManaged Waste Disposal Sites – Wood Waste Landfills, CH_4;
- IPPU—Product Uses as Substiutes for Ozone Depleting Substances, HFCs;
- Agriculture—Enteric Fermentation, CH_4; and
- Waste—Solid Waste Disposal – Managed Waste Disposal Sites, CH_4.

When the LULUCF emissions and removals are included, the uncertainty in the national total was found to be ±9%.

The trend uncertainty, not including LULUCF, was found to be 1%. Therefore, the total increase in emissions of 126 Mt (+21%) since 1990 has a 95% probability of being within this range. The trend uncertainty, including LULUCF, was found to be 9%.

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:

1. Categories that are not occurring in Canada;
2. Data unavailability at the category level;
3. Methodological issues specific to national circumstances; and/or
4. Emission estimates are considered insignificant[11].

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 which 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).

11 An emission should only be considered insignificant if the likely level of emissions is below 0.05 per cent 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 per cent of the national total GHG emissions (UNFCCC, 2014).

CHAPTER 2

GREENHOUSE GAS EMISSIONS TRENDS

2.1. Summary of Emissions Trends

In 2018, Canada's greenhouse gas (GHG) emissions were 729 megatonnes of carbon dioxide equivalent (Mt CO_2 eq),[1] a net decrease of 0.4 Mt or 0.1% from 2005 emissions (Figure 2–1).[2] Dating back to 1990, annual emissions steadily increased for 10 years, fluctuated between 2000 and 2008, dropped in 2009 and gradually increased thereafter.

Emissions increases since 2009 can be attributed to increases in oil and gas extraction (34 Mt); the number of light-duty gasoline trucks (12 Mt) and heavy-duty diesel vehicles in operation (12 Mt); consumption of halocarbons, sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) (5.6 Mt); and the application of inorganic nitrogen fertilizers (3.6 Mt). During the same period, a 30 Mt decrease in emissions from electricity generation partly offset emissions growth. Section 2.3 provides more detail on these and other key drivers of these trends.

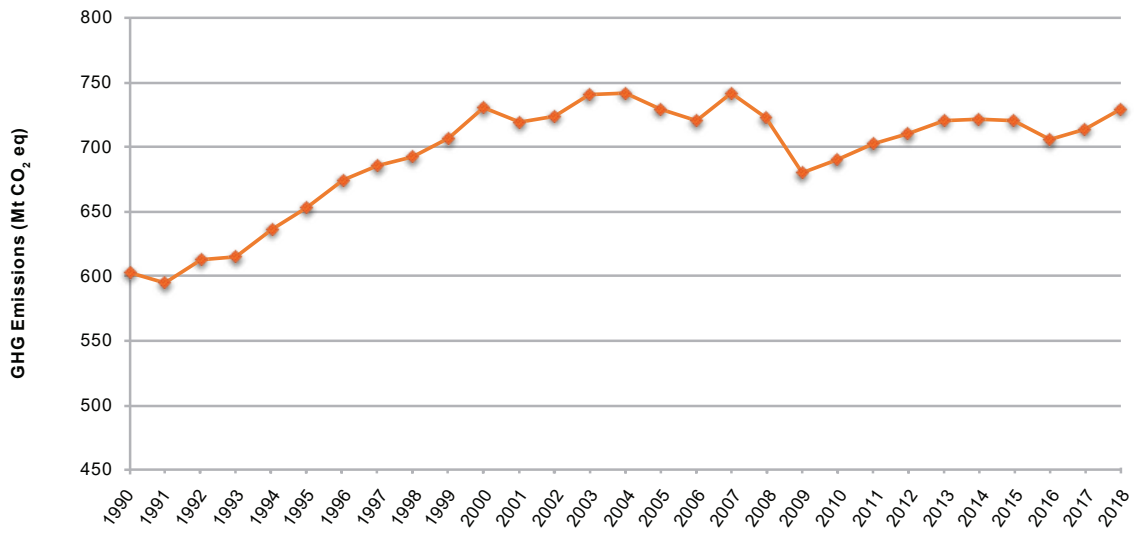
Over the long term, Canada's economy has grown more rapidly than its GHG emissions. As a result, the emissions intensity for the entire economy (or GHGs per Gross Domestic Product [GDP]) has declined by 36% since 1990, and by 20% since 2005 (Table 2–1). The decline in emissions intensity since 1995 (Figure 2–2) can be attributed to fuel switching, increases in efficiency, the modernization of industrial processes and structural changes in the economy.

Canada accounted for approximately 1.6% of global GHG emissions in 2014 (CAIT, 2017), although it is one of the highest per capita emitters. Canada's per capita emissions have dropped substantially since 2005, when this indicator was 22.6 t CO_2 eq/capita, reaching new lows between 19.5 and 19.7 t CO_2 eq/capita since 2016 (Figure 2–3).

1 Unless explicitly stated otherwise, all emission 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 percentages) were performed using unrounded data.

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



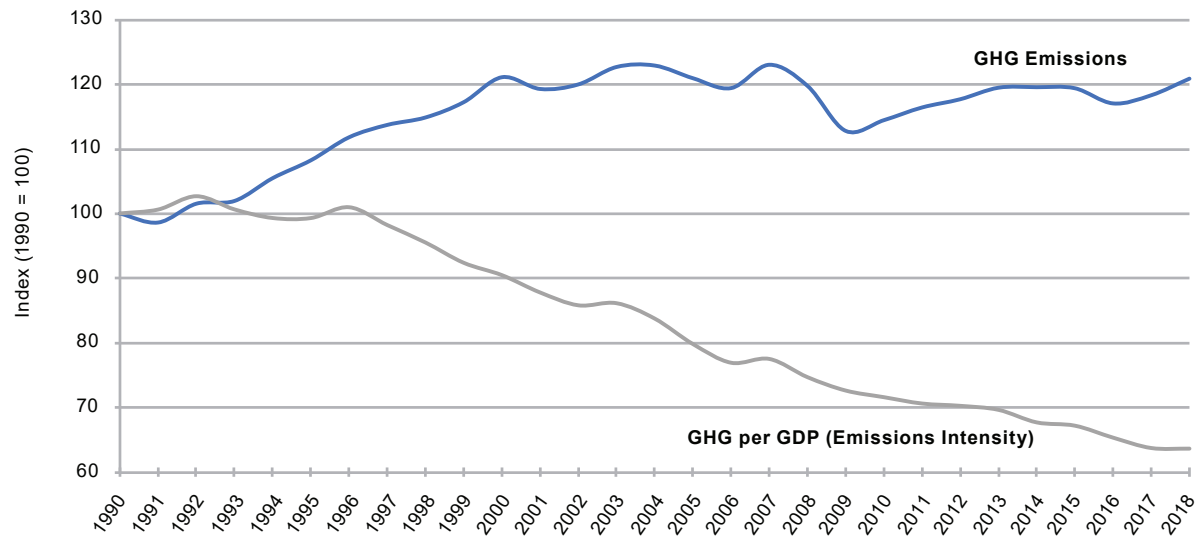
2.1.1. Emissions Trends by Province/ Territory

Emissions vary significantly by province due to 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 their electricity generation emit relatively more GHGs than those that rely more on low-emitting energy sources, such as nuclear power, hydroelectric generation, wind turbines, solar photovoltaic cells and tidal power (Figure 2–4).

Historically, Alberta and Ontario have been the highest-emitting provinces. Since 2005, emission patterns in these two provinces have diverged. Emissions in Alberta increased from 232 Mt in 2005 to 273 Mt in 2018 (18%), primarily as a result of the expansion of oil and gas operations (Table 2–2). In contrast, Ontario's emissions have decreased since 2005 (by 38 Mt or 19%), owing primarily to the closure of coal-fired electricity generation plants.

Saskatchewan's emissions increased by 8.4 Mt (12%) between 2005 and 2018 as a result of expanding activities in the oil and gas industry, uranium mining and transportation. Emissions in

Figure 2–2 **Indexed Trend in GHG Emissions and GHG Emissions Intensity (1990–2018)**



GDP data source: StatCan a

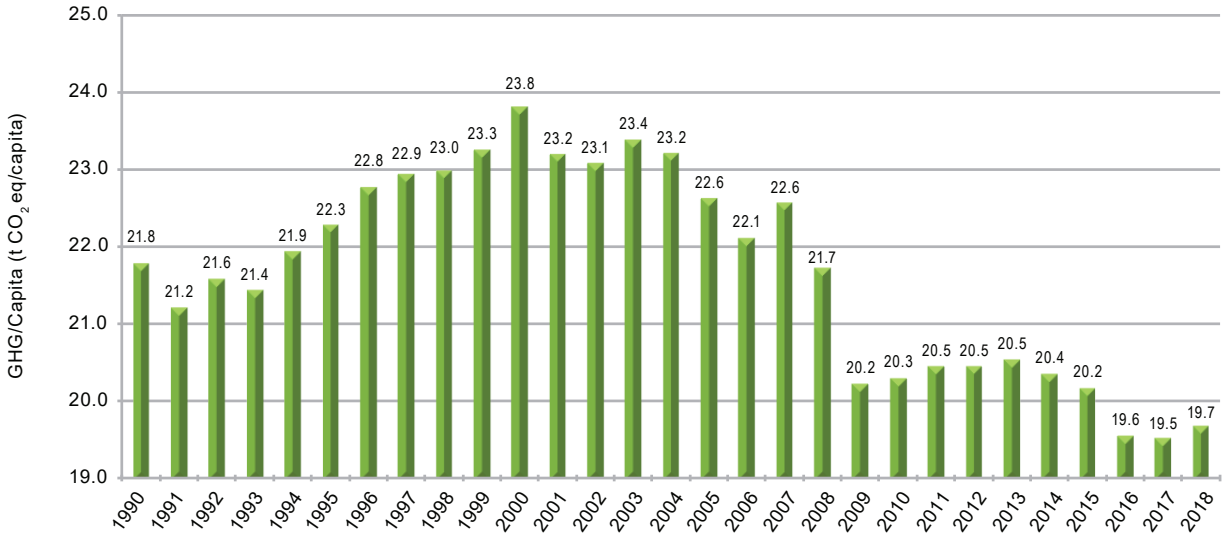
Table 2–1 **Trends in Emissions and Economic Indicators, Selected Years**

Year	1990	2005	2013	2014	2015	2016	2017	2018
Total GHG (Mt)	**603**	**730**	**721**	**721**	**720**	**706**	**714**	**729**
Change since 2005 (%)	NA	NA	-1.2%	-1.2%	-1.3%	-3.2%	-2.2%	-0.1%
Change since 1990 (%)	NA	21%	20%	20%	19%	17%	18%	21%
GDP (Billion 2012$)	**1 092**	**1 654**	**1 871**	**1 926**	**1 938**	**1 953**	**2 024**	**2 071**
Change since 2005 (%)	NA	NA	13%	16%	17%	18%	22%	25%
Change since 1990 (%)	NA	51%	71%	76%	78%	79%	85%	90%
GHG Intensity (Mt/$B GDP)	**0.55**	**0.44**	**0.39**	**0.37**	**0.37**	**0.36**	**0.35**	**0.35**
Change since 2005 (%)	NA	NA	-13%	-15%	-16%	-18%	-20%	-20%
Change since 1990 (%)	NA	-20%	-30%	-32%	-33%	-35%	-36%	-36%

Notes:
GDP data source: StatCan a
NA not applicable

British Columbia increased by 3.5 Mt (5.6%) over the same time period. Emissions in Manitoba as well as Newfoundland and Labrador have also increased since 2005, but to a lesser extent (1.7 Mt or 8.3% and 0.6 Mt or 5.3%, respectively). Provinces that have seen significant decreases in emissions include New Brunswick (6.7 Mt or a 34% reduction), Nova Scotia (6.1 Mt or a 26% reduction), Quebec (3.5 Mt or a 4.1% reduction) and Prince Edward Island (0.4 Mt or a 19% reduction).

Figure 2–3 **Canadian Per Capita Greenhouse Gas Emissions (1990–2018)**



Population data source: StatCan b

Figure 2–4 **Emissions by Province/Territory in 2005, 2010 and 2018**

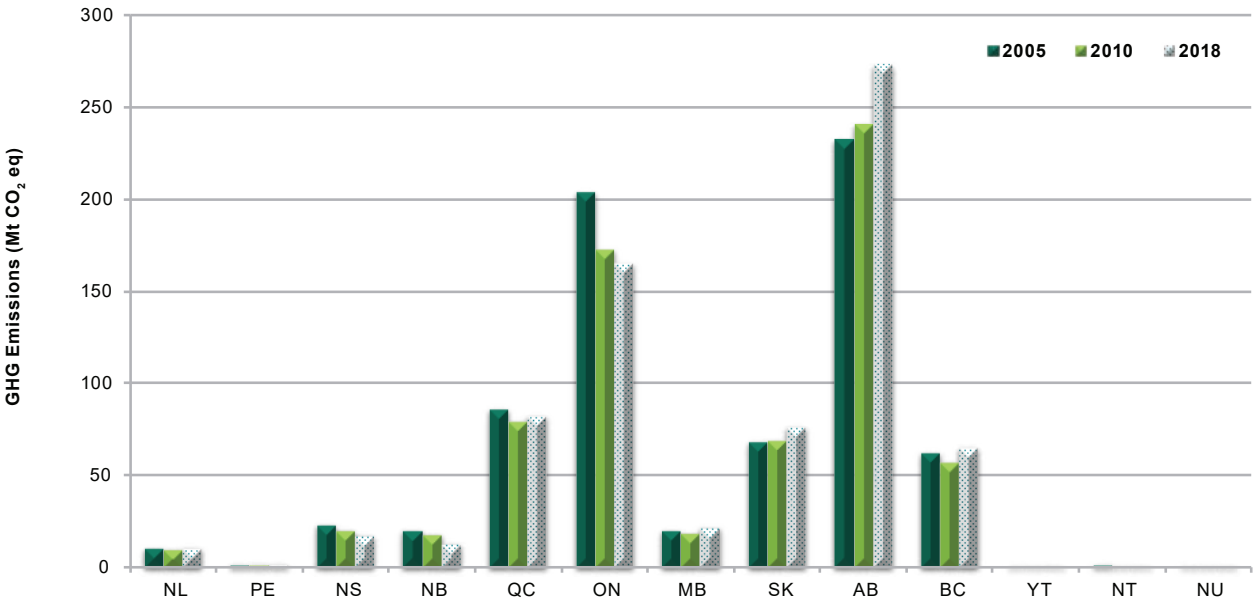


Table 2–2 **GHG Emissions by Province/Territory, Selected Years**

	GHG Emissions (Mt CO_2 eq)								Change (%)
Year	1990	2005	2013	2014	2015	2016	2017	2018	2005–2018
GHG Total (Canada)	**603**	**730**	**721**	**721**	**720**	**706**	**714**	**729**	**-0.1%**
NL	9.8	10	10	11	11	11	11	11	5.3%
PE	2.0	2.1	1.8	1.7	1.6	1.7	1.7	1.7	-19%
NS	20	23	18	17	17	16	16	17	-26%
NB	16	20	15	14	14	14	14	13	-34%
QC	87	86	80	78	79	78	80	83	-4.1%
ON	179	203	167	165	163	160	155	165	-19%
MB	18	20	21	21	21	21	21	22	8.3%
SK	44	68	72	75	77	75	77	76	12%
AB	173	232	272	277	276	265	272	273	18%
BC	52	62	60	60	59	62	63	66	5.6%
YT	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.6	14%
NT	NA	1.6	1.3	1.5	1.7	1.6	1.3	1.2	-22%
NU	NA	0.6	0.8	0.7	0.6	0.7	0.7	0.7	24%

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

2.2. Emissions Trends by Gas

Canada's emissions profile is similar to that of most industrialized countries in that carbon dioxide (CO_2) is the largest contributor to Canada's GHG emissions, accounting for 587 Mt (80% of total emissions) in 2018. As a result, trends in CO_2 emissions follow the same pattern as total 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 2018 amounted to 91 Mt or 13% of Canada's total emissions. These emissions are largely from fugitive sources in oil and natural gas systems (43% of total CH_4 emissions), agriculture (31% of total CH_4 emissions) as well as solid waste disposal (municipal landfills) and industrial wood waste landfills (17% of total CH_4 emissions). Nationally, CH_4 emissions have increased by 0.9 Mt (1%) since 1990, largely due to the development of petroleum resources.

Nitrous oxide (N_2O) emissions accounted for 38 Mt (5%) of Canada's emissions in 2018, down 0.9 Mt (2.4%) from 1990 levels. These emissions primarily arise from the application of nitrogen to agricultural soils and from transport. In 2018, the Agriculture sector accounted for 76% of national N_2O emissions, up from 53% in 1990. Since 1990, a 10 Mt decrease in N_2O emissions has also occurred due to the cessation of adipic acid production in Canada.

Together, perfluorocarbons (PFCs), SF_6, hydrofluorocarbons (HFCs) and NF_3 accounted for 13 Mt or 1.8% of Canada's emissions in 2018. From 1990 to 2018, emissions of HFCs rose by 12 Mt (1193%), while emissions of PFCs and SF_6 decreased by 6.9 Mt (92%) and 2.9 Mt (90%), respectively. The increase in HFC emissions can be explained by the replacement of ozone-depleting substances (ODSs) by HFCs for refrigeration and air conditioning.

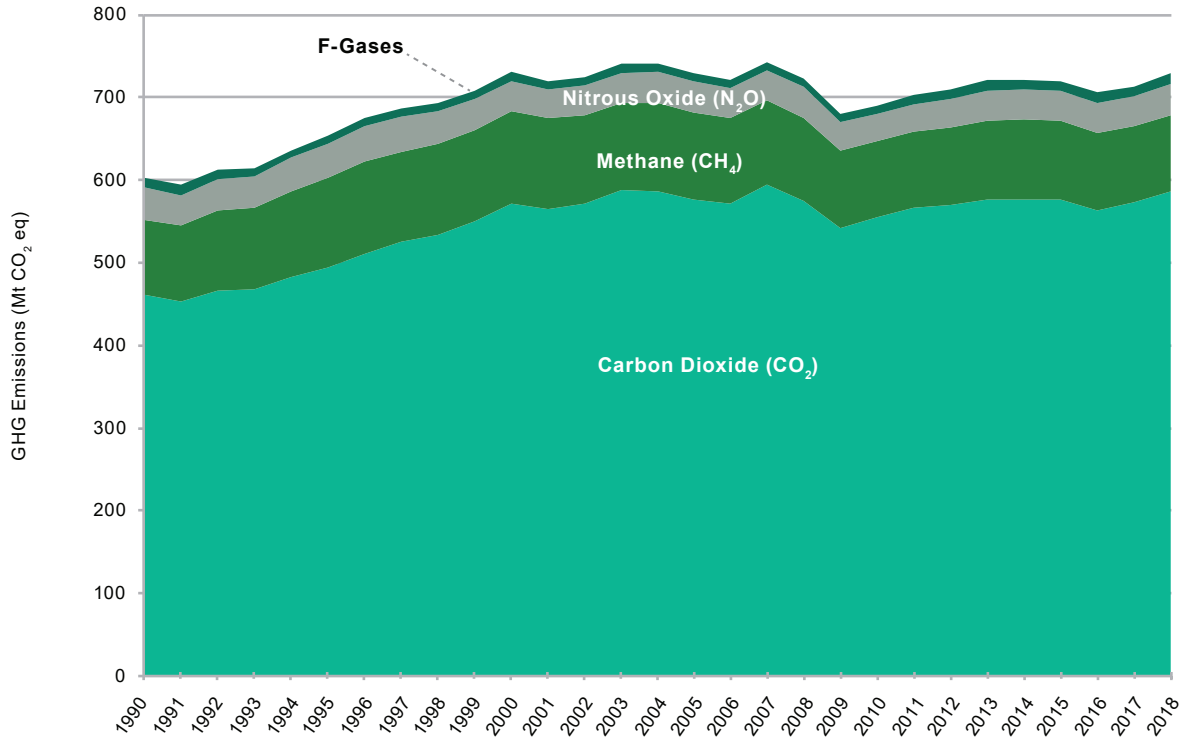
2.3. Emissions Trends by Intergovernmental Panel on Climate Change (IPCC) Category

In 2018, the Energy sector accounted for 596 Mt or 82% of Canada's total GHG emissions (Figure 2–6). The remaining emissions were largely generated by the Agriculture (8%) and Industrial Processes and Product Use (IPPU) (8%) sectors, with minor contributions from the Waste sector (2%).

The Energy sector dominated the long-term trend over the 1990–2018 period, with increases of 72 Mt (49%) in Transport, 39 Mt (14%) in Stationary Combustion and 6.5 Mt (13%) in Fugitive Sources. Over the same period, emissions in the Agriculture sector increased by 12 Mt (27%), while the IPPU sector saw a decrease of 0.6 Mt (1.0%). The Land Use, Land-Use Change and Forestry (LULUCF) sector was a 13 Mt sink in 2018; net removals of CO_2 from the atmosphere by the Land sector decreased by 47 Mt, down from 60 Mt in 1990. Emissions in the Waste sector remained relatively steady (Figure 2–6 and Table 2–3).

Since 2005, emissions from Stationary Combustion, Fugitive Sources, Waste and IPPU have all decreased (by 18 Mt, 5.4 Mt, 2.2 Mt and 0.2 Mt, respectively), while

Figure 2–5 **Trends in Canadian GHG Emissions by Gas (1990–2018)**



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

Agriculture emissions have remained steady. Emissions from Transport have increased by 26 Mt since 2005 and LULUCF sector removals have increased by 0.2 Mt.

Several emissions sources, while not major contributors to Canada's overall emissions, have experienced a significant change since 1990. These include a 12 Mt (or 1187%) increase in emissions from the production and consumption of halocarbons, a 5.7 Mt (99%) increase from the non-energy use of fuels and solvents; a 1.4 Mt (119%) increase in CO_2 emissions from the application of lime, urea and carbon-containing fertilizers; and a 0.2 Mt (78%) decrease in emissions from field burning of agricultural residues.

2.3.1. **Energy Sector** (2018 GHG emissions, 596 Mt)

In 2018, the Energy sector contributed 81.7% of 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, Transport, Fugitive Sources, and CO_2 Transport and Storage. A detailed description of each category is provided in Chapter 3.

2.3.1.1. **Stationary Combustion** (2018 GHG Emissions, 324 Mt)

Stationary Combustion accounts for 54.3% of emissions from the Energy sector. In 2018, emissions totalled 324 Mt, an increase of 13.8% from the 1990 emissions level of 284 Mt and a decrease of 5.4% from the 2005 emissions level of 342 Mt (Figure 2–7, Table 2–4). Dominant categories in Stationary Combustion Sources are Oil and Gas Extraction and Public Electricity and Heat Production, which in 2018 contributed 32.7% and 21.6%, respectively, of the total Stationary Combustion emissions. Manufacturing Industries, Residential Buildings, and Commercial and Institutional Buildings contributed 13.6%, 14.0% and 10.1%, respectively, of total Stationary Combustion emissions in 2018.

Public Electricity and Heat Production
(2018 GHG emissions, 70 Mt)

Emissions from the Public Electricity and Heat Production category decreased by 26% between 1990 and 2018.

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 2018, electricity generation

Table 2–3 **Canada's GHG Emissions by IPCC Sector (1990–2018)**

Greenhouse Gas Categories		1990	2005	2013	2014	2015	2016	2017	2018
		Mt CO_2 equivalent							
TOTAL[a, b]		**603**	**730**	**721**	**721**	**720**	**706**	**714**	**729**
ENERGY		**479**	**593**	**587**	**591**	**590**	**574**	**584**	**596**
a.	**Stationary Combustion Sources**	**284**	**342**	**326**	**329**	**328**	**318**	**321**	**324**
	Public Electricity and Heat Production	95	125	88	84	87	81	78	70
	Petroleum Refining Industries	17	20	18	18	18	18	16	16
	Oil and Gas Extraction	35	63	91	96	97	99	102	106
	Mining	4.6	4.3	5.4	5.1	4.6	4.3	4.7	4.9
	Manufacturing Industries	56	48	45	45	44	42	42	44
	Construction	1.9	1.5	1.3	1.3	1.3	1.3	1.3	1.4
	Commercial and Institutional	26	33	30	31	30	30	32	33
	Residential	47	46	44	46	43	39	41	45
	Agriculture/Forestry/Fishing	2.4	2.2	3.8	3.8	3.6	3.8	3.7	3.8
b.	**Transport**	**145**	**191**	**201**	**199**	**201**	**201**	**207**	**217**
	Domestic Aviation	7.2	7.6	7.6	7.2	7.1	7.1	7.4	8.0
	Road Transportation	84	130	144	142	143	145	148	154
	Light-Duty Gasoline Vehicles	42	41	36	34	34	35	34	34
	Light-Duty Gasoline Trucks	20	38	43	43	45	48	49	52
	Heavy-Duty Gasoline Vehicles	6.3	12	13	12	12	13	13	14
	Motorcycles	0.09	0.20	0.26	0.26	0.27	0.29	0.30	0.30
	Light-Duty Diesel Vehicles	0.47	0.61	0.86	0.86	0.90	0.84	0.84	0.81
	Light-Duty Diesel Trucks	0.15	0.34	0.53	0.64	0.81	0.90	1.1	1.2
	Heavy-Duty Diesel Vehicles	14	37	50	50	49	47	49	52
	Propane and Natural Gas Vehicles	1.2	0.38	0.02	0.01	0.01	0.01	0.01	0.01
	Railways	6.9	6.6	7.3	7.5	7.1	6.5	7.5	7.6
	Domestic Navigation	3.8	4.8	4.3	4.1	3.9	3.9	4.0	4.0
	Other Transportation	44	42	38	39	40	39	40	44
	Off-Road Agriculture & Forestry	9.0	11	10	10	10	9.7	10	11
	Off-Road Commercial & Institutional	1.5	2.4	2.7	2.8	2.7	2.6	2.8	2.9
	Off-Road Manufacturing, Mining & Construction	9.2	10	12	12	13	12	14	15
	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	4.3	4.5	4.8	4.9	5.1	5.3
	Pipeline Transport	6.9	10	6.7	7.9	8.2	8.4	7.4	8.3
c.	**Fugitive Sources**	**49**	**61**	**61**	**63**	**60**	**55**	**55**	**55**
	Coal Mining	2.8	1.4	1.5	1.3	1.1	1.3	1.2	1.3
	Oil and Natural Gas	46	60	59	62	59	54	54	54
d.	**CO_2 Transport and Storage**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**
INDUSTRIAL PROCESSES AND PRODUCT USE		**57**	**57**	**57**	**55**	**54**	**55**	**54**	**56**
a.	**Mineral Products**	**8.4**	**10**	**7.8**	**7.8**	**8.1**	**7.9**	**8.5**	**8.9**
	Cement Production	5.8	7.6	6.0	5.9	6.3	6.2	6.8	7.2
	Lime Production	1.8	1.7	1.4	1.5	1.4	1.4	1.4	1.4
	Mineral Product Use	0.86	0.91	0.38	0.38	0.41	0.39	0.33	0.32
b.	**Chemical Industry**	**18**	**10**	**7.3**	**7.2**	**7.6**	**7.7**	**6.9**	**7.7**
c.	**Metal Production**	**24**	**20**	**15**	**15**	**14**	**15**	**15**	**15**
d.	**Production and Consumption of Halocarbons, SF_6 and NF_3**	**1.0**	**5.1**	**10**	**11**	**11**	**11**	**12**	**13**
e.	**Non-Energy Products from Fuels and Solvent Use**	**5.8**	**10**	**16**	**13**	**13**	**12**	**11**	**12**
f.	**Other Product Manufacture and Use**	**0.37**	**0.54**	**0.56**	**0.48**	**0.57**	**0.63**	**0.66**	**0.74**
AGRICULTURE		**47**	**60**	**59**	**58**	**58**	**59**	**58**	**59**
a.	**Enteric Fermentation**	**22**	**31**	**25**	**24**	**24**	**24**	**24**	**24**
b.	**Manure Management**	**6.1**	**8.8**	**7.8**	**7.7**	**7.8**	**7.9**	**7.9**	**7.9**
c.	**Agricultural Soils**	**17**	**19**	**24**	**23**	**24**	**25**	**24**	**25**
d.	**Field Burning of Agricultural Residues**	**0.22**	**<0.05**	**0.05**	**0.05**	**0.06**	**0.05**	**0.05**	**0.05**
e.	**Liming, Urea Application and Other Carbon-containing Fertilizers**	**1.2**	**1.4**	**2.7**	**2.5**	**2.6**	**2.5**	**2.5**	**2.6**
WASTE		**21**	**20**	**17**	**17**	**18**	**18**	**18**	**18**
a.	**Solid Waste Disposal**	**15**	**14**	**12**	**12**	**12**	**12**	**12**	**12**
b.	**Biological Treatment of Solid Waste**	**0.06**	**0.29**	**0.44**	**0.46**	**0.45**	**0.45**	**0.45**	**0.45**
c.	**Wastewater Treatment and Discharge**	**0.92**	**1.0**	**1.1**	**1.2**	**1.2**	**1.1**	**1.1**	**1.1**
d.	**Incineration and Open Burning of Waste**	**0.47**	**0.58**	**0.32**	**0.36**	**0.40**	**0.39**	**0.39**	**0.39**
e.	**Industrial Wood Waste Landfills**	**3.8**	**4.3**	**3.8**	**3.7**	**3.6**	**3.5**	**3.5**	**3.4**
LAND USE, LAND-USE CHANGE AND FORESTRY		**-60**	**-13**	**-25**	**-25**	**-18**	**-19**	**-16**	**-13**
a.	**Forest Land**	**-203**	**-145**	**-150**	**-150**	**-143**	**-144**	**-143**	**-140**
b.	**Cropland**	**8.1**	**-11**	**-10**	**-9.5**	**-8.6**	**-7.7**	**-6.8**	**-6.2**
c.	**Grassland**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**
d.	**Wetlands**	**5.3**	**3.1**	**3.1**	**3.1**	**2.9**	**2.9**	**3.0**	**2.6**
e.	**Settlements**	**2.1**	**2.1**	**2.3**	**2.3**	**2.2**	**2.1**	**1.9**	**1.8**
f.	**Harvested Wood Products**	**128**	**139**	**130**	**129**	**128**	**128**	**129**	**129**

Notes:

a. National totals exclude all GHGs from the LULUCF sector.

b. These summary data are presented in more detail at open.canada.ca.

Figure 2–6 **Trends in Canadian GHG Emissions by IPCC Sector (1990–2018)**

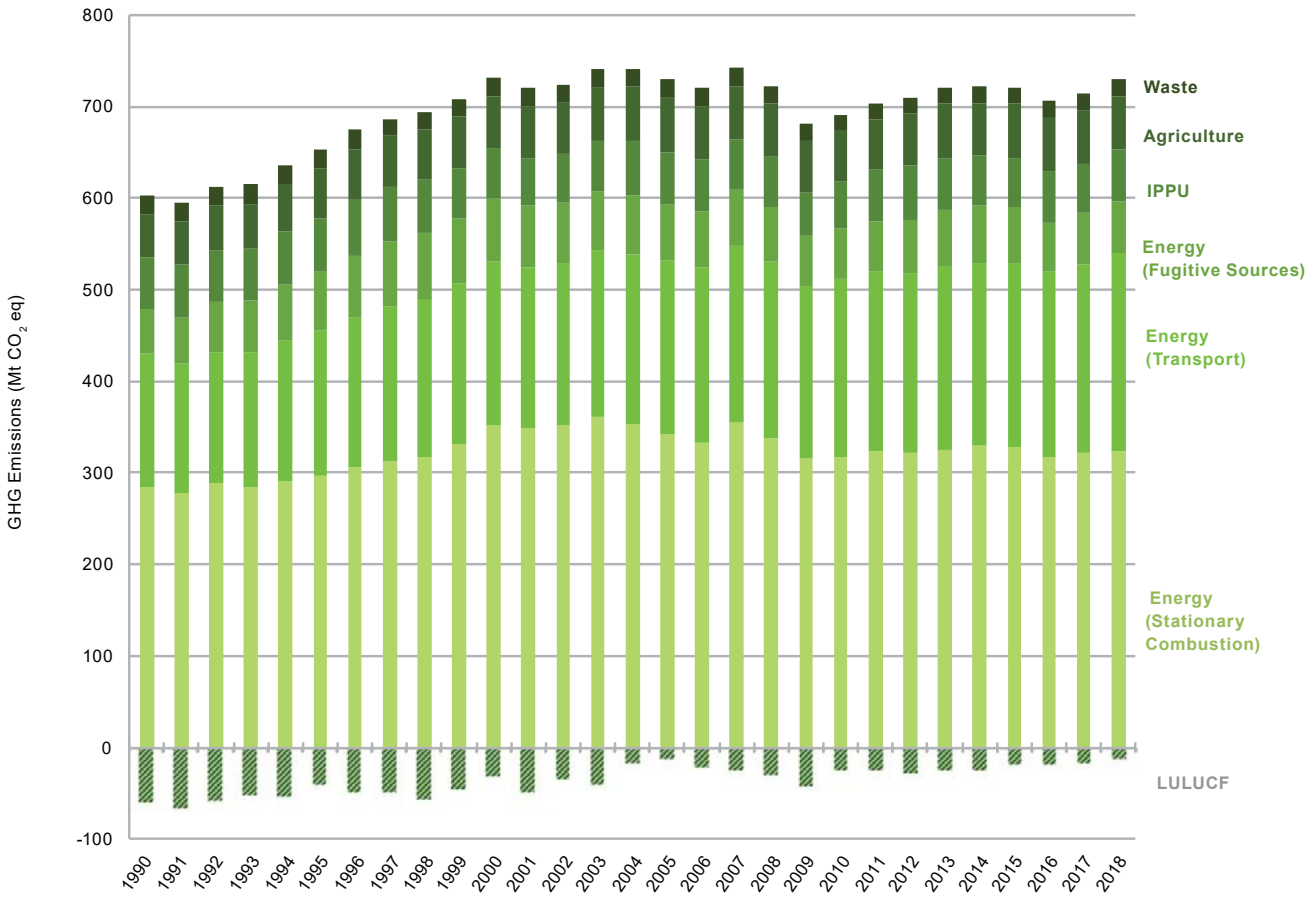
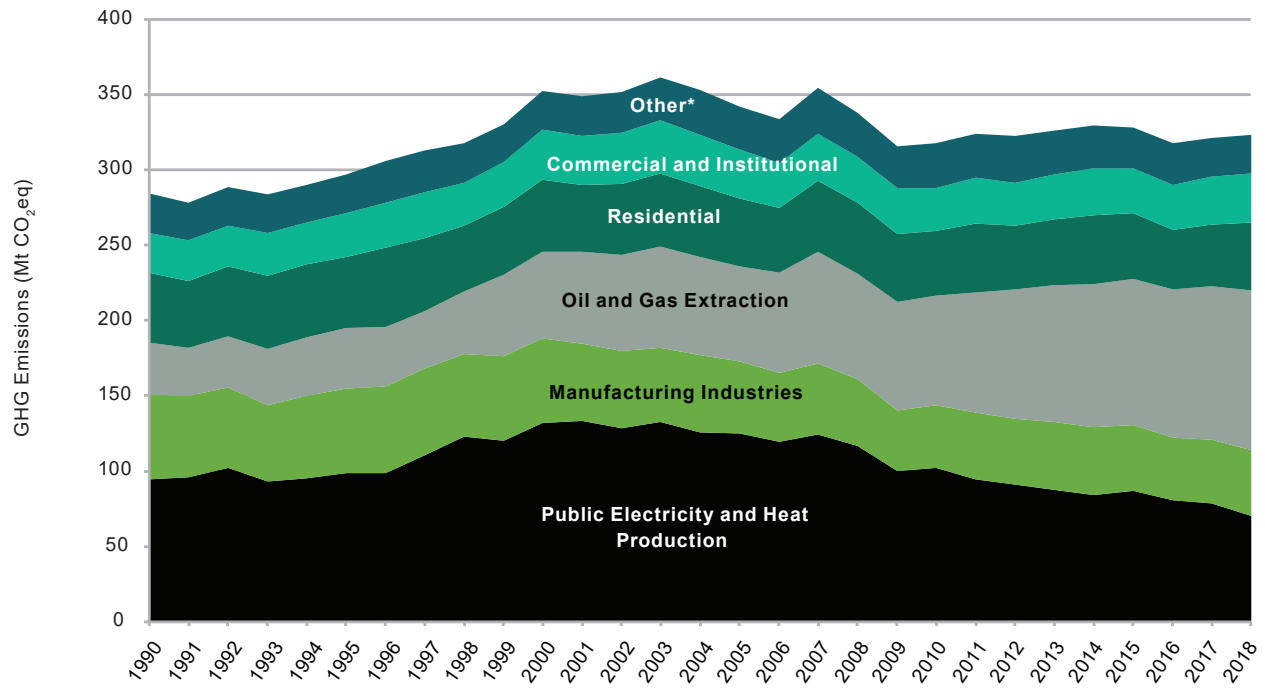


Table 2–4 **GHG Emissions from Stationary Combustion Sources, Selected Years**

	GHG Emissions (Mt CO_2 eq)								Change (%)	
GHG Source Category	1990	2005	2013	2014	2015	2016	2017	2018	1990–2018	2005–2018
Stationary Combustion Sources	**284**	**342**	**326**	**329**	**328**	**318**	**321**	**324**	**14%**	**-5%**
Public Electricity and Heat Production	**95**	**125**	**88**	**84**	**87**	**81**	**78**	**70**	**-26%**	**-44%**
Petroleum Refining	**17**	**20**	**18**	**18**	**18**	**18**	**16**	**16**	**-9%**	**-22%**
Oil and Gas Extraction	**35**	**63**	**91**	**96**	**97**	**99**	**102**	**106**	**205%**	**69%**
Mining	**4.6**	**4.3**	**5.4**	**5.1**	**4.6**	**4.3**	**4.7**	**4.9**	**7%**	**15%**
Manufacturing Industries	**56**	**48**	**45**	**45**	**44**	**42**	**42**	**44**	**-22%**	**-8%**
Iron and Steel	4.9	5.6	5.6	6.0	5.7	5.6	5.9	6.4	28%	14%
Non-Ferrous Metals	3.3	3.7	3.1	2.9	3.1	3.2	3.2	2.8	-16%	-24%
Chemicals	8.3	8.3	12	12	12	11	10	12	41%	39%
Pulp, Paper and Print	14	8.7	6.2	6.1	6.0	5.9	6.3	6.8	-53%	-22%
Cement	4.0	5.4	3.9	4.0	3.9	3.8	4.2	4.0	0%	-27%
Other Manufacturing	21	16	14	14	13	13	13	13	-41%	-23%
Construction	**1.9**	**1.5**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**	**1.4**	**-27%**	**-5%**
Commercial and Institutional	**26**	**33**	**30**	**31**	**30**	**30**	**32**	**33**	**24%**	**0%**
Residential	**47**	**46**	**44**	**46**	**43**	**39**	**41**	**45**	**-3%**	**-1%**
Agriculture/Forestry/Fishing	**2.4**	**2.2**	**3.8**	**3.8**	**3.6**	**3.8**	**3.7**	**3.8**	**57%**	**73%**

Note:
Totals may not add up due to rounding.

Figure 2–7 **Trends in Canadian GHG Emissions from Stationary Combustion Sources (1990–2018)**



*Other includes Petroleum Refining, Construction, Mining, Agriculture and Forestry

(driven by demand) increased by 35% (StatCan 1991-2019), from 474 TWh[3] to 640 TWh. Despite the increasing demand over this period, GHG emissions dropped by 26% (24.6 Mt) between 1990 and 2018. Likewise, between 2005 and 2018 electricity generation rose by 6%, while corresponding emissions fell by 44% (55.0 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 2–8).

Low-emitting non-combustion sources—hydroelectric generation, nuclear power, wind turbines, solar photovoltaic cells and tidal power—accounted for 90% of the increased generation between 1990 and 2018, and for 83% of the total electricity generated in Canada in 2018. Hydroelectric generation alone accounted for 61%, with nuclear following at 16% and non-hydro-based renewables at 6%. The increased level of non-combustion sources in the generation mix in 2018 was the largest contributor to emission reductions since 1990 (24 Mt) and 2005 (37 Mt) (Figure 2–9).

In addition, the fuel mix used for combustion generation has been steadily moving to less GHG-intensive fossil fuels. Between 2005 and 2018, the quantity of electricity generated by natural gas–fired units increased by 45% (14 TWh), while the amount generated by coal and refined petroleum products decreased by about 50% (47 TWh) and 73% (7.9 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 16 Mt between 1990 and 2018, and about 12 Mt between 2005 and 2018.

The efficiency of combustion equipment has also played a role in the GHG emissions reductions. Energy efficiency improvements resulted in an approximately 6.7 Mt reduction in GHG emissions between 1990 and 2018 and a 12 Mt reduction between 2005 and 2018.

3 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 2–8 **Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 1990–2018 (Mt CO_2 eq)**

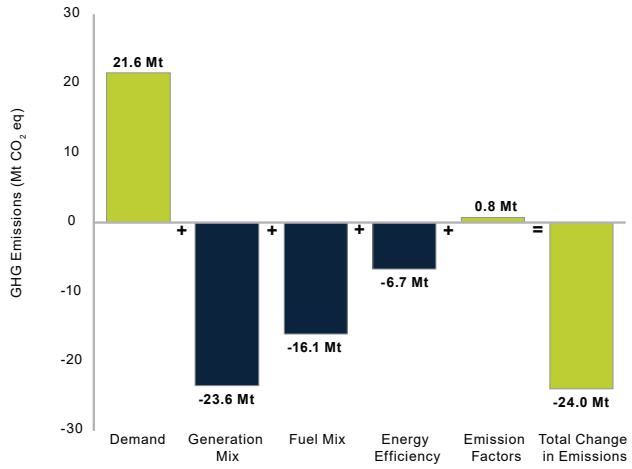
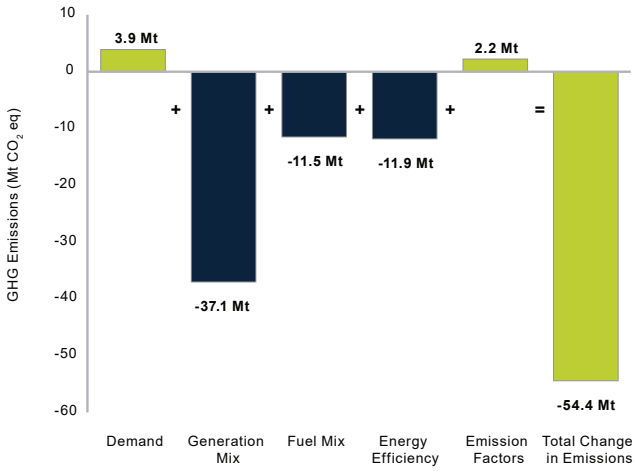


Figure 2–9 **Factors Contributing to the Change in GHG Emissions from the Public Electricity and Heat Production Category, 2005–2018 (Mt CO_2 eq)**



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.

Oil and Gas Extraction (2018 GHG emissions, 106 Mt)

Stationary combustion emissions from Oil and Gas Extraction increased by 71 Mt (205%) between 1990 and 2018 and by 43 Mt (69%) between 2005 and 2018. 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 180% increase in the production of crude bitumen and synthetic crude oil from the oil sands industry since 2005 (AER, 2019; Husky, 2019) 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 96% (Statistics Canada, 1991–2019), and SAGD production has increased by over 1300% (AER, 2019). In general, while increases from Oil and Gas Extraction may originate from multiple activities, they tend to be consistent with the 300% 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 5% (StatCan, 1991–2019) and conventional oil production by 6% (StatCan c, 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). A short discussion of trends in the oil and gas industry by economic sector is also presented in section 2.4.1.

Manufacturing Industries (2018 GHG emissions, 44 Mt)

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

In 2018, GHG emissions from the Manufacturing Industries category were 44 Mt, which represents a 22% decrease from 1990 and an 8% decrease since 2005.

Within the Manufacturing Industries category, the Other Manufacturing and Pulp, Paper and Print subcategories showed the largest emissions decreases. Emissions from the Other Manufacturing subcategory decreased by 8.6 Mt (41%) between 1990 and 2018, in keeping with a 16% decrease in fuel combustion. Between 1990 and 2018, the Pulp, Paper and Print subcategory decreased by 7.7 Mt (53%), based on a 17% reduction in fuel combustion. In contrast, combustion emissions from chemical industries showed the largest increase in emissions within the category, increasing by 3.4 Mt (41%). This is generally consistent with a 19%[4] growth in the production of chemicals between 1990 and 2018.

Residential, Commercial and Institutional

(2018 GHG emissions, 78 Mt)

GHG emissions in the Residential and Commercial and Institutional subcategories come from the combustion of fuels such as natural gas, home heating oil and biomass fuels (non-CO_2 only), primarily to heat residential, commercial and institutional buildings. Emissions in these categories contributed about 78 Mt of GHG emissions in 2018, a 7.0% increase since 1990.

Overall, residential emissions decreased by 1.3 Mt (2.8%) between 1990 and 2018, and 0.4 Mt (0.9%) between 2005 and 2018. Commercial and Institutional emissions increased by 6.4 Mt (24%) between 1990 and 2018, while showing a 0.04 Mt (0.1%) increase between 2005 and 2018. Changes in energy efficiency, 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 Commercial and Institutional subcategories (Figure 2–10 and Figure 2–11).

In the Residential subcategory, population and floor space per capita are the most significant upward drivers of emissions. Since 1990, the 34% increase in population accounts for an emissions increase of 13 Mt, while a 30%[5] increase in floor space per capita accounts for an emissions increase of 11.6 Mt (Figure 2–10). The sum of these two drivers, i.e., 24.6 Mt, represents the

4 Griffin B. 2020. Personal communication (email from Griffin B. to Kay J., Physical Scientist, PIRD, dated January 10, 2020). Canadian Energy and Emissions Data Centre.

5 Wang, J. 2019. Personal communication (email from Wang, J. to Tracey K., Senior Program Engineer, PIRD, dated December 11, 2019). Office of Energy Efficiency, Natural Resources Canada.

Figure 2–10 **Factors Contributing to the Change in Stationary GHG Emissions from the Residential Subcategory between 1990 and 2018**

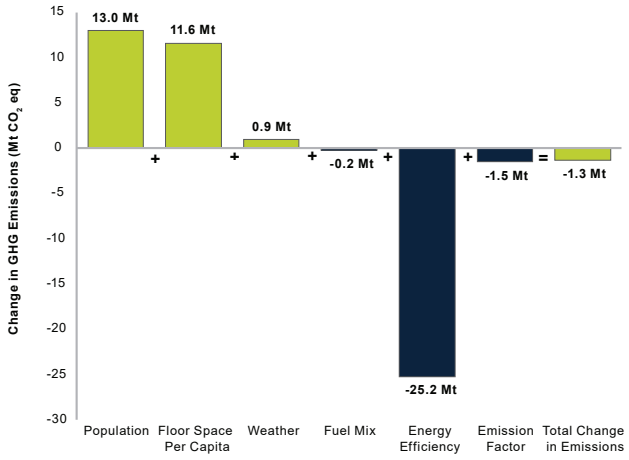
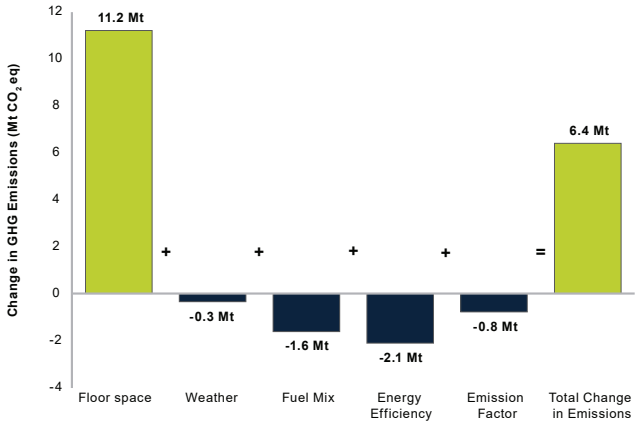


Figure 2–11 **Factors Contributing to the Change in Stationary GHG Emissions from the Commercial and Institutional Subcategory between 1990 and 2018**



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.

total impact of floor space. These increases have been more than offset by improvements in energy efficiency, which are equivalent to a 25.2 Mt decrease in emissions between 1990 and 2018. It should be noted that this pattern of increasing population and floor space per capita being offset by improvements in energy efficiency can also be demonstrated between 2005 and 2018.

In the long term, floor space was the most significant upward driver of emissions in the Commercial and Institutional subcategory, having increased by 48% since 1990.[6] The resulting 11.2 Mt increase in emissions was partially offset by improvements in energy efficiency, equivalent to a 2.1 Mt decrease in GHG emissions (Figure 2–11). A similar offsetting pattern applied over the last decade, which saw emissions fluctuating, but remaining in the area of 30 Mt.

Weather patterns can have a non-negligible effect on emissions when comparing one year with another, as suggested by the close tracking between heating degree-days (HDDs) and GHG emissions (Figure 2–12). The influence that weather can have on space heating requirements and demand for fuels results in emission patterns that mirror inter-annual weather variability.

6 Kaymak, D. 2019. Personal communication (email from Brugger M. to Tracey K., Program Engineer, PIRD, dated December 09, 2019). Economic Analysis Directorate, Environment and Climate Change Canada.

Other Stationary Combustion Sources
(2018 GHG emissions, 26 Mt)

Other Stationary Combustion Sources comprise fuel combustion emissions from the Petroleum Refining, Mining, Construction, and Agriculture and Forestry subcategories. Of this group, the Mining Industry exhibited emissions that are fairly consistent with 1990 levels, while Petroleum Refining emissions have fallen by about 1.6 Mt (9%) since 1990. The Agriculture and Forestry subcategory exhibited increases in GHG emissions of 57% (1.4 Mt) from 1990 to 2018. The Construction subcategory exhibited decreases in GHG emissions of 27% (0.51 Mt) from 1990 to 2018.

2.3.1.2. **Transport** (2018 GHG emissions, 217 Mt)

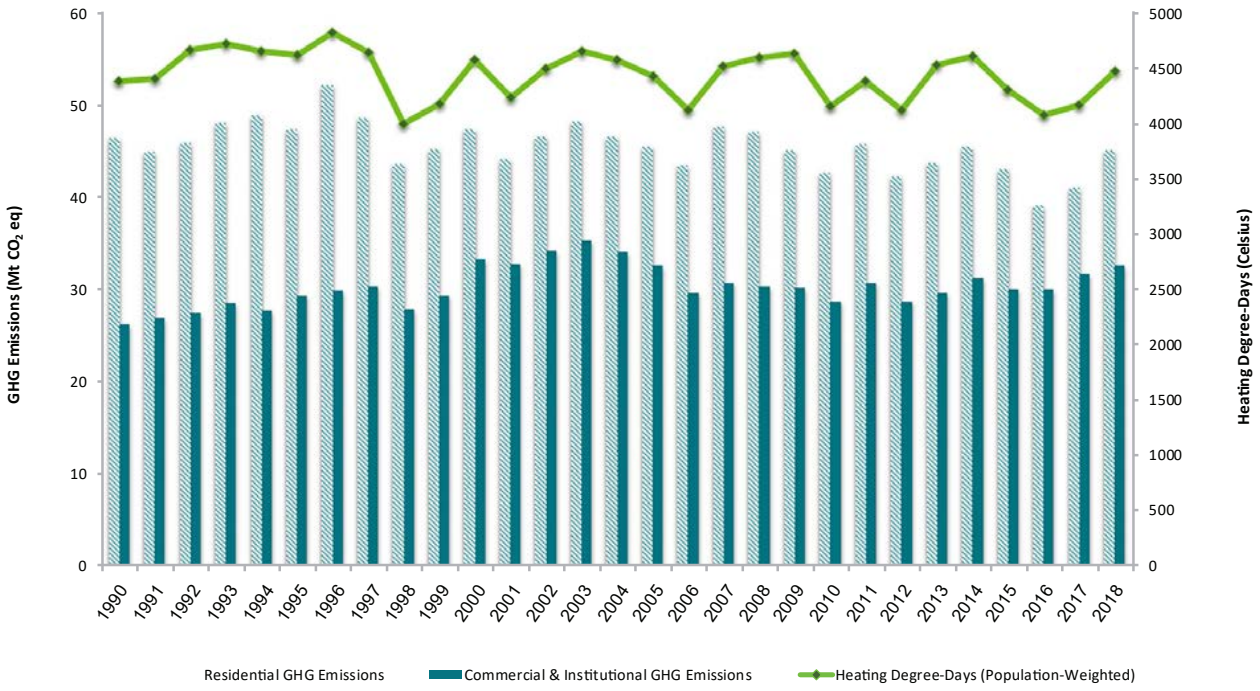
Transport is a large and diverse sector, accounting for 217 Mt of GHG emissions or 36% of Canada's Energy sector emissions in 2018. Transport includes emissions from fuel combustion in six categories: Road Transportation, Domestic Aviation, Domestic Navigation, Railways, Other Transportation (Off-road) and Pipeline Transport (Table 2–5). From 1990 to 2018, Transport emissions rose by 49% (72 Mt), accounting for a significant portion of Canada's emissions growth.

Emissions from Transport result primarily from Road Transportation, which includes personal transportation (light-duty gasoline vehicles and trucks) and heavy-duty diesel vehicles (Figure 2–13). Off-road is the second largest subcategory, accounting for 16% of Transport

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

CRF Code		GHG Emissions Mt CO_2 eq								Change (%)	
		1990	2005	2013	2014	2015	2016	2017	2018	1990–2018	2005–2018
1.A.3	**Transport**	**145**	**191**	**201**	**199**	**201**	**201**	**207**	**217**	**49%**	**14%**
1.A.3.a	**Domestic Aviation**	**7.2**	**7.6**	**7.6**	**7.2**	**7.1**	**7.1**	**7.4**	**8.0**	**11%**	**5%**
1.A.3.b	**Road Transportation**	**84**	**130**	**144**	**142**	**143**	**145**	**148**	**154**	**83%**	**19%**
1.A.3.b.i	Light-Duty Gasoline Vehicles	42	41	36	34	34	35	34	34	-19%	-18%
1.A.3.b.ii	Light-Duty Gasoline Trucks	20	38	43	43	45	48	49	52	156%	36%
1.A.3.b.iii	Heavy-Duty Gasoline Vehicles	6.3	12	13	12	12	13	13	14	116%	17%
1.A.3.b.iv	Motorcycles	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	238%	49%
1.A.3.b.i	Light-Duty Diesel Vehicles	0.5	0.6	0.9	0.9	0.9	0.8	0.8	0.8	74%	34%
1.A.3.b.ii	Light-Duty Diesel Trucks	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.2	670%	244%
1.A.3.b.iii	Heavy-Duty Diesel Vehicles	14	37	50	50	49	47	49	52	280%	41%
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	-99%	-97%
1.A.3.c	**Railways**	**6.9**	**6.6**	**7.3**	**7.5**	**7.1**	**6.5**	**7.5**	**7.6**	**11%**	**16%**
1.A.3.d	**Domestic Navigation**	**3.8**	**4.8**	**4.3**	**4.1**	**3.9**	**3.9**	**4.0**	**4.0**	**7%**	**-15%**
1.A.4	**Other Transportation**	**44**	**42**	**38**	**39**	**40**	**39**	**40**	**44**	**0%**	**4%**
1.A.4.c.ii	Off-Road Agriculture & Forestry	9.0	11	10	10	10	9.7	10	11	24%	-2%
1.A.4.a.ii	Off-Road Commercial & Institutional	1.5	2.4	2.7	2.8	2.7	2.6	2.8	2.9	92%	22%
1.A.2.g.vii	Off-Road Manufacturing, Mining & Construction	9.2	10	12	12	13	12	14	15	58%	40%
1.A.4.b.ii	Off-Road Residential	0.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	420%	0%
1.A.3.e.ii	Off-Road Other Transportation	17	6.4	4.3	4.5	4.8	4.9	5.1	5.3	-68%	-16%
1.A.3.e.i	Pipeline Transport	6.9	10	6.7	7.9	8.2	8.4	7.4	8.3	21%	-18%

Figure 2–12 **Heating Degree-Days (HDDs) and GHG Emissions from the Residential and Commercial and Institutional Subcategories, 1990–2018**



emissions, mainly through diesel fuel combustion. The Domestic Aviation, Domestic Navigation and Railways categories combined contributed to approximately 9% of the Transport emissions in 2018 and, overall, have been stable over the 1990–2018 time series.

Road Transportation (2018 GHG emissions, 154 Mt)

The growth in Road Transportation emissions is largely due to more driving as measured in vehicle kilometres travelled in both the light- and heavy-duty subclasses. The total vehicle fleet has increased by 82% since 1990 (40% since 2005) most notably for light-duty trucks and heavy-duty vehicles (Table 2–6). The vehicle fleet grew steadily for most vehicle sectors due to population and economic factors. Absolute growth in vehicles was greater in 2005–2018 compared with the 1990–2005 interval. Since 2005, the overall fleet expansion explains the 27% increase in the total kilometres travelled for the light-duty vehicle fleet, despite a reduction in kilometres driven per vehicle. While no emissions were reported for electric vehicles in the transportation sector, approximately 24 000 fully electric vehicles were in the vehicle fleet in 2018.

Light-Duty Gasoline Vehicles
(2018 GHG emissions, 34 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, the total number of light-duty gasoline vehicles and VKTs increased, while the fleet average fuel consumption ratio decreased, resulting in a net emissions decrease of 19% and 18% (from 42 Mt and 41 Mt in 1990 and 2005, respectively, to 34 Mt in 2018). 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 2–14). Implementation of emission control technologies and increased use of biofuels since the 1990s have also resulted in decreased emissions.

Light-Duty Gasoline Trucks (2018 GHG emissions, 52 Mt)

On average, light-duty trucks—including sport utility vehicles (SUVs), many pickups and all minivans—emitted 31% more GHGs per kilometre than cars in 2018. Emissions from Light-Duty Gasoline Trucks increased 156% between 1990 and 2018 (from 20 Mt

Figure 2–13 **Trends in Canadian GHG Emissions from Transport (1990–2018)**

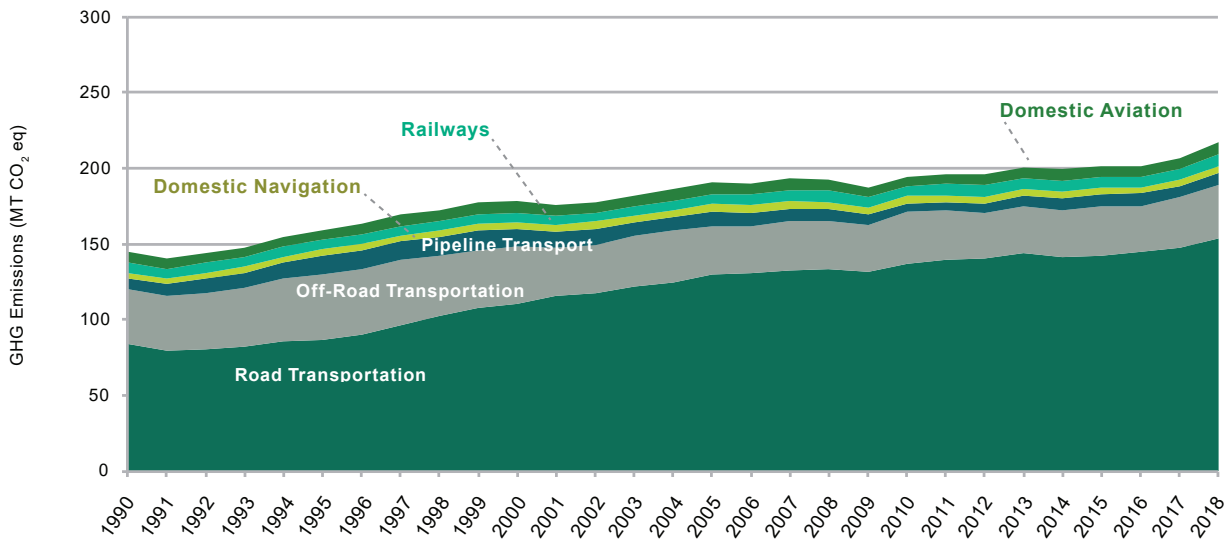


Table 2–6 **Trends in Vehicle Populations for Canada, 1990–2018**

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
2013	12 264	10 243	2 270	25 530
2014	12 570	11 003	2 303	26 657
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
Change since 1990	10%	280%	179%	82%
Change since 2005	7%	86%	57%	40%

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

in 1990 to 52 Mt in 2018). While a decrease in the associated fleet fuel consumption ratios was observed between 1990 and 2018, this was offset by an increase in both vehicle population and associated VKTs, reflecting the trend towards the increasing use of SUVs, minivans and pickups for personal transportation.

Heavy-Duty Diesel Vehicles (2018 GHG emissions, 52 Mt)

In 2018, emissions from Heavy-Duty Diesel Vehicles contributed 52 Mt to Canada's total GHG emissions (an increase of about 280% from 1990 and 41% 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 f). 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)
(2018 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 2018, off-road manufacturing, mining and construction and off-road agriculture and forestry account for 41% and 32% of off-road emissions, respectively. The net emissions for the whole off-road subcategory have decreased by 4% since 1990 and increased by 11% since 2005.

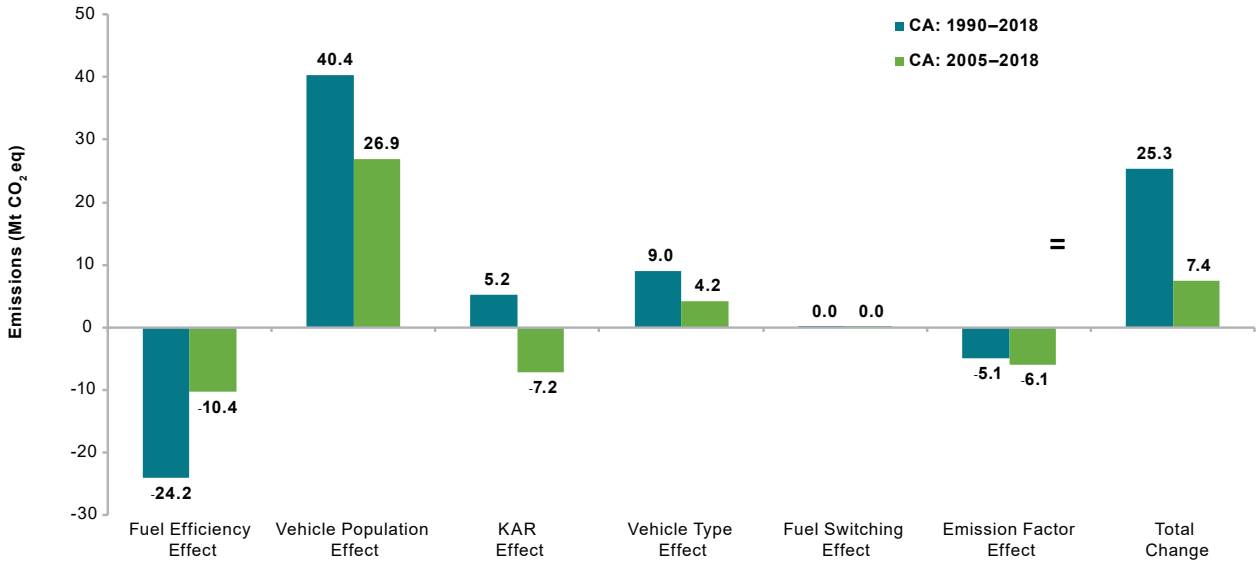
Other Transportation (Pipeline Transport)

(2018 GHG emissions, 8.3 Mt)

Pipeline emissions result from the combustion of natural gas at compressor stations used for natural gas transport. In 2018, over 99% of marketable natural gas production occurred in Western Canada: Alberta (69.1%), British Columbia (27.5%) and Saskatchewan (2.4%). While these provinces account for 67% of marketable natural gas consumption, Ontario, the most populous province, accounts for approximately 24% of natural gas consumption but produces less than 0.05% of natural gas (StatCan, 1991–2019). 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 in 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, 1991–2019) and as more natural gas was consumed in Alberta's Oil Sands industry. In general, as imports into Ontario increase, inter-regional transfers of Western gas decrease, resulting in a decrease in combustion emissions from pipelines (Figure 2–15). The increase in pipeline emissions in 2018 reflects the increase in inter-regional transfers to Ontario.

Figure 2–14 **Factors Contributing to Change in Light-Duty Vehicle Emissions, 1990–2018 and 2005–2018**



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 (1/100 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, 1990–2018 and 2005–2018.

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.

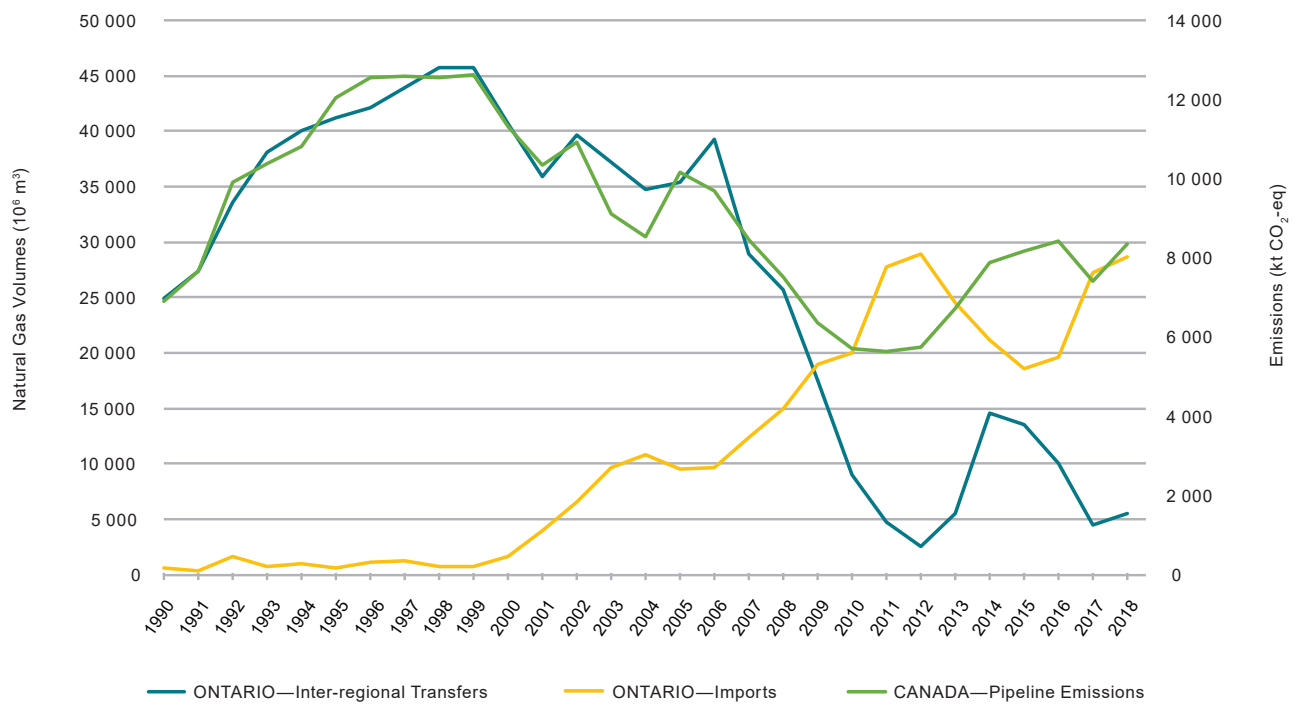
Kilometre accumulation (KAR) effect refers to the change in emissions due to average annual driving rates.

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.

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



2.3.1.3. **Fugitive Sources** (2018 GHG Emissions, 55 Mt)

Fugitive emissions are the 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%).

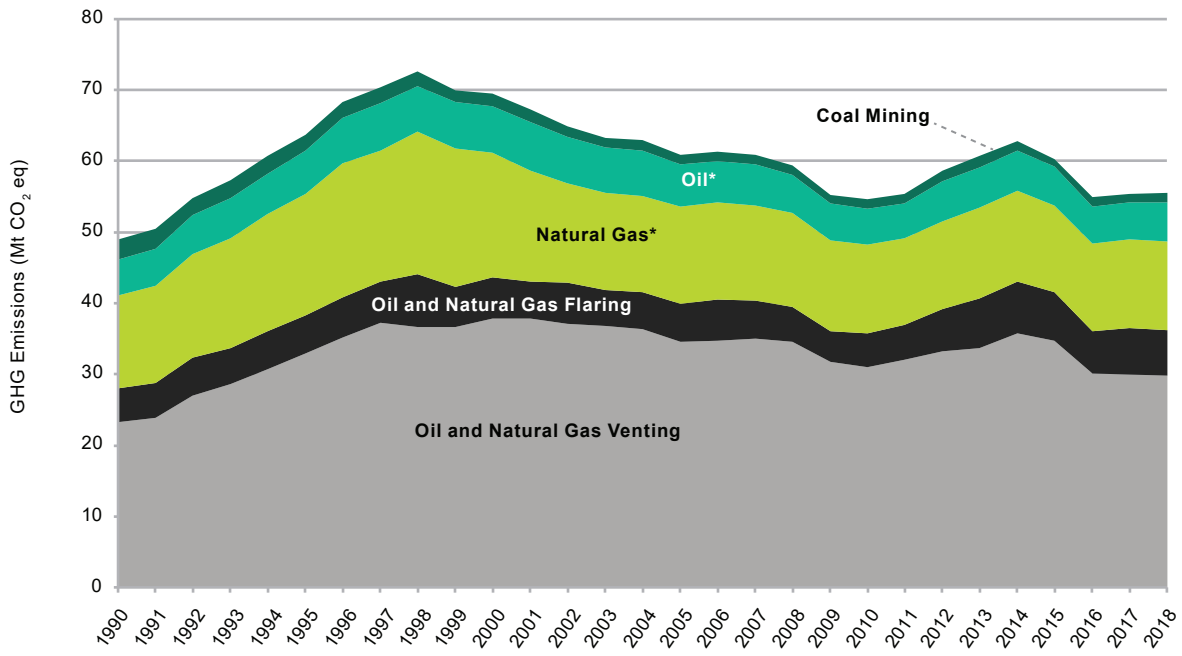
Overall, fugitive emissions increased from 49 to 55 Mt (14%) between 1990 and 2018 (Table 2–7), contributing 5.2% to the growth in total Canadian emissions between 1990 and 2018. Fugitive emissions from Oil and Natural Gas alone increased by 8 Mt (17%), while releases from Coal Mining decreased by 1.5 Mt (53%), mainly due to mine closures in Eastern Canada.

The 17% growth in Oil and Natural Gas fugitive emissions since 1990 (Figure 2–16) is a result of increased activity in the Oil and Gas sector. Since 1990, over 400,000 oil and gas wells have been drilled, and the number of producing oil and gas wells has increased by 190% (CAPP, 2019). As the number of facilities in the oil and gas industry have become more abundant and disperse, the sources of fugitive emissions have increased significantly.

Even though production from the oil sands accounted for approximately 70% of total oil production in Canada in 2018, it accounted for only 15% of total oil and gas fugitive emissions. Since the vast majority of fugitive emissions originate from conventional wells, the increase in bitumen production from the oil sands has little impact on fugitive emissions.

Fugitive emissions peaked in the late 1990s (Figure 2–16); until 2010, the combined effect of improved inspection and maintenance programs, better industry practices, technological improvements and regulations resulted in a decreasing trend in emissions. For example, in 1999 the province of Alberta introduced Directive 060 regulations to reduce flaring and venting emissions from its oil industry by requiring operators to connect to gas gathering systems under specific conditions (AER, 2014). In 2006, leak detection and repair best management practices were added to *Directive 060* to reduce emissions from fugitive equipment leaks. Between 2000 and 2010, these measures contributed to a reduction in fugitive emissions of 8.3 Mt (20%) in Alberta.

Figure 2–16 **Trends in Canadian GHG Emissions from Fugitive Sources (1990–2018)**



Notes
* 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	2013	2014	2015	2016	2017	2018	1990–2018	2005–2018
Fugitive Sources[a]	**49**	**61**	**61**	**63**	**60**	**55**	**55**	**55**	**13%**	**-9%**
Coal Mining	**2.8**	**1.4**	**1.5**	**1.3**	**1.1**	**1.3**	**1.2**	**1.3**	**-53%**	**-4%**
Oil and Natural Gas	**46**	**60**	**59**	**62**	**59**	**54**	**54**	**54**	**17%**	**-9%**
Oil[b]	5.0	5.9	5.7	5.6	5.4	5.2	5.2	5.5	9%	-8%
Natural Gas[b]	13	14	13	13	12	12	12	12	-6%	-10%
Venting	23	35	34	36	35	30	30	30	28%	-14%
Flaring	4.7	5.3	7.0	7.2	6.9	5.9	6.5	6.5	37%	23%

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.

In 2010, British Columbia introduced the *Flaring and Venting Reduction Guideline* (BCOGC, 2015), and in 2012, Saskatchewan adopted the *Saskatchewan Upstream Petroleum Industry Associated Gas Conservation Standards* (Directive S-10), both of which are similar to Directive 060.

In spite of these efforts, emissions from venting and flaring increased by 7 Mt (20%) between 2010 and 2014. Oil producers are only required to connect associated gas production to gas gathering systems beyond specific production volumes and economic indicators. Smaller and more disperse facilities along with low natural gas prices resulted in more associated gas being vented and flared.

From 2014 to 2016, emissions dropped by almost 8 Mt (13%), mainly due to reductions in venting and flaring. Since 2016, emissions have been fairly consistent. Fluctuations in fugitive emissions since 2012 demonstrate the contrasting effects of better industry practices versus production activity. Although technological improvements and regulations have had a positive effect on emission reductions, they are affected by economics and can be overshadowed by the impacts of changing industry activity (i.e. production, drilling, number of active facilities, etc.), which is the primary driver of emission growth.

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.

All other current and previous CO_2 Transport and Storage in Canada are associated with enhanced oil recovery operations at Weyburn, Saskatchewan. Beginning in 2014, most of the CO_2 captured at the Boundary Dam coal-fired power plant in Saskatchewan was also transported to Weyburn for enhanced oil recovery.

Details of CO_2 capture volumes are presented in Table A10-3 (Annex 10). Consistent with the origin of the captured CO_2 (an upgrading facility and coal power plant), 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.

Emissions from CO_2 transport systems are presented in the annual GHG Emission Summary tables for Canada in Annex 9 and by provincial/territorial regions in Annex 11 of this report.

2.3.2. Industrial Processes and Product Use (2018 GHG emissions, 56 Mt)

The IPPU sector includes GHG emissions that result from manufacturing processes and use of products. Subsectors include Mineral Products; the 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 56 Mt (7.7%) to Canada's 2018 emissions, compared with 57 Mt (9.4%) in 1990, a decrease of approximately 0.6 Mt or 1.0%. 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 in Adipic Acid Production (N_2O), Aluminium Production (PFCs), Use of SF_6 in Magnesium Production (SF_6), and Iron and Steel Production (CO_2) since 1990. These reductions were mainly offset by increases observed in Non-Energy Products from Fuels and Solvent Use (CO_2),[7] and Production and Consumption of Halocarbons (HFCs) (Figure 2–17 and Table 2–8). In 2018, the largest contributions to emissions in the sector originated from

7 Non-Energy Products from Fuels and Solvent Use 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.

Figure 2–17 **Trends in Canadian GHG Emissions from IPPU Sources (1990–2018)**

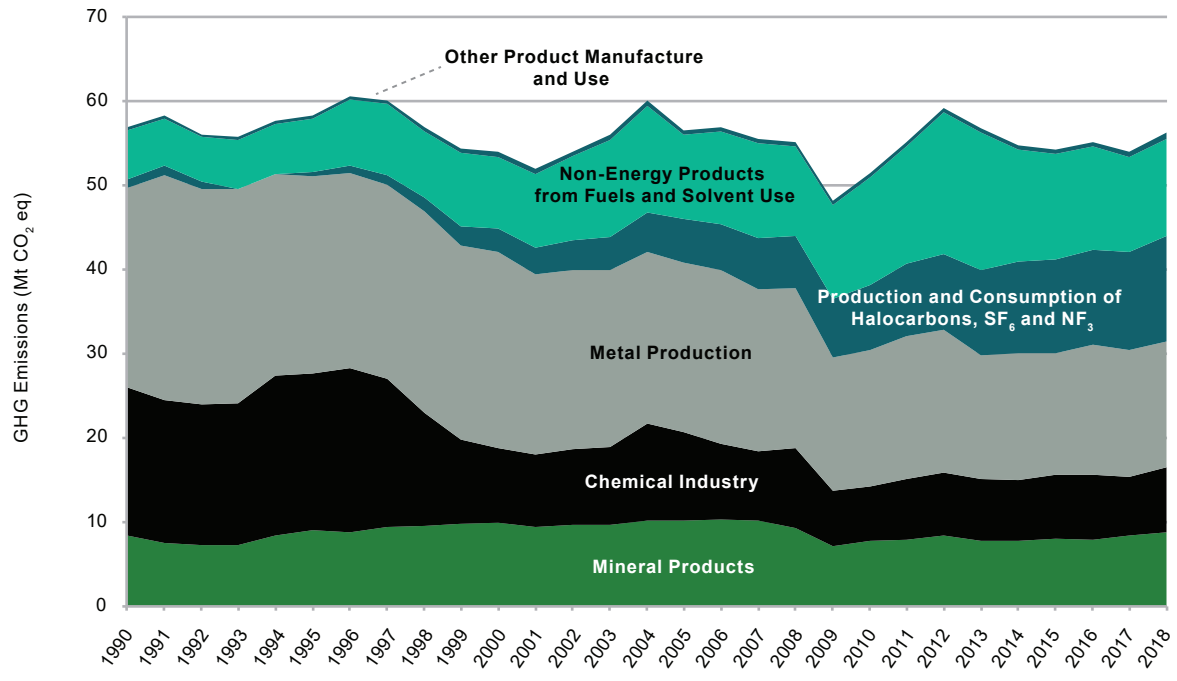


Table 2–8 **GHG Emissions from IPPU Categories, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2013	2014	2015	2016	2017	2018	1990–2018	2005–2018
Total—Industrial Processes	**57**	**57**	**57**	**55**	**54**	**55**	**54**	**56**	**-1%**	**-0.4%**
Mineral Products	**8.4**	**10**	**7.8**	**7.8**	**8.1**	**7.9**	**8.5**	**8.9**	**5%**	**-14%**
Cement Production	5.8	7.6	6.0	5.9	6.3	6.2	6.8	7.2	25%	-6%
Lime Production	1.8	1.7	1.4	1.5	1.4	1.4	1.4	1.4	-24%	-22%
Mineral Product Use	0.9	0.9	0.4	0.4	0.4	0.4	0.3	0.3	-62%	-64%
Chemical Industry	**18**	**10.4**	**7.3**	**7.2**	**7.6**	**7.7**	**6.9**	**7.7**	**-56%**	**-26%**
Ammonia Production	2.8	2.7	2.9	2.5	2.8	2.8	2.6	2.4	-12%	-10%
Nitric Acid Production	1.0	1.2	1.0	1.0	1.1	1.0	0.9	1.1	13%	-9%
Adipic Acid Production	10	2.5	-	-	-	-	-	-	-100%	-100%
Petrochemical Production & Carbon Black Production	3.5	4.0	3.4	3.7	3.6	3.9	3.4	4.1	17%	4%
Metal Production	**24**	**20**	**15**	**15**	**14**	**15**	**15**	**15**	**-37%**	**-26%**
Iron and Steel Production	10	10	8.0	8.9	8.5	9.3	9.0	9.3	-11%	-9%
Aluminium Production	10	8.7	6.5	5.8	5.7	6.0	6.0	5.5	-47%	-37%
SF_6 Used in Magnesium Smelters and Casters	3.0	1.2	0.2	0.2	0.2	0.1	0.1	0.1	-95%	-89%
Production and Consumption of Halocarbons, SF_6 and NF_3	**1.0**	**5.1**	**10.1**	**11**	**11**	**11**	**12**	**13**	**1187%**	**145%**
Non-Energy Products from Fuels and Solvent Use	**5.8**	**10**	**16**	**13**	**13**	**12**	**11**	**12**	**99%**	**16%**
Other Product Manufacture and Use	**0.4**	**0.5**	**0.6**	**0.5**	**0.6**	**0.6**	**0.7**	**0.7**	**97%**	**36%**

Note:
Totals may not add up due to rounding.

Metal Production (15 Mt), followed by the Consumption of Halocarbons (mostly HFCs) and Non-Energy Fuel Use, accounting for 13 Mt and 12 Mt, respectively (Table 2–8).

2.3.2.1. Mineral Products (2018 GHG Emissions, 8.9 Mt)

Mineral Products include Cement Production, Lime Production and uses of carbonates (magnesite, soda ash and limestone). Although emissions in this subsector have varied over the years, in 2018 they had more or less returned to their 1990 levels.

Cement production dominates this category, accounting for 81% of emissions from Mineral Products in 2018. Fluctuations over the years largely result from variations in clinker capacity, especially circa 2009, with some gradual recovery with the opening of a new facility in Québec in 2017.

2.3.2.2. Chemical Industry (2018 GHG Emissions, 7.7 Mt)

A decrease of 9.9 Mt (56%) from 1990 to 2018 is observed in emissions from the Chemical Industry as a whole. The main driver of emission reductions in this industry was the discontinuation of adipic acid production since 2009; this alone represents a decrease of 10.3 Mt from 1990.[8] Other changes included a small decrease (0.34 Mt) in Ammonia Production and small increases in Nitric Acid Production and Petrochemical and Carbon Black Production (0.12 Mt and 0.6 Mt, respectively).

2.3.2.3. Metal Production (2018 GHG Emissions, 15 Mt)

Emission reductions in the production of magnesium, aluminium, and iron and steel contributed to Metal Production overall reductions of 8.8 Mt (37%) between 1990 and 2018, and of 5.3 Mt (26%) from 2005–2018.

The aluminium industry decreased its PFC emissions by 6.9 Mt (92%), while increasing production by 87% between 1990 and 2018 (AAC, 2018), largely due to technological improvements. The Magnesium Production industry 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 2018, emissions in the iron and steel industry decreased by 0.98 Mt (9.5%). The main driver behind the decrease in emissions was reductions in overall production levels (StatCan, 2004–2012; CSPA, 2013–2018).

8 Hendriks J. 2013. Personal communication (email from Hendriks J. from 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 (2018 GHG Emissions, 13 Mt)

There is currently no HFC production in Canada. HFC-23 was generated as a by-product of HCFC-22 production, which ended in 1992. Hence, all emissions in the category are associated with the consumption of halocarbons only. The consumption of HFCs accounted for a 12 Mt increase in emissions from 1995 to 2018 or a 7.4 Mt increase (145%) from 2005 to 2018. 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, NF_3) in this subsector do not have a significant impact on emissions trends as the next largest source (PFCs) has emissions of less than 1% of the HFC emissions value.

2.3.2.5. Non-Energy Products from Fuels and Solvent Use (2018 GHG Emissions, 12 Mt)

The Non-Energy Products from Fuels and Solvent Use category is one of the largest emission sources in the IPPU sector, with emissions increasing by 5.7 Mt (99%) from 1990 to 2018. The observed change is mostly attributable to the emissions from the feedstock use of waxes, paraffin and unfinished products, which increased by 4.7 Mt (920%) over the period.

2.3.3. Agriculture Sector (2018 GHG Emissions, 59 Mt)

In 2018, emissions from the Agriculture sector accounted for 59 Mt or 8.1% of total GHG emissions in Canada, a decrease of 0.5 Mt or 1% from 2005 levels, but corresponding to an increase of 12 Mt or 27% since 1990 (Figure 2–18, Table 2–9). In 2018, the Agriculture sector accounted for 31% of national CH_4 emissions and 76% of national N_2O emissions, up from 53% of the national N_2O emissions in 1990.

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

Figure 2–18 **Trends in Canadian GHG Emissions from Agriculture Sources (1990–2018)**

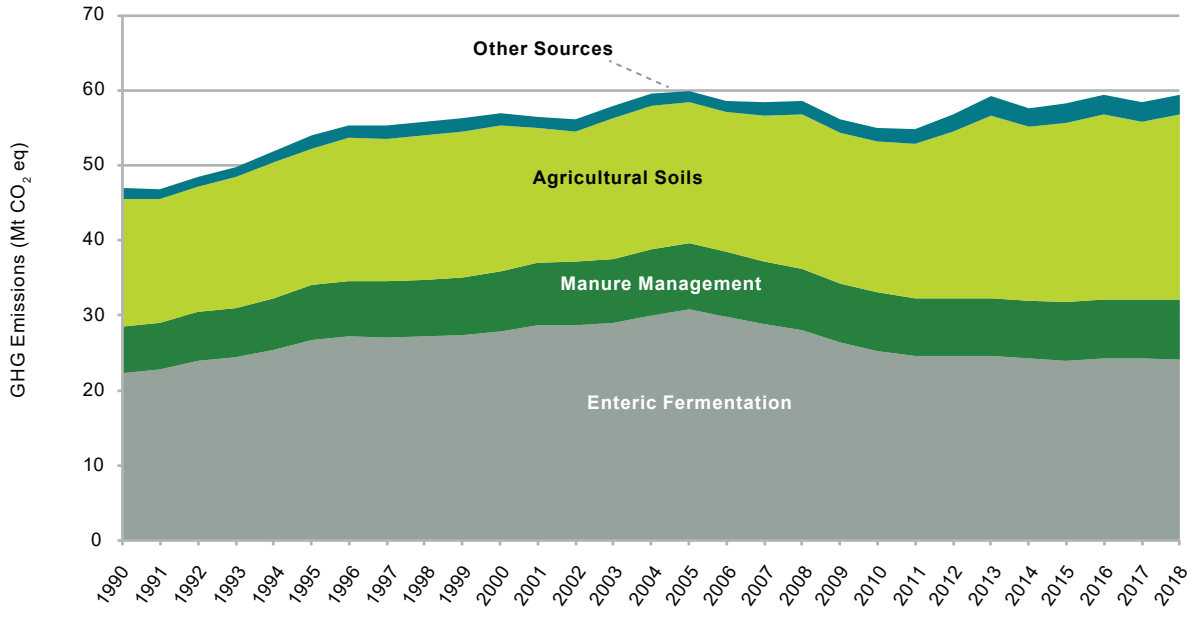


Table 2–9 **GHG Emissions from Agriculture, Selected Years**

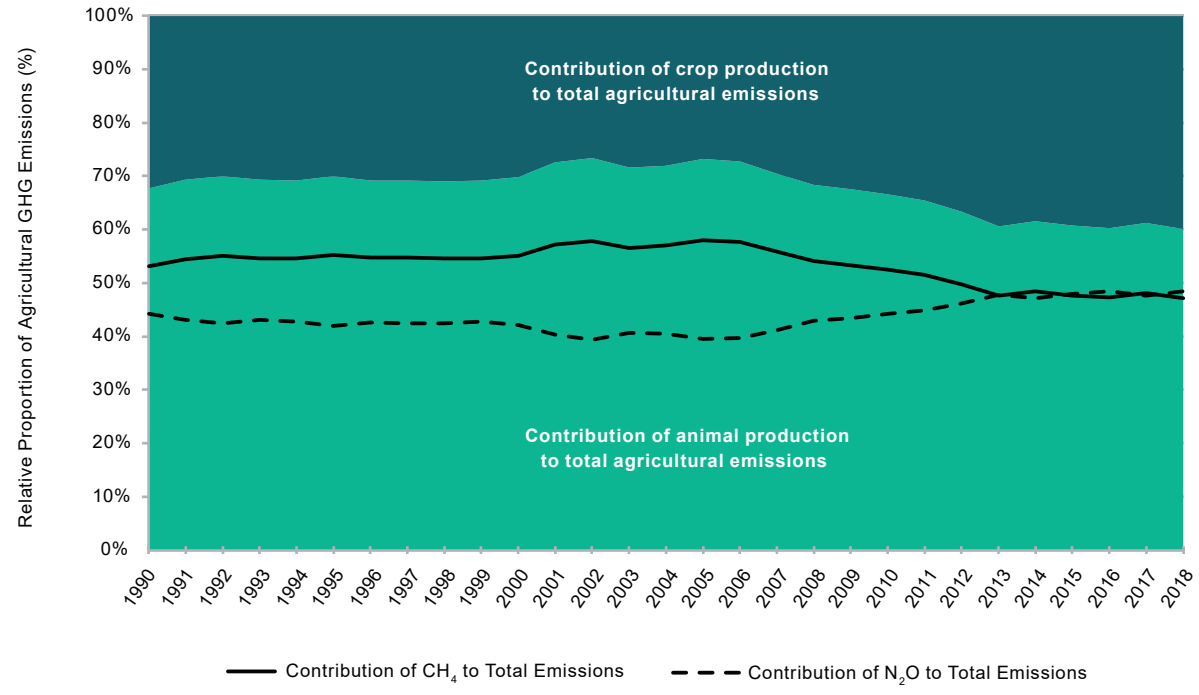
GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2013	2014	2015	2016	2017	2018	1990–2018	2005–2018
Agriculture	**47**	**60**	**59**	**58**	**58**	**59**	**58**	**59**	**27%**	**-1%**
Enteric Fermentation	22	31	25	24	24	24	24	24	8%	-22%
Manure Management	6.1	8.8	7.8	7.7	7.8	7.9	7.9	7.9	29%	-10%
Agricultural Soils	17	19	24	23	24	25	24	25	45%	32%
Field Burning of Agricultural Residues	0.22	0.04	0.05	0.05	0.06	0.05	0.05	0.05	-78%	15%
Liming, Urea Application and Other Carbon-containing Fertilizers	1.2	1.4	2.7	2.5	2.6	2.5	2.5	2.6	119%	83%

Note:
Totals may not add up due to rounding.

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

The main drivers of the emission trend in the Agriculture sector are the fluctuations in livestock populations and continuous increases in the application of inorganic nitrogen fertilizers in the Prairie provinces. Beef, swine and poultry populations in Canada in 2018 are 7%, 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 (60%), considerably lower than the proportion in 2005 (73%) (Figure 2–19). As a result of this shift, total agricultural emissions now consist of slightly higher proportions of N_2O (mainly from crop production) than CH_4 (from livestock production), which is unprecedented. The

Figure 2–19 **Proportions of Canadian Agricultural Greenhouse Gas Emissions Emitted as Methane and Nitrous Oxide, or attributed to Livestock and Crop Production (1990–2018)**



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).

2.3.3.1. Enteric Fermentation (2018 GHG Emissions, 24 Mt)

Emissions from enteric fermentation originate almost entirely (96%) from Cattle Production in Canada. From 1990 to 2018, emissions increased from 22 Mt to 24 Mt, or 8%. Emissions increased from 1990 to 2005 mainly as a result of an increase in the population and weight of beef cattle, driven by high commodity prices. Beef populations peaked in 2005, and subsequently declined by 26% due to a sharp decrease in prices after an outbreak of bovine spongiform encephalopathy (BSE, or mad cow disease) in 2003. In recent years, animal commodity prices remained strong, and animal populations and livestock emissions have stabilized.

At the same time, emissions associated with dairy cows have fallen by approximately 17% since 1990, mainly due to a 29% reduction in the dairy cow population from 1990 to 2018 (StatCan e). However, the average dairy cow today also consumes more feed and produces 48% 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 21% increase in per-animal emissions since 1990.

2.3.3.2. Manure Management (2018 GHG emissions, 7.9 Mt)

Emissions from animal manure management systems increased from 6.1 Mt in 1990 to 7.9 Mt in 2018 (or by 29%), driven by increases in livestock populations of beef, swine and poultry. The storage of manure results in both CH_4 (14% total agricultural CH_4) and N_2O (14% total agricultural N_2O). The management of beef and poultry manure produces mainly N_2O, whereas pork manure produces mainly 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 3.8 Mt (57%). N_2O emissions closely follow the trend in beef populations, increasing from 3.7 Mt in 1990 to 4.9 Mt (34%) in 2005 and subsequently declining to 4.1 Mt (11%) in 2018. 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 (2018 GHG Emissions, 25 Mt)

Emissions from Agricultural Soils originate from the application of inorganic and organic (manure and biosolids) nitrogen fertilizers and from crop residue decomposition; these emissions can be modified by crop management practices. Emissions increased from 17 Mt in 1990 to 25 Mt in 2018, an increase of 45%, due mainly to an increase in inorganic nitrogen fertilizer use.

Total emissions from the application of inorganic nitrogen fertilizers increased from 6.8 Mt in 1990 to 14 Mt in 2018, an increase of 101%, as inorganic nitrogen fertilizer consumption increased steadily from 1.2 Mt N to 2.6 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 2018. The first period was a result of the intensification of cropping systems and the reduction of summer fallow on the Canadian Prairies. The second period reflected an increase in grain prices that encouraged farmers to use more nutrient inputs and convert lands from perennial to annual crop production, coinciding with a reduction in grazing cattle operations on the Canadian Prairies. The increase in fertilizer use since 1990 also resulted in a 1.6 Mt (201%) increase in emissions of CO_2 from urea-based carbon-containing fertilizers.

Emissions from crop residue decomposition ranged from a minimum of 3.3 Mt in 2002 (a drought year) to a maximum of 6.5 Mt in 2017, depending mainly on weather conditions and their impact on crop yield. 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 summer fallow and irrigation, contributed 1.3 Mt to total emissions from soils. The adoption of conservation tillage (approximately 17 million hectares of cropland since 1990) and intensification of cropping systems (92% reduction in summer fallow areas) have reduced emissions by 0.91 Mt in 2018.

2.3.4. Land Use, Land-Use Change and Forestry Sector (2018 Net GHG Removals, 13 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 (HWP) 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 2018, LULUCF was estimated to remove 13 Mt of CO_2 from the atmosphere, compared with net removals of 60 Mt in 1990 and 13 Mt in 2005. The long-term trend in net removals is mainly driven by the decrease in net CO_2 removals from Forest Land from 1990 to 2007 (Figure 2–20 and Table 2–10), partially attenuated by increasing net CO_2 removals in Cropland until 2006 and a continued decrease in emissions from the conversion of forest to other land use over the entire time series. Net removals from the LULUCF sector have fluctuated over recent years, increasing from 13 Mt in 2005 to 42 Mt in 2009, and have since decreased to 13 Mt in 2018.

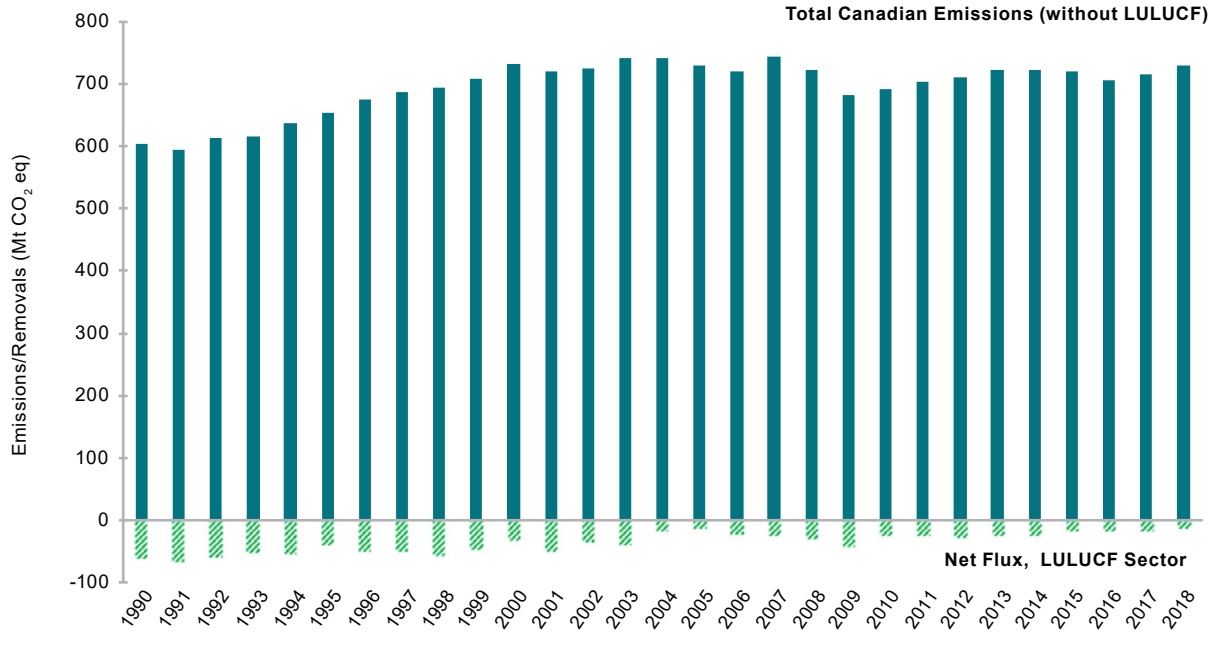
National totals are reported to the United Nations Framework Convention on Climate Change (UNFCCC) with and without emissions and removals in the LULUCF sector. The estimated net removals in the LULUCF sector amount to 9.9%, 1.7% and 1.8% of Canada's total GHG emissions in 1990, 2005 and 2018, respectively.

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

Sectoral Category	Net GHG Flux (Mt CO_2 eq)								Change	
	1990	2005	2013	2014	2015	2016	2017	2018	1990–2018	2005–2018
Land Use, Land-Use Change and Forestry TOTAL	**-60**	**-13**	**-25**	**-25**	**-18**	**-19**	**-16**	**-13**	**47**	**-0.2**
a. Forest Land	-200	-150	-150	-150	-140	-140	-140	-140	63	5.7
b. Cropland	8.1	-11	-10	-10	-9	-7.7	-6.8	-6.2	-14	4.8
c. Grassland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d. Wetlands	5.3	3.1	3.1	3.1	2.9	2.9	3.0	2.6	-2.7	-0.4
e. Settlements	2.1	2.1	2.3	2.3	2.2	2.1	1.9	1.8	-0.3	-0.2
f. Harvested Wood Products	130	140	130	130	130	130	130	130	0.8	-10

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

Figure 2–20 **Net Flux from LULUCF Relative to Total Canadian Emissions, 1990–2018**



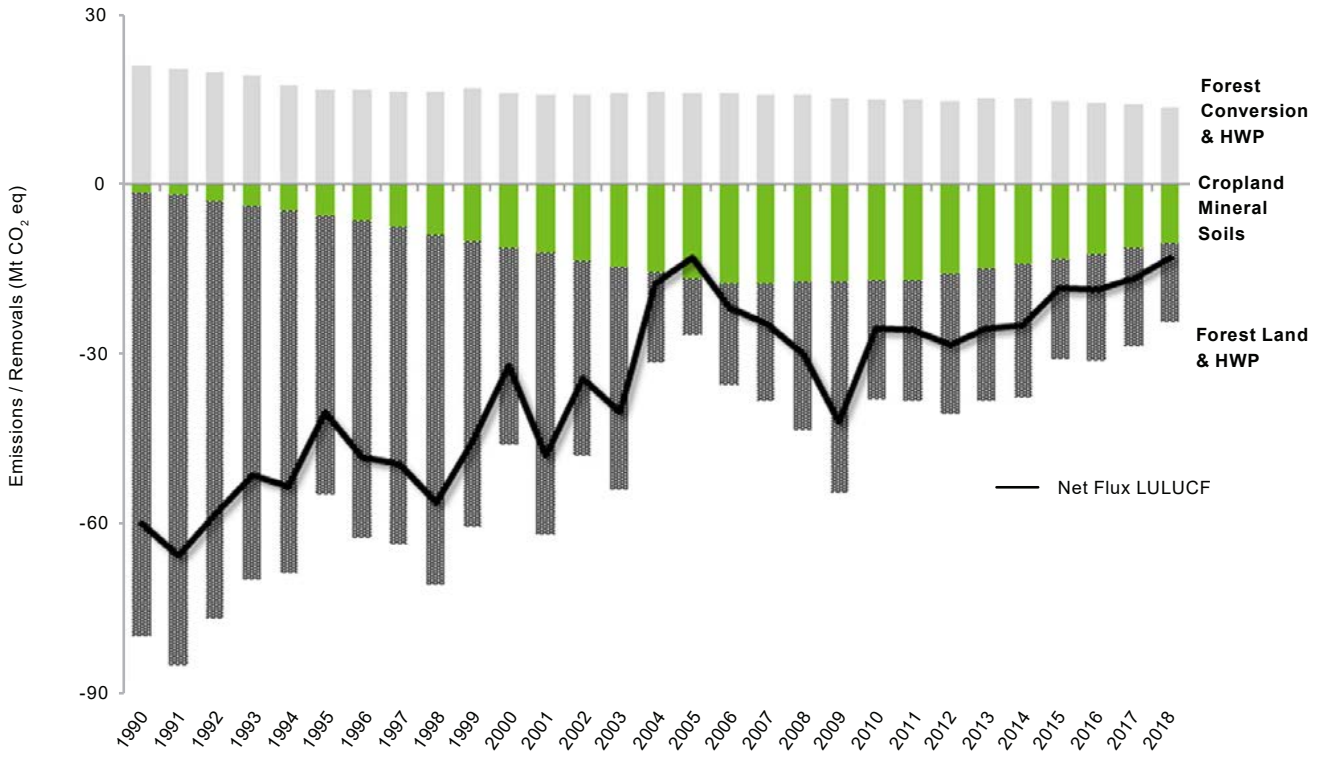
2.3.4.1. **Forest Land and Harvested Wood Products** (2018 GHG Removals, 14 Mt)

The Forest Land and Harvested Wood Products (HWP) categories combined include GHG fluxes between the atmosphere and Canada's managed forests and emissions from harvested wood products originating from domestic harvest. The total net flux from managed forests and HWP amounted to an estimated removal of 14 Mt of CO_2 in 2018 (Figure 2–21), which combines net removals of 140 Mt from Forest Land and net emissions of 126 Mt from HWP.

Net removals from Forest Land—after separating GHG fluxes associated with severe natural disturbances from anthropogenic fluxes—decreased from 200 Mt in 1990 to 140 Mt in 2007. The predominant anthropogenic trend directly associated with human activities in managed forests is the 32% 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 140 and 150 Mt. Harvest levels have gradually increased since 2009, but in 2018 were still 24% below their peak in 2004. This recent trend is driven by a slow increase in the global demand for Canadian wood products since 2010 (NRCan, 2018).

The decrease in forest removals nationally is dominated by trends in the Montane Cordillera and Boreal Plains that can be traced back to the severe insect outbreaks in the Montane Cordillera in the early 2000s. Subsequent high rates of harvest on impacted forest stands reset large areas of previously productive forest to early growth stages, 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 and increased 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 early growth stages. The combination of reduced absorption and storage of CO_2 in biomass and increased emissions of CO_2 from decomposition resulted in a net decrease in removals from forest in these regions—largely between 1997 and 2007—that was large enough to influence the national trend. Although emissions and removals associated with severe natural disturbances are differentiated from anthropogenic fluxes, disturbances nevertheless influence reported GHG fluxes.

Figure 2–21 **LULUCF Sector Net GHG Flux and Major Emission and Removal Components, 1990–2018**



Emissions from HWP reflect the long-term storage of carbon in wood harvested in Canada's forests. Approximately one-third of HWP emissions (30% in 2018) result from long-lived wood products reaching the end of their economic life decades after the wood was harvested. End-of-life emissions for short-lived products, namely pulp and paper and bioenergy products, accounted for 30% and 34% of HWP emissions, respectively, in 2018. Short-lived wood products more closely track recent trends in forest harvest rates. Emissions from HWP fluctuated between 120 Mt in 2009, the lowest harvest year, and a peak of 150 Mt in 1995.

2.3.4.2. Forest Conversion (2018 GHG Emissions, 14 Mt)

Forest conversion[9] is not a reporting category *per se*, since it overlaps with the subcategories of Land converted to Cropland, Land converted to Wetlands and Land converted to Settlements. It also includes the emissions from HWP resulting from forest conversion activities since 1990. Emissions due to forest conversion fell from 21 Mt in 1990 to 14 Mt in 2018.

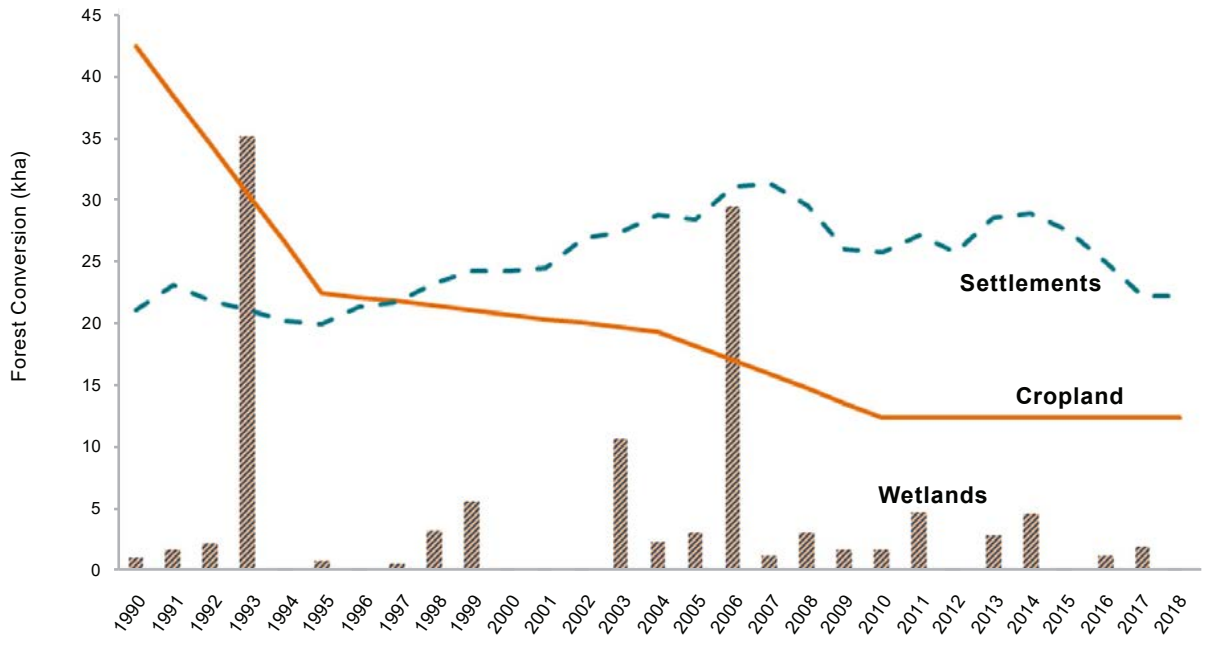
The conversion of forests to other land use is a prevalent yet declining practice in Canada; it is driven by a variety of circumstances across the country, including policy and regulatory frameworks, market forces and resource endowment. Since 1990, 1.4 million hectares of forest have been converted to other land uses in Canada. Geographically, the highest average annual rates of forest conversion occur in the Boreal Plains (22 kha per year) and the Boreal Shield East (8 kha per year), which account for 46% and 16%, respectively, of the total loss of forest area in Canada.

With a current annual conversion rate of 25 kha, Forest Land converted to Settlements now accounts for the largest share of forest loss, comprising 64% in 2018, up from 33% in 1990 and 57% in 2005. Forest clearing for agricultural expansion (Cropland) is the second largest driver of forest conversion, accounting for 36% of all forest area lost in 2018. Annual rates dropped from 42 kha in 1990 to 12 kha in 2018, predominantly in the Boreal Plains, Subhumid Prairies and Montane Cordillera of Western Canada, following a period of active agricultural expansion in previous decades.

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 2–22). Cumulative areas of forest converted for the creation of hydro reservoirs and the associated infrastructure equal 184 kha, accounting for 13% of total forest conversion areas over the reporting period. Hydroelectric development occurs mainly in the Taiga Shield East and the Boreal Shield East.

9 Forest conversion emissions are incorporated within sums of emissions of other land-use categories; therefore, the 14 Mt reported in this section is included in the sums associated with the other land-use category totals.

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



2.3.4.3. **Cropland** (2018 GHG Removals, 6.2 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 emissions showed a steady decrease from net CO_2 emissions of 8.1 Mt in 1990 to net removals of 12 Mt in 2006, a total change of 20 Mt. This trend is a result of changes in agricultural land management practices in Western Canada that enhanced soil carbon conservation, such as the extensive adoption of conservation tillage practices (≈17 million hectares of cropland since 1990) and a 95% reduction in summer fallow by 2018.

Since 2011, net removals have gradually declined to 6.2 Mt. The main drivers of this trend are an increasing net conversion from perennial to annual crops on the Prairies since 2006, declining rates in the adoption of conservation tillage and reduced summer fallow, as well as a decrease in the contribution of these historical land management conversions to the soil sink.

The increase in the conversion of perennial to annual crops since 2006 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 contributed to the trend of the increasing removals during the period from 1990 to 2010, but has since levelled off (see section 2.3.4.2).

2.3.4.4. **Other LULUCF Sources/Sinks** (2018 GHG emissions, 4.5 Mt)

Other LULUCF sources/sinks include Wetlands, Settlements and Grassland, which contributed 2.6 Mt, 1.8 Mt and 0.001 Mt, respectively, to their combined net emissions of 4.5 Mt reported in 2018, down from 7.4 Mt in 1990. The Settlements category includes the growth of urban trees (annual removals of 4.0 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** (2018 GHG Emissions, 18 Mt)

The Waste sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from the Waste sector contributed 17.7 Mt (2.4%) to Canada's total emissions in 2018, comparable to emission levels of 20.7 Mt in 1990 (3.4% of total emissions) and of 19.9 Mt (2.7%) in 2005 (Figure 2–23 and Table 2–11). In 2018, landfilling (including municipal solid waste and industrial wood waste disposal) accounted for 15.7 Mt (or 89% of total Waste sector emissions), while Biological Treatment of Solid Waste (composting), Wastewater Treatment and Discharge, and Incineration and Open Burning of Waste (excluding CO_2 emissions from incineration of biomass material) contributed 0.5 Mt, 1.1 Mt and 0.4 Mt, respectively.

Figure 2–23 **Trends in Canadian GHG Emissions from Waste (1990–2018)**

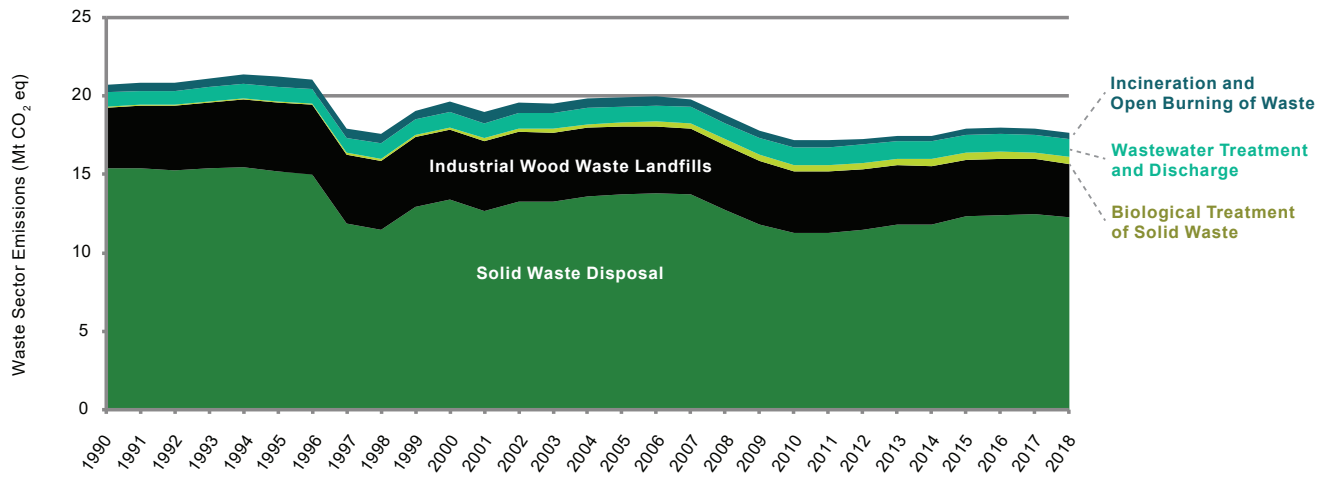


Table 2–11 **GHG Emissions from Waste, Selected Years**

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2013	2014	2015	2016	2017	2018	1990–2018	2005–2018
Waste Sector	**21**	**20**	**17**	**17**	**18**	**18**	**18**	**18**	**-15%**	**-11%**
Biological Treatment of Solid Waste	0.06	0.29	0.44	0.46	0.45	0.45	0.45	0.45	708%	52%
Incineration and Open Burning of Waste	0.47	0.58	0.32	0.36	0.40	0.39	0.39	0.39	-17%	-32%
Industrial Wood Waste Landfills	3.8	4.3	3.8	3.7	3.6	3.5	3.5	3.4	-12%	-21%
Solid Waste Disposal	15.4	13.7	11.8	11.8	12.3	12.4	12.5	12.3	-20%	-11%
Wastewater Treatment and Discharge	0.92	1.0	1.1	1.2	1.2	1.1	1.1	1.1	25%	14%

Note:
Totals may not add up due to rounding.

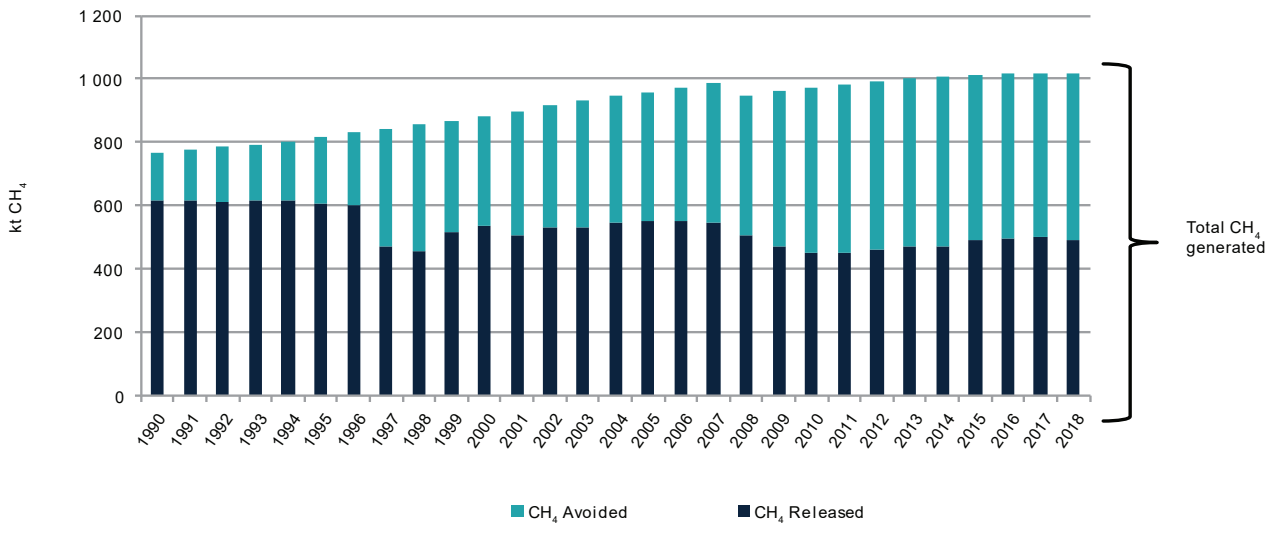
2.3.5.1. Solid Waste Disposal and Industrial Wood Waste Landfills
(2018 GHG Emissions, 15.7 Mt)

The Solid Waste Disposal category reports CH_4 emissions from municipal solid waste (MSW) landfills and the Industrial Wood Waste Landfill category reports these 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 2018, emissions from MSW landfills were 12.3 Mt, while emissions from wood waste landfills were 3.4 Mt. Emissions from MSW landfills have decreased by 20% since 1990, and 11% since 2005. Emissions from wood waste landfills have decreased by 12% since 1990 and 21% since 2005. The amount of CH_4 generated by MSW landfills has steadily increased from 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 2018, 52% of the LFG generated in landfills was recovered through LFG capture technologies, compared with recovery rates of 19% in 1990 (Figure 2–24). 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 2–24 **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 (2018 GHG Emissions, 2.0 Mt)

Over the 1990–2018 time series, emissions from the Biological Treatment of Solid Waste (composting), Wastewater Treatment and Discharge (municipal and industrial wastewater treatment), and Incineration and Open Burning subcategories collectively increased by 27% (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 the emissions from the Biological Treatment of Solid Waste subcategory by 708% since 1990 and 50% since 2005.

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, Transportation, Heavy Industry,[10] 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 2018 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 Transportation 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 Transportation 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 (1990–2018) 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 Transportation 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).

10 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

Oil and Gas

In 2018, the Oil and Gas sector produced the largest share of GHG emissions in Canada (27%). Between 1990 and 2018, emissions from this sector increased by 87 Mt. While fluctuations due to economic conditions (e.g. crude oil and natural gas prices) have caused short-term increases and decreases in emissions between 1990 and 2018, in general, emissions from this sector have increased steadily over the long-term. The majority of this increase (69 Mt) is due to massive expansion in Canada's oil sands. Since 1990, oil sands production has increased by almost 750% and emissions have increased by over 450% (see following text box).

Transportation

Canada's Transportation sector is the second-largest contributor to Canada's GHG emissions, accounting for 26% of total emissions in 2018. Between 1990 and 2010, emissions rose by 47 Mt (39%); since then, emissions from this sector have continued to increase gradually. Section 2.3 discusses the main drivers of historical emissions trends associated with passenger and freight transport.

Electricity

In 2018, the Electricity sector (excluding industrial and commercial cogeneration) contributed 8.8% to total Canadian emissions. 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. 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. 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 8.6 Mt between 2005 and 2018.

Buildings

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. While residential fuel use has remained relatively steady since 1990, increases in the service industry have resulted in emissions increases from 74 Mt to 92 Mt (25%).

Agriculture and Waste & Others

Emissions from the Agriculture sector continued a slow upward trend throughout the reporting period, rising from 57 Mt in 1990 to 73 Mt in 2018. 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 decreased over the time series, from a high of 53 Mt in 1990 to 42 Mt in 2018.

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 2018, the largest contributor to O&G emissions was the Oil Sands category (84 Mt, or 43%), followed by Natural Gas Production and Processing (50 Mt, or 26%), Conventional Oil Production (29 Mt, or 15%) and Petroleum Refining (19 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

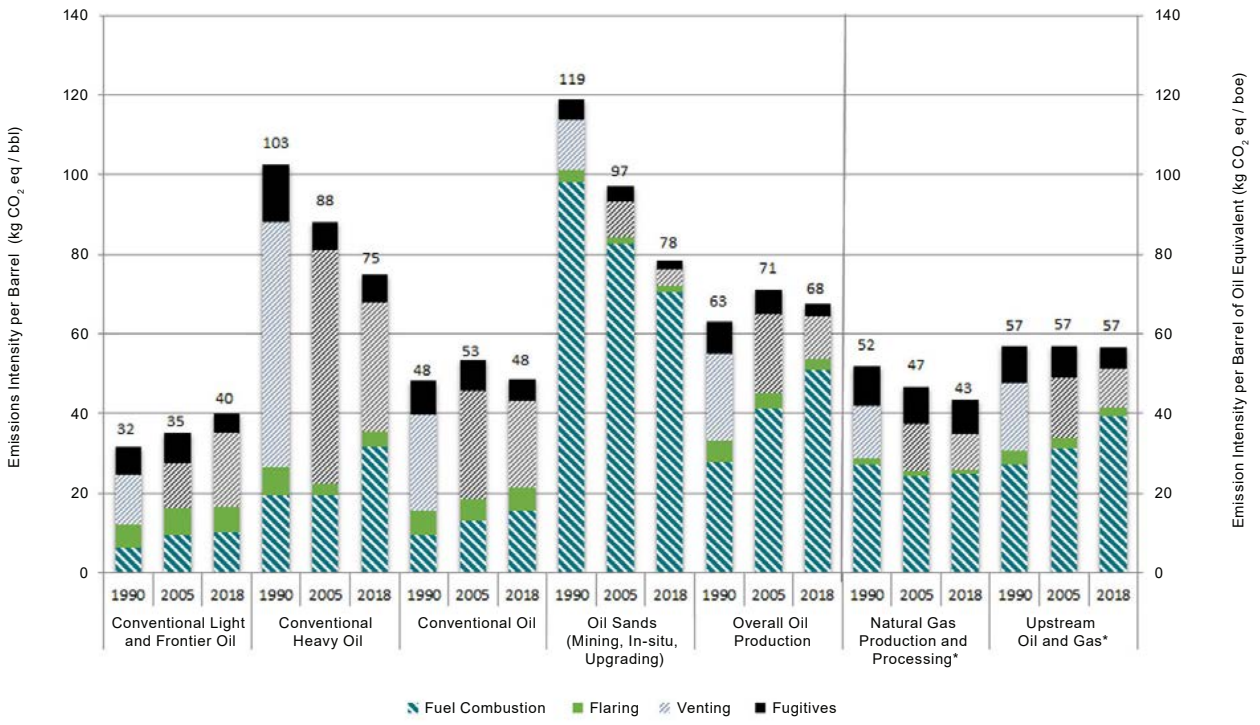
From 1990 to 2018, the production of total crude oil increased by 170% (StatCan c, d). The increase was driven almost entirely by Canada's oil sands operations, which accounted for almost 100% of total production growth. Total oil sands output (non-upgraded bitumen and synthetic crude oil production) has increased by almost 750% since 1990. Consistent with the production increases, emissions from total crude oil production increased by 74 Mt (about 193%), with emissions from oil sands alone increasing by 69 Mt (456%).

Emissions Intensity

The emissions intensity of overall oil production in Canada increased by about 7% between 1990 and 2018, from 63 to 68 kg CO_2 eq per barrel (Figure 2–25). 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. While fuel combustion emissions have increased by approximately 83% per barrel of oil extracted (28 kg CO_2-eq per bbl in 1990 to 51 kg CO_2-eq per bbl in 2018), venting, flaring and fugitive emissions have decreased by 49%, 43% and 59%, respectively. These reductions are due to increased oil sands production, which produces much fewer fugitive emissions per barrel than conventional oil production, and initiatives such as Alberta's Directive 60 (AER 2014), British Columbia's *Flaring and Venting Reduction Guideline* (BCOGC, 2015), Saskatchewan's *Directive S-10* and the Canadian Association of Petroleum Producers (CAPP) *Best Management Practice for Fugitive Emissions* (CAPP, 2007).

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 78 kg CO_2 eq per barrel in 2018. 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 has 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 2018, when non-upgraded bitumen production increased by over 160% while SCO production increased by only 31%. 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 2018, 1.07 Mt of CO_2 was captured at Scotford, reducing the emissions intensity of overall oil sands operations by approximately 1.3%.

Figure 2–25 **Emissions Intensity by Source Type for Oil and Gas (1990, 2005 and 2018)**



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 from: StatCan 1991–2019, c, d and AER 2019.

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

	1990	2005	2013	2014	2015	2016	2017	2018
	Mt CO_2 eq							
NATIONAL GHG TOTAL	**603**	**730**	**721**	**721**	**720**	**706**	**714**	**729**
Oil and Gas	**106**	**158**	**185**	**191**	**191**	**187**	**188**	**193**
Upstream Oil and Gas	86	134	161	169	168	164	167	173
Natural Gas Production and Processing	36	55	52	53	50	49	49	50
Conventional Oil Production	23	30	32	35	34	29	29	29
Conventional Light Oil Production	11	11	15	17	17	15	15	16
Conventional Heavy Oil Production	12	17	15	16	16	13	12	11
Frontier Oil Production	0	2	2	2	2	2	2	2
Oil Sands (Mining, In-situ, Upgrading)	15	37	68	71	74	75	80	84
Mining and Extraction	4	9	15	16	17	17	18	18
In-situ	4	11	27	29	33	35	38	41
Upgrading	6	17	26	25	24	22	23	24
Oil, Natural Gas and CO_2 Transmission	12	12	9	10	10	11	10	11
Downstream Oil and Gas	20	23	24	23	22	23	21	20
Petroleum Refining	18	22	23	21	21	22	20	19
Natural Gas Distribution	2	1	1	1	1	1	1	1
Electricity	**95**	**119**	**81**	**77**	**81**	**75**	**73**	**64**
Transportation	**121**	**161**	**174**	**172**	**172**	**174**	**179**	**186**
Passenger Transport	71	90	91	89	91	94	95	99
Cars, Trucks and Motorcycles	64	82	82	81	83	86	86	90
Bus, Rail and Domestic Aviation	7	8	9	8	8	8	9	9
Freight Transport	31	60	75	74	72	71	75	78
Heavy Duty Trucks, Rail	26	54	70	69	67	66	69	73
Domestic Aviation and Marine	5	6	5	5	5	5	5	5
Other: Recreational, Commercial and Residential	18	10	8	8	9	9	9	9
Heavy Industry	**97**	**87**	**79**	**80**	**79**	**77**	**76**	**79**
Mining	7	7	8	8	8	7	7	8
Smelting and Refining (Non-Ferrous Metals)	17	14	11	10	10	11	11	10
Pulp and Paper	15	9	7	7	6	7	7	7
Iron and Steel	16	16	15	16	15	15	15	16
Cement	10	13	10	10	10	10	11	11
Lime & Gypsum	3	3	2	3	2	2	3	2
Chemicals & Fertilizers	29	25	26	27	27	25	22	24
Buildings	**74**	**86**	**86**	**89**	**86**	**82**	**85**	**92**
Service Industry	28	40	42	42	41	41	43	45
Residential	47	46	45	47	44	40	42	47
Agriculture	**57**	**72**	**73**	**71**	**71**	**72**	**71**	**73**
On-Farm Fuel Use	11	12	13	13	13	13	13	14
Crop Production	15	16	23	22	23	24	23	24
Animal Production	32	44	36	36	35	36	36	36
Waste & Others	**53**	**46**	**43**	**41**	**41**	**41**	**42**	**42**
Waste	21	20	17	17	18	18	18	18
Coal Production	4	2	3	3	2	2	2	3
Light Manufacturing, Construction & Forest Resources	28	24	22	21	21	21	21	22

Notes:

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.

Totals may not add up due to rounding.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex 11 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 2018, the Energy sector accounted for 596 Mt (or 82%) of Canada's total greenhouse gas (GHG) emissions (Table 3–1). The Energy sector emissions total includes, with exceptions, all GHG (carbon dioxide [CO_2], methane [CH_4] and nitrous oxide [N_2O]) emissions 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. The non-energy use of peat is reported 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 sub-category within the Other Sector (1.A.4). For biomass use as fuels, such as biodiesel, residential fuel wood and spent pulping liquor, only CH_4 and N_2O emissions are included in the Energy sector estimates, whereas CO_2 emissions resulting from the combustion of biomass 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. Reported emissions from international aviation and international navigation activities are 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 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

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

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
Energy Sector	**479 000**	**520 000**	**600 000**	**593 000**	**567 000**	**575 000**	**577 000**	**587 000**	**591 000**	**590 000**	**574 000**	**584 000**	**596 000**
Fuel Combustion Activities (1.A)	**430 000**	**456 000**	**531 000**	**533 000**	**512 000**	**520 000**	**518 000**	**527 000**	**529 000**	**530 000**	**519 000**	**528 000**	**541 000**
Energy Industries (1.A.1)	147 000	155 000	208 000	208 000	195 000	193 000	197 000	198 000	198 000	203 000	198 000	197 000	192 000
Manufacturing Industries and Construction (1.A.2)	71 300	74 000	72 500	63 800	60 400	63 700	62 300	63 100	63 000	62 100	59 100	61 200	64 000
Transport (1.A.3)	124 000	131 000	151 000	164 000	166 000	167 000	169 000	174 000	172 000	173 000	175 000	179 000	187 000
Other Sectors (1.A.4)	86 800	95 200	98 600	96 200	90 200	95 900	89 400	92 100	95 500	91 300	86 600	90 900	97 400
Other (Not Specified Elsewhere) (1.A.5)	198	161	164	117	109	119	163	178	175	199	213	205	212
Fugitive Emissions from Fuels (1.B)	**49 000**	**64 000**	**69 000**	**61 000**	**55 000**	**55 000**	**59 000**	**61 000**	**63 000**	**60 000**	**55 000**	**55 000**	**55 000**
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**	**0.27**

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

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 the 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).

CO_2 from some facilities (e.g. electricity generators and hydrogen production) is captured, transported and injected for long-term geologic storage or enhanced oil recovery (EOR) during extraction activities. Volumes captured appear in the category where they occur. CRF category 1.C includes releases of CO_2 to the atmosphere from CO_2 pipeline/distribution infrastructure and injection equipment used for the purpose of long-term geological storage. Fugitive estimates in CRF category 1.B include emissions from the use of CO_2 for EOR operations.

Continuous methodological improvements and revised activity data resulted in several recalculations of GHG emissions in the Energy sector; see Table 3–2. A general list, with explanations, of activities resulting in revised emission estimates can be found in each section of Chapter 3; Chapter 8 provides a summary of recalculations for all sectors.

Overall, recalculations resulted in an increase of 0.2 Mt compared to last year's submitted value for 2017. Recalculations occurred for the following reasons.

Activity data—Revisions to fuel data in the *Report on Energy Supply and Demand* (RESD) generally result in a recalculation of most combustion sources. Revisions to activity data are a result of quality control checks, revised data or new information, and are as follows:

- revision to the 2017 *Report on Energy Supply and Demand* (RESD) data have been incorporated (as per standard practice) as an update to the preliminary 2017 data[2] along with corrections to some historical data utilized in last year's national inventory submission to the UNFCCC:
    - o additions to sub-bituminous volumes of coal miscategorised as foreign bituminous in the RESD between 2014 and 2017;
    - o revised petroleum coke data in the RESD, between 2015 and 2017.
- corrections to estimates of landfill gas quantities used for energy purposes based on facility-specific operations details between 1990 and 2017;
- corrections to residential firewood consumption data for 2016 and 2017;
- updates to flared volumes of natural gas between 2010 and 2017;
- revisions to various activity data used in the oil and gas fugitive emissions models (refer to the recalculation discussion in section 3.3.2 for more details);
- updates to the fleet profile of off-road equipment used for oil sands mining (refer to discussion in section 3.2.6.5 for more details).

Methodology—Changes to the following methods resulted in recalculations:

- medical waste for energy purposes has been reallocated from the Waste sector to the Energy sector (see Annex 3, section A3.6.3 for more details); and,
- an updated marine methodology is now being used to allocate emissions based on the IPCC 2006 guidebook definition of domestic and international navigation (refer to Annex 3, section A3.1.4.2.3 for more details).

2 Statistics Canada annually publishes a revised, final version of the previous year's (preliminary) energy data. Currently, energy data for 2017 is preliminary and is subject to revision in late 2019.

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

IPCC Categories	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017
1 Energy Sector	GHG Emissions, Mt CO_2 eq											
2017 Inventory Inventory Report	479	519	600	595	569	576	578	589	594	592	575	583
2018 Inventory Inventory Report	479	520	600	593	567	575	577	587	591	590	574	584
Total change due to recalculations	**-0.7**	**0.1**	**-0.2**	**-1.4**	**-1.8**	**-1.0**	**-1.5**	**-2.1**	**-2.6**	**-2.3**	**-1.6**	**0.2**
1.A—Fuel Combustion	-0.8	0.0	-0.2	-1.4	-1.9	-1.0	-1.6	-1.9	-2.7	-2.3	-1.6	0.4
1.B—Fugitive and 1.C—CO_2 Transport & Storage	0.1	0.0	0.0	-0.1	0.0	0.0	0.0	-0.1	0.1	0.1	0.0	-0.2

Note:
Totals may not add up due to rounding.

Emission Factors—Implementation of improved emission factors, based on new information, resulted in recalculations. Revised emission factors for:

- stationary fuel combustion of coal, diesel, wood and wood waste and spent pulping liquor have been incorporated into the inventory (see Annex 3, section A3.1.3, for more details).

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 fuels and CH_4 and N_2O emissions from biomass fuels. 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 2018, about 541 Mt (74 %) 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 25.8% since 1990. Between 1990 and 2018, emissions from the Energy Industries (1.A.1), Manufacturing Industries and Construction (1.A.2) and Other Sectors (1.A.4) categories increased by 15.9% (48.4 Mt), and emissions from the Transport (1.A.3) category increased by 50.1% (62.4 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 summarizing the results.

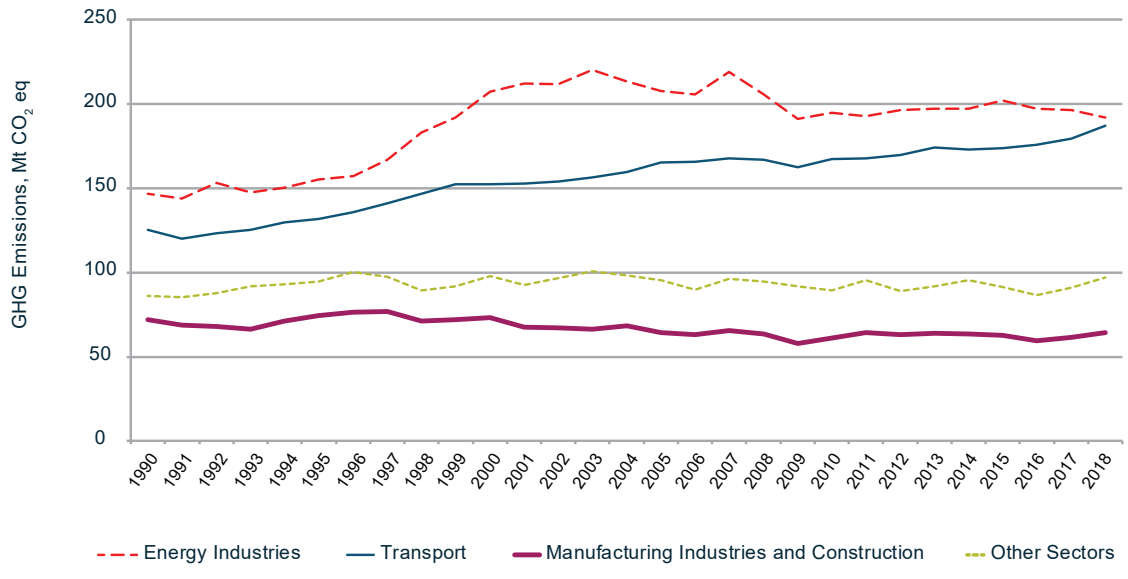
3.2.2. International Bunker Fuels

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

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

Emissions (Table 3–3) were calculated using the same methods listed in the Domestic Aviation section (see section 3.2.6.2). Fuel-use data are reported in the *Report on Energy Supply and Demand in Canada* (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.

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



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). A new approach to allocate fuel use based on vessel movement was implemented since fuel-use data in the RESD is based on the quantity 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.

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

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 2018, the Energy Industries category accounted for 192 Mt (26.4%) of Canada's total GHG emissions, with a 30.7% increase in total GHG emissions since 1990. The Public Electricity and Heat Generation subcategory accounted for 36.4% (69.9 Mt) of the GHG emissions

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

GHG Source Category	GHG Emissions, kt CO_2 eq									
	1990	2005	2011	2012	2013	2014	2015	2016	2017	2018
International Aviation	6 150	10 200	9 710	11 000	11 400	11 400	11 900	12 500	13 600	15 300
Domestic & Military Aviation	7 180	7 620	6 330	7 300	7 570	7 220	7 140	7 080	7 430	7 990
Total	**13 300**	**17 800**	**16 000**	**18 300**	**19 000**	**18 600**	**19 000**	**19 600**	**21 000**	**23 200**

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	2011	2012	2013	2014	2015	2016	2017	2018
International Navigation	4 580	5 840	4 580	5 110	5 520	5 520	5 250	4 550	5 020	5 180
Domestic, Fishing & Military Navigation	3 760	4 770	4 710	4 500	4 290	4 080	3 870	3 920	3 980	4 030
Total	**8 340**	**10 600**	**9 290**	**9 600**	**9 810**	**9 600**	**9 110**	**8 470**	**8 990**	**9 210**

Note:
Totals may not add up due to rounding.

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
Energy Industries TOTAL (1.A.1)	**147 000**	**155 000**	**208 000**	**208 000**	**195 000**	**193 000**	**197 000**	**198 000**	**198 000**	**203 000**	**198 000**	**197 000**	**192 000**
Public Electricity and Heat Generation	94 500	98 800	132 000	125 000	102 000	94 500	91 300	87 500	83 900	87 100	80 500	78 500	69 900
Petroleum Refining	17 400	16 300	17 300	20 200	19 100	18 300	19 500	18 400	17 800	17 800	18 100	16 200	16 000
Manufacture of Solid Fuels and Other Energy Industries[a]	35 200	40 500	58 300	63 000	73 800	80 300	86 300	91 800	96 100	97 700	99 000	102 000	106 000

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.

from Energy Industries, while the Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries subcategories contributed 8.3% (16 Mt) and 55.4% (106 Mt), respectively (Table 3–5). Chapter 2, Emissions Trends has further discussion of trends in emissions from the Energy Industries category.

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

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

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

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

The electricity supply grid in Canada includes combustion-derived electricity as well as hydro, nuclear and other renewables (wind, solar and tidal power). Total power generated by wind, tidal and solar resources is small relative to that generated by Canada's significant hydro and nuclear installations. Nuclear, hydro, wind, solar and tidal electricity generators only emit small quantities of GHGs, generally from diesel generators 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 are reported under Manufacturing Industries and Construction. 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.

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)

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. The GHG emissions from industrial electricity generation are reallocated to their respective industrial subcategories using the detailed industry information that feed the RESD. See Annex 3.1 for methodological details.

The 2006 IPCC Guidelines divide the Public Electricity and Heat Generation subcategory into three additional subcategories: Electricity Generation (1.A.1.a.i), Combined Heat and Power Generation (1.A.1.a.ii), and Heat Plants (1.A.1.a.iii). StatCan does not differentiate fuel-use data in the RESD using these subcategories; rather, they aggregate data into one category titled Transformed to Electricity by Utilities. The GHG emissions from the RESD Transformed to Electricity by Utilities category is disaggregated into the Electricity Generation and Combined Heat and Power Generation CRF subcategories using the RESD input data.[3] 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. Emissions of CH_4 and N_2O from the combustion of biomass were reallocated to their respective categories using 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.

3.2.4.3. Uncertainties and Time-Series Consistency

The estimated uncertainty range for the Energy Industries category is ±4% for CO_2, CH_4 and N_2O combined and ±3% 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

3 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.)

(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 (±127%) and N_2O (±225%) 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 42% of the 2018 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 estimate for emissions from the combustion of this fuel is influenced by the CO_2 (±6%) 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 physical composition of unprocessed natural gas (which will vary from plant to plant) is unavailable.

3.2.4.4. QA/QC and Verification

The completed quality control (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.

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 2017 decreasing by 6.4 Mt CO_2 eq compared to the previous submission.

Revisions to the Public Electricity and Heat Production subcategory occurred back to 1990, because of changes to activity data and emission factors. Changes to emission factors affect the entire time series, while changes to the activity data, in the form of updates in the RESD, affect the time series between 2005 and 2017. Emission estimates for 2017 decreased by 0.2 Mt CO_2 eq because of these improvements.

Revisions to the allocation of purchased fuels in the mining and oil and gas industries have resulted in changes to emission estimates for the Manufacture of Solid Fuels and Other Energy Industries subcategory back to 1990. The RESD reports purchased fuel consumption under the category Total Mining and Oil and Gas Extraction, which includes coal mining, conventional oil and gas extraction, oil sands extraction and upgrading, metal mining and non-metal mining industries. Because the RESD aggregates fuel in this way, emissions from purchased fuel combustion in the oil and gas industry were previously reported in the Manufacturing Industries and Construction—Mining (Excluding Fuels) and Quarrying (1.A.2.g.iii) subcategory. A new method reallocates these emissions to the Manufacture of Solid Fuels and Other Energy Industries subcategory, resulting in an increase of 42.4 Mt CO_2 eq for 2016 compared to the previous submission. As this is simply a reallocation of fuel volumes, there is an equivalent decrease in emissions in the Mining (Excluding Fuels) and Quarrying subcategory, with no change in the overall stationary combustion emission estimates due to the reallocation.

Also in the Manufacture of Solid Fuels and Other Energy Industries subcategory, revisions to activity data resulted in the recalculation of emission estimates for 2005 through 2017. Changes to petroleum coke consumption data caused a decrease in emissions of 0.4 Mt CO_2 eq in 2017, balanced by a 0.4 Mt increase from changes to still gas consumption. Revisions to natural gas consumption resulted in an emissions decrease of 3.1 Mt in 2017. Minor changes to butane and diesel fuel oil caused small changes to emission estimates (0.0002 to 0.05 Mt CO_2 eq).

Finally, changes to the quantities of flared gas in Saskatchewan and Newfoundland and Labrador, that are subtracted from producer consumption of

natural gas, resulted in decreased emission estimates between 2010 and 2017 ranging from -0.3 to -1.6 Mt CO_2 eq. As described in Annex 3.2, section A3.2.2.7, flaring emissions are estimated separately using the various fugitive models and are reported as fugitives, while the producer consumed natural gas volumes reported in the RESD and included in stationary combustion emission estimates include the amount of flared gas. Therefore, subtraction of the volumes of flared gas and associated emissions, from the combustion estimates, avoids a double count.

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. Quality control processes identified by this working group contribute to annual improvements to the national energy balance resulting in recalculations. 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 in their respective sections or in the general overview section of this chapter.

Statistics Canada is in the process of modernizing some surveys to better capture supply and demand of fossil and renewable fuels. As examples, refinements and updates are being made so: 1) the monthly-refined petroleum production survey will capture information from an expanded pool of respondents beyond refineries, 2) the monthly oil product pipeline survey will provide additional information on fossil fuels transported via pipelines, and 3) the new monthly renewable fuels survey will provide details on types of biodiesel and ethanol produced in Canada. StatCan is also working to improve the data collection methods regarding the movement of fossil, and renewable, fuels via rail and marine vessels. These future updates will improve the quality and enhance the transparency of RESD data.

There are planned improvements to country-specific natural gas emission factors. An assessment of regional (provincial and territorial) natural gas energy conversion factors from 1990 onward, using available data reported to StatCan, found the information insufficient to reliably track the variation in energy density across Canada. To update CO_2 emission factors a new data collection approach is underway focused on working with the natural gas industry to obtain regional volumetric flows, heating values and carbon contents. Priority for emission factor improvements has been on fuels with the largest contribution to combustion emissions, such as coal, gasoline, diesel and natural gas. In recent years, coal, gasoline and diesel CO_2 emission factors and heating values were revised based on new test results and information. Annex 6 of this report presents the results of these improvement activities.

Western Canada produces the vast majority of natural gas and it ships this product to eastern Canadian regions and internationally. A natural gas project, whose goal is to collect representative natural gas data across Canada for use in updating CO_2 emission factors and high heat values [HHV]is underway. The first stage of the project identified key natural gas transmission and distribution points to assure a representative compositional mix for natural gas consumed across Canada. The second stage of the project involves working with industry to collect the necessary volumetric flow and fuel composition data for each of these points. Members of the Canadian Energy Partnership for Environmental Innovation (which is made up of natural gas transmission and distribution companies) support this project and many have provided detailed data. Industry interest, and voluntary participation, in updating natural gas CO_2 emission factors and HHVs, along with efforts to ensure sufficient and transparent information, will be critical to the success of this project. The preliminary set of data for analysis will be available in spring of 2020 with data quality assessment work to follow. Also, work will begin on the collection of historical data, with an expected completion date of early 2021.

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 generation and heat plants.

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

3.2.5.1. Source Category Description

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

In 2018, the Manufacturing Industries and Construction category accounted for 64 Mt (8.8%) of Canada's total GHG emissions, with a 10% (7.4 Mt) decrease

in overall emissions since 1990 (refer to Table 3–6 for more details). Within the Manufacturing Industries and Construction category, 33Mt (52%) of the GHG emissions are from the Other subcategory, which is made up of mining, construction and other manufacturing activities. This subcategory is followed by, in order of decreasing contributions, the Chemicals (10.9 Mt, 17.1%), Pulp, Paper and Print (6.9 Mt, 10.8%), Iron and Steel (6.38 Mt, 10%), Non-metallic Minerals (3.96 Mt, 6.2%); and Non-ferrous Metals (2.78 Mt, 4.3%) subcategories. GHG emissions from Food Processing, Beverages and Tobacco are included in the Other Manufacturing subcategory of the Manufacturing Industries and Construction category 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 (as presented in 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) are reported 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 below 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.

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
Manufacturing Industries and Construction TOTAL (1.A.2)	**71 300**	**74 000**	**72 500**	**63 800**	**60 400**	**63 700**	**62 300**	**63 100**	**63 000**	**62 100**	**59 100**	**61 200**	**64 000**
Iron and Steel	4 950	5 780	6 210	5 550	4 980	5 290	5 500	5 580	6 030	5 700	5 560	5 940	6 380
Non-ferrous Metals	3 310	3 220	3 580	3 660	3 070	3 420	2 970	3 100	2 920	3 110	3 190	3 220	2 780
Chemicals	8 260	10 300	10 700	8 330	9 920	11 100	11 000	11 600	12 400	12 000	10 700	9 600	10 900
Pulp, Paper and Print	14 500	12 800	12 600	8 650	5 970	6 220	5 990	6 230	6 090	6 040	5 950	6 320	6 900
Food Processing, Beverages and Tobacco[a]	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Non-metallic Minerals	3 970	4 160	4 640	5 430	4 070	4 310	4 030	3 860	4 030	3 940	3 770	4 170	3 960
Other	36 400	37 700	34 900	32 200	32 400	33 300	32 900	32 800	31 500	31 300	29 900	31 900	33 000
Mining (excluding fuels) and Quarrying[b]	4 130	4 390	4 280	3 960	5 070	4 980	5 290	4 720	4 520	4 110	3 810	4 270	4 440
Construction	1 880	1 180	1 080	1 450	1 520	1 370	1 390	1 290	1 300	1 300	1 280	1 290	1 390
Off-road Manufacturing, Mining and Construction	9 160	12 500	11 300	10 400	12 600	13 200	12 000	12 300	12 200	13 100	12 200	13 500	14 500
Other Manufacturing	21 200	19 700	18 200	16 400	13 200	13 800	14 200	14 400	13 600	12 800	12 600	12 800	12 700

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.

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 category, with the exception of waste fuel, which comes from annual industry data supplied by the Canadian Energy and Emissions Data Centre.

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

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

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

3.2.5.3. Uncertainties and Time-Series Consistency

The estimated uncertainty for the Manufacturing Industries and Construction category is ±2% for CO_2, CH_4 and N_2O combined.

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

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

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

3.2.5.4. QA/QC and Verification

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

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

3.2.5.5. Recalculations

There are revised emissions estimates for all years, with estimates for 2017 decreasing by 0.3 Mt CO_2 eq over the previous submission, because of the following changes:

- revised RESD data;
- revised emission factors for diesel fuel oil, coal, solid wood waste and spent pulping liquor; and,
- updated version of activity data used to estimate off-road equipment used in oil sands mining operations (ECCC 2018a).

Revisions to the Manufacturing Industries and Construction category occurred back to 1990. Changes to emission factors affect the entire time series, while changes to the activity data, in the form of updates in the RESD, affects 2017. The revised RESD data resulted in a 0.4 Mt decrease in emissions for 2017.

The revised emission factors resulted in decreases to emissions ranging from 0.04 Mt to 0.08 Mt between 1990 and 2016, and a 0.1Mt increase in emissions in 2017.

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 Statistics Canada and the Trilateral Energy Working Group's activities.

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. Additional data sources and methods are being investigated with the goal of reallocating the data, as required.

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

Transport-related GHG emissions total 187 Mt, accounting for about 26% 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 156% (32 Mt) for LDGTs, 670% (1.0 Mt) for LDDTs and 280% (38 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 8.9 Mt since 1990. Emissions from the Transport category have increased 50% and have contributed the equivalent of 49% of the total overall growth in emissions observed in Canada.

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; and
- 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

Table 3–7 **Transport GHG Emissions**

GHG Source Category	GHG Emissions, kt CO_2 eq												
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018
Transport	**124 000**	**131 000**	**151 000**	**164 000**	**166 000**	**167 000**	**169 000**	**174 000**	**172 000**	**173 000**	**175 000**	**179 000**	**187 000**
Domestic Aviation[a]	7 010	6 500	7 580	7 520	6 360	6 250	7 200	7 470	7 140	7 060	6 990	7 340	7 900
Road Transportation	83 800	86 600	111 000	130 000	137 000	139 000	140 000	144 000	142 000	143 000	145 000	148 000	154 000
Light-Duty Gasoline Vehicles	41 600	40 400	40 400	41 400	37 800	36 500	35 400	35 600	34 200	34 500	34 600	33 700	33 900
Light-Duty Gasoline Trucks	20 300	23 900	31 800	38 100	41 300	41 400	41 900	43 300	43 400	45 300	48 100	49 200	52 000
Heavy-Duty Gasoline Vehicles	6 320	7 170	10 500	11 700	12 500	12 100	12 800	13 400	12 400	12 300	13 000	13 300	13 600
Motorcycles	90	78	123	203	248	251	260	262	260	271	287	296	304
Light-Duty Diesel Vehicles	467	400	600	605	663	793	798	856	857	901	842	841	811
Light-Duty Diesel Trucks	153	156	338	344	421	482	473	531	641	813	903	1 080	1 180
Heavy-Duty Diesel Vehicles	13 600	13 600	26 500	36 900	44 200	47 600	48 700	50 000	49 800	48 600	46 900	49 300	51 800
Propane and Natural Gas Vehicles	1 160	903	522	381	38	40	30	18	9	8	9	10	10
Railways	6 920	6 260	6 530	6 580	6 540	7 390	7 560	7 290	7 470	7 120	6 540	7 490	7 650
Domestic Navigation[a, b]	3 000	3 190	3 590	3 990	4 150	4 050	3 940	3 830	3 730	3 620	3 670	3 720	3 780
Other Transportation[c]	23 600	28 300	23 000	16 500	12 000	10 100	10 000	11 000	12 400	13 000	13 300	12 500	13 700
Off-Road	16 700	16 300	11 700	6 390	6 300	4 450	4 310	4 300	4 540	4 830	4 920	5 120	5 350
Pipeline Transport	6 900	12 000	11 300	10 200	5 710	5 650	5 730	6 720	7 890	8 160	8 420	7 420	8 340

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 the Other Sectors categories.

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.

In response to an ERT concern, an investigation into the activity and related GHG emissions attributable to steam train operations in Canada was conducted in early 2016 since those emissions had never been included in previous submissions. The investigation identified fewer than 20 locomotives operating in Canada, mostly only in a historic or demonstration capacity, and found that they collectively produce only slightly more than 0.5 kt CO_2 eq including any CO_2 from biomass. As this is less than 0.05% of total emissions and less than the 500 kt threshold as specified in paragraph 37(b) of the UNFCCC Annex I Inventory Reporting guidelines, this source is considered insignificant.

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

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

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

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

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

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

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

Other Transportation (Off-road)

(CRF Category 1.A.3.e.ii)

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

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

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

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

3.2.6.3. Uncertainties and Time-Series Consistency

Transport

The overall uncertainty of the 2017 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 ±7.2%. The Domestic Aviation subcategory only contributed approximately 4% 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 ±1.3%, 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 3% of the Transport category GHG inventory and therefore did not significantly influence the overall uncertainty results.

Emissions from Domestic Navigation

The uncertainty associated with emissions from the Domestic Navigation category was estimated to be ±2.7%. 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 ±40%. 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 ±1.5%, driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO_2 emissions.

3.2.6.4. QA/QC and Verification

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

In addition, certain verification steps were performed during the model preparation stage. Since MOVES uses national fuel data defined by type and region combined with country-specific emission factors, primary scrutiny is applied to the vehicle population profile, as this dictates the fuel demand per vehicle category and, hence, emission rates and quantities. Interdepartmental relationships have been developed 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

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

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 1990–2018 period as follows.

i. RESD fuel: Revised preliminary 2017 RESD data as well as the motor gasoline and diesel fuel volumes for 2005–2017.

ii. Off-road oil sands mining update: Source data was updated which consisted of minor changes to the quantity of active units and some refinements to engine specifications.

iii. Marine methodology update: Marine methodology was updated to allocate emissions based on the IPCC 2006 guidebook definition of domestic and international navigation (refer to Annex 3, section A3.1.4.2.3 for more details). The change affected the whole time series and the impact ranges from -2.7Mt to 0.1Mt.

The net impact of these recalculations is summarized in Table 3–2.

3.2.6.6. Planned Improvements

Planned improvements have been identified for the Transport category. Current high priorities include reviewing emission factors in MOVES2014 to determine their suitability for inclusion in the national inventory. Reviews of emission factors and activity data for the off-road sector are also planned and could potentially result in updates for the next inventory submission.

Further refinements to off-road activity are also planned. Specifically, it is planned to continue collecting hours of use activity data to refine equipment activity and to undertake reviews on select equipment types or sectors (e.g., recreational boating, agriculture, etc.)

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 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. Emissions from CH_4 and N_2O 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 2018, the Other Sectors category contributed 97.4 Mt (13%) of Canada's total GHG emissions, with an overall growth of about 12% (10.6Mt) since 1990. Within the Other Sectors category, the Residential subcategory contributed emissions of about 46.5 Mt (47.7%), followed by the Commercial/Institutional subcategory with emissions of 35.8 Mt (36.8%) and the Agriculture/Forestry/Fishing subcategory with 15.1 Mt (15.5%). Since 1990, GHG emissions have grown by 28.7% (8 Mt) in the Commercial/Institutional subcategory and 24% (2.9 Mt) in the Agriculture/Forestry/Fishing subcategory, while GHG emissions in the Residential subcategory have declined by about 0.7% (0.31 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

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
Other Sectors TOTAL (1.A.4)	**86 800**	**95 200**	**98 600**	**96 200**	**90 200**	**95 900**	**89 400**	**92 100**	**95 500**	**91 300**	**86 600**	**90 900**	**97 400**
Commercial/Institutional	27 800	31 400	35 500	35 000	31 400	33 500	31 200	32 400	34 100	32 800	32 700	34 500	35 800
Commercial and Other Institutional	26 300	29 400	33 400	32 700	28 800	30 700	28 700	29 700	31 300	30 100	30 100	31 700	32 800
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	2 930
Residential	46 800	47 900	48 200	46 800	43 900	47 100	43 600	45 000	46 800	44 300	40 400	42 300	46 500
Stationary Combustion	46 500	47 500	47 400	45 600	42 700	45 800	42 300	43 800	45 600	43 100	39 200	41 100	45 200
Off-road Residential	241	380	775	1 250	1 170	1 300	1 220	1 180	1 210	1 220	1 170	1 190	1 250
Agriculture/Forestry/Fishing	12 200	15 900	15 000	14 300	14 900	15 300	14 600	14 700	14 500	14 200	13 600	14 200	15 100
Agriculture and Forestry	2 410	2 770	2 570	2 190	3 110	3 680	3 780	3 790	3 840	3 630	3 810	3 710	3 790
Off-Road Agriculture/ Forestry/Fishing	9 790	13 170	12 400	12 140	11 800	11 670	10 870	10 870	10 700	10 560	9 790	10 440	11 340

Note: Totals may not add up due to rounding.

GHG totals exclude CO_2 emissions from the biogenic portion of the waste; these numbers appear separately in the UNFCCC CRF tables as a memo item.

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

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

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

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

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

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

Annex 3.1.4.2.3, Domestic Navigation, discusses the method to reallocate RESD data and estimate emissions from fishing vessels operating in Canadian waters.

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

3.2.7.3. Uncertainties and Time-Series Consistency

The estimated uncertainty range for the Other Sectors category is ±6% for CO_2, CH_4 and N_2O combined and ±1% 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 9% 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 3.2.4.3, 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 landfill gas data;
- revised coal, diesel and solid wood waste emission factors;
- a new method for allocating medical waste combustion for energy purposes to the Energy sector where the combustion occurred; and,
- reallocated fishing vessels emissions from the Domestic Navigation category (1.A.3.d).

Revisions to the Other Sectors category occurred back to 1990. Changes to emission factors affect the entire time series, while changes to the activity data, in the form of updates to the RESD, affects 2017. The revised RESD data resulted in a 0.6 Mt increase in emissions for 2017.

The revised landfill gas data affected the entire time series; however, these impacts were minimal, ranging from 0.1 to 0.2 kt. The new allocation of medical waste incineration for energy purposes affected the time series between 1990 and 2014, resulting in impacts ranging from to 1.0 kt to 3.0 kt.

The revised emission factors resulted in an increase in emissions ranging from 0.5 kt to 8.6 kt between 1990 and 2017.

Refer to the recalculations discussion in the overview, section 3.1, for additional details.

3.2.7.6. Planned Improvements

Although improvements have been 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 Statistics Canada and the Trilateral Energy Working Group's activities.

In 2017, ECCC and StatCan worked on expanding an existing StatCan survey in order to collect residential wood consumption data on a biennial basis, and disaggregated to a level that better represents the changing wood supply characteristics across Canada. The first year of data collection was for 2017, and the second collection year was 2019. ECCC is currently analyzing the results from the first year of the survey, along with historical data in order to develop a new residential biomass emission model.

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.

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.

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

	GHG Emissions, kt CO_2 eq												
GHG Source Category	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018
Other (Not Specified Elsewhere) TOTAL (1.A.5)	**198**	**161**	**164**	**117**	**109**	**119**	**163**	**178**	**175**	**199**	**213**	**205**	**212**

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 2018, the Fugitive Emissions from Fuels category accounted for 55 Mt (7.6%) of Canada's total GHG emissions, with 13% (6.5 Mt) growth in emissions since 1990. Fugitive emissions from oil and natural gas increased 17.3% to 54 Mt, and those from coal decreased to 1.5 Mt (53%) since 1990. The oil and gas production, processing, transmission and distribution activities contributed 98% of the fugitive emissions. Refer to Table 3–10 for more details.

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

3.3.1.1. Source Category Description

The only significant fugitive emissions from solid fuel transformation in Canada come from active and abandoned coal mines. Fugitive emissions from coke manufacturing (flaring) are captured under combustion in CRF category 1.A.2.a. 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 2016, 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 2017, emissions from abandoned mines were 65 kt CO_2 eq. The increase from 53 kt CO_2 eq in 2015 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, or activated carbon, from coal. There is currently only one facility in Canada engaged in this activity and emissions were determined to be negligible.

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

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
Fugitive Emissions from Fuels (1.B)	**49 000**	**64 000**	**69 000**	**61 000**	**55 000**	**55 000**	**59 000**	**61 000**	**63 000**	**60 000**	**55 000**	**55 000**	**55 000**
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**
a. Underground—Mining activities	1 500	700	100	90	90	90	70	90	50	30	NO	60	100
b. Abandoned Underground Mines	190	400	550	170	150	140	140	140	50	50	70	70	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
Oil and Natural Gas (1.B.2)	**46 000**	**61 000**	**68 000**	**60 000**	**53 000**	**54 000**	**57 000**	**59 000**	**62 000**	**59 000**	**54 000**	**54 000**	**54 000**
a. Oil[a]	5 000	6 100	6 500	5 900	5 100	4 900	5 700	5 700	5 600	5 400	5 200	5 200	5 500
b. Natural Gas[a]	13 000	17 000	18 000	14 000	12 000	12 000	12 000	13 000	13 000	12 000	12 000	12 000	12 000
c. Venting and Flaring[ab]	28 000	38 000	44 000	40 000	36 000	37 000	39 000	41 000	43 000	42 000	36 000	37 000	36 000
i. Venting	23 000	33 000	38 000	35 000	31 000	32 000	33 000	34 000	36 000	35 000	30 000	30 000	30 000
ii. Flaring	4 740	5 370	5 760	5 300	4 720	5 010	5 850	7 000	7 210	6 870	5 850	6 500	6 510

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.

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.

A field-testing campaign to measure fugitive emissions of CH_4, CO_2, and VOCs was performed on four coal mines in late February 2014:

- Sites 1 & 2: two subbituminous coal mines in central Alberta;
- Site 3: one bituminous coal mine in northeast BC; and
- 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.

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

Revisions to 2016 and 2017 emission estimates resulted from data updates and corrections. During 2016 and 2017, a mine in Nova Scotia whose production was reported as above ground was actually producing from an underground source.

Abandoned Underground Mines

A mine in Nova Scotia previously reported as abandoned returned to production in 2016.

3.3.1.6. Planned Improvements

Coal Mining and Handling

There are currently no planned improvements.

Abandoned Underground Mines

There are currently no planned improvements.

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

3.3.2.1. Source Category Description

Fugitive emissions in the Oil and Natural Gas category include emissions from oil and gas production, processing, oil sands mining, bitumen extraction, in-situ bitumen production, heavy oil/bitumen upgrading, 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 is produced 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 highly viscous, dense 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 is processed 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 Blows and Gas Migration: At some wells, fluids will flow into the surface casing from the surrounding formation. Depending on the well, the fluids will be collected, sealed in the casing, flared or vented. The vented emissions are estimated in this section. 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.

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.

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
Abandoned Oil and Gas Wells	**40**	**50**	**60**	**80**	**130**	**140**	**160**	**170**	**190**	**210**	**230**	**250**	**270**
Abandoned Oil Wells[a]	30	30	40	50	70	80	80	90	100	110	130	140	150
Abandoned Gas Wells[b]	10	20	20	30	60	60	70	80	90	100	110	110	130

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

3.3.2.2. Methodological Issues

Upstream Oil and Gas

Fugitive emission estimates from the UOG industry are based on 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)—referred to here as the CAPP study—and an update to this inventory, which was completed in 2014 for Environment Canada by Clearstone Engineering Ltd.—referred to here 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 were developed using an IPCC Tier 3 bottom-up assessment, beginning at the individual facility and process unit level and aggregating the results to ultimately 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 of which are interconnected by tens of thousands of kilometres of pipeline carrying hydrocarbons from wells to batteries to plants and ultimately markets. The resulting 2011 inventory database contains more than 7.5 million point-source emission records. The inventory includes emission estimates from flaring, venting, equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses and accidental releases.

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

The 1990–1999 fugitive emissions were estimated using 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 3.2 provides a more detailed description of the methodology.

Abandoned Oil and Gas Wells

Emissions from abandoned wells are estimated using an IPCC Tier 1 approach. The CH_4 emission factors are from a study on abandoned oil and gas wells in the United States titled Emissions of Coalbed and Natural Gas Methane from Abandoned Oil and Gas Wells in the United States (Townsend-Small et al. 2016). 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. Emissions data for the natural gas transmission and storage industry were compiled by ORTECH Consulting Inc. (2013) 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 2015–2018 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. Facility inventories were reviewed to ensure 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 2004–2018 fugitive emission estimates. An oil sands estimation model (referred to here as the oil sands model) was developed to allow 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 2019) and annual reports from Husky Energy Inc. (Husky 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, the Fort Hills Mine and the Sturgeon Refinery, 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 captured CO_2, which is transported and injected into storage, is subtracted from the CO_2 venting emission estimates for this facility.

Downstream Oil and Gas Production

Calculating fugitive emissions from refineries uses information contained in the Canadian Petroleum Products Institute (CPPI) study, *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI 2004). Refer to the CPPI report for full details on the study. The Canadian Energy and Emissions Data Centre (CEEDC) and Canadian refineries provided historical fuel, energy and emission data, for the years 1990 and 1994–2002. Fugitive, venting and flaring emissions for the years 1991–1993 and 2003 onward were extrapolated, using data in the CPPI report and the petroleum refinery energy consumption and production data from the RESD (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 were obtained from published sources and from specialized surveys of gas distribution system 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. Emissions data for the natural gas distribution industry were compiled by ORTECH Consulting Inc. (2013) for CEPEI. CEPEI provided emissions data for the years 2000–2004, 2006–2010 and 2012–2014 following an IPCC Tier 3 approach. Emissions for 2015–2018 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 2018 upstream oil and gas fugitive emissions is -8.8% to +10.1%. 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

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	-8.7 to +8.6	-6.9 to +6.8	-15.9 to +20.6	—	-21.8 to +19.7	—
Fugitive	± 11.2	± 12.1	-26.3 to +27.7	± 49.5	-23.1 to +25.7	-47.0 to +69.9
Venting	-8.3 to +8.6	-9.6 to +23.2	-20.3 to +22.8	—	-26.5 to +35.0	—
Total	**-6.0 to + 6.2**	**-7.4 to +17.2**	**-19.4 to +20.6**	**± 49.5**	**-19.9 to +18.1**	**-47.0 to +69.9**

equipment failures, and abandoned oil and gas wells, have the highest uncertainty, while oil production and transport have the lowest uncertainty.

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

Oil Sands/Bitumen

The overall uncertainty for the 2018 oil sands/bitumen fugitive emissions is -18.6% to +19.6%. 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).

Table 3–13 **Uncertainty in Oil Sands/Bitumen Fugitive Emissions**	
GHG Source Category	Uncertainty (%)
	Oil Sands/Bitumen
Flaring	-22.0 to +22.1
Fugitive	-28.3 to +34.9
Venting	-29.8 to +30.4
Overall	-18.6 to +19.6

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

3.3.2.4. QA/QC and Verification

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.

3.3.2.5. Recalculations

Fugitive emissions from oil and natural gas were revised for the 1990–2017 period because of changes to activity data. See Table 3–2 for a summary of recalculations.

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

- **Flaring**—the following text describes a number of changes to flaring emission estimates. Flaring emissions increased in the years 1990–1996, 1998–2002, 2006–2010 and 2012. There was no change in the year 2011 and emissions decreased in 1997, 2003–2005 and 2013–2017.

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

a) **Newfoundland and Labrador**—New flaring data from the Canada-Newfoundland Offshore Petroleum Board (CNLOPB) for the years 1997 to 2018 was used to estimate flaring emissions in Newfoundland. This data replaces data previously provided by Statistics Canada. The use of this new data has resulted in recalculations to flaring emissions from 1997 to 2017. Recalculations range from -92.3 kt CO_2-eq in 2016 to +0.3 kt CO_2-eq in 2012.

b) **British Columbia**—new flaring data for the years 1996 to 2018, provided by the British Columbia Oil and Gas Commission (BCOGC), was used to estimate flaring emissions. This data replaces discontinued data previously provided by the BC Department of Farming, Natural Resources & Industry. Emission estimates prepared using the new, more detailed, flared volumes resulted in recalculations ranging from +154.3 kt CO_2-eq in 2008 to -133.7 kt CO_2-eq in 2017.

c) **Manitoba, Saskatchewan and Alberta**—updated activity data in Manitoba, Saskatchewan, and Alberta resulted in changes to calculated flaring emissions from 1990 to 2009. These changes were communicated last year with an intended incorporation into the 2019 NIR, however this did not occur. In most years, there was an increase in emissions, ranging from +2 kt CO_2-eq in 2009 to +753 kt CO_2-eq in 1992. Emissions decreased by 171 kt in 1997, 6 kt in 2002, 17 kt in 2003 and 65 kt in 2005.

- **Abandoned Oil and Gas Wells**—changes to internal procedures for determining abandoned well counts from provincial data and updated datasets from Saskatchewan and British Columbia have resulted in changes to abandoned well counts for the 1990 to 2017 period. These changes resulted in an increase in emissions from abandoned oil wells ranging from +0.8 kt to +8.6 kt CO_2-eq. For abandoned gas wells, emissions changed ranging from -2.1 kt CO_2-eq in 2005 to +5.6 kt CO_2-eq in 2017.
- **Petroleum Refining**—for the entire time series, revised diesel and motor gasoline energy conversion factors caused changes to the refinery energy consumption used to estimate fugitives. Fugitive emissions increases across the time series range from 0.2 kt to 3.1 kt CO_2-eq. with a decrease of 10.7 kt CO_2-eq in 2017 specifically caused by revised fuel consumption volumes from StatCan.
- **Accidents and Equipment Failures**—activity data changes to the number of spills and the number of operating wells resulted in recalculations of emissions from spills/pipeline ruptures and surface casing vent flow/gas migration.

  a) **Spills/Pipeline Ruptures**—revisions to Saskatchewan UOG Incident Report resulted in changes to the number of spills that occurred in Saskatchewan between 2014 and 2017. These activity data changes resulted in an increase in emissions in 2014 and 2015 (+0.6 kt and +3.4 kt CO_2-eq) and a decrease in emissions in 2016 and 2017 (-4.5 kt and -2.2 kt CO_2-eq).

  b) **Surface Casing Vent Flow/Gas Migration**—the number of operating wells in Alberta in 2017 was revised from 155,689 to 147,348. This resulted in a decrease in emissions of -263.2 kt CO_2-eq in 2017.
- **Natural Gas Production**—revisions to non-associated gas production in Alberta resulted in recalculations of fugitive emissions from natural gas production of +36.9 kt, +47.9 kt, +27.1 kt and +73.9 kt CO_2-eq in the years 2014 through 2017, respectively.
- **Natural Gas Transmission, Distribution and Storage**—minor revisions to pipeline lengths resulted in an increase of +4.6 kt CO_2-eq in 2016 and -14.9 kt CO_2-eq in 2017.
- **Venting**—venting emissions increased in 2011 (+5.3 kt), 2014 (+94.1 kt), 2015 (+122.3 kt), 2016 (+70.3 kt) and 2017 (+125.9 kt CO_2-eq) due to changes in activity data.

  a) **Non-associated gas production**—revisions to non-associated gas production volumes resulted in recalculations of unreported venting emissions in Alberta for the years 2014 through 2017. This was the main reason for the recalculations in venting emissions.

  b) **Heavy Crude Oil Production**—a correction to a small transcription error from the UOG study (EC 2014) resulted in a +5.3 kt CO_2-eq increase in emissions from unreported venting from Heavy Crude Oil Production in Alberta for the year 2011.

3.3.2.6. Planned Improvements

Upstream Oil and Gas

As described above, emission estimates for the UOG industry are currently based on detailed studies that are conducted approximately every 5 to 10 years, with emissions for intervening years extrapolated from the

latest dataset. This approach does not facilitate the adoption of new scientific data (i.e. emission factors) as they become available, nor does it properly capture the emissions impact of technological improvements or regulations in a timely manner. Work is underway to develop a robust method of estimating emissions that is more adaptable. Additionally, the Alberta Energy Regulator (AER) has supplied new data on accidental venting from well surface casing vents, which currently account for 13% of all oil and gas fugitive emissions. The new data are being reviewed and a method for incorporating them is being developed.

3.4. CO_2 Transport and Storage (CRF 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 shows the two sources of CO_2 transported in Canada: CO_2 imported from the Dakota Gasification Company in North Dakota (in the United States) and domestically captured CO_2 from SaskPower's Boundary Dam power station, in Saskatchewan, and Shell's Scotford bitumen upgrader, in Alberta. In 2018, CO_2 emissions from these pipelines were approximately 0.3 kt, an increase of about 0.21 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 and from a coal-fired power station in Saskatchewan acts as a flooding agent in EOR operations to increase crude oil production volume at two 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 Apache 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. As of January 1, 2019, the Boundary Dam facility had captured approximately 2.4 Mt of CO_2 for shipment to the Weyburn site (SaskPower 2019). 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 2.8 Mt per year.[6] From 2000 to 2017, the Weyburn site injected over 30 Mt of new CO_2 purchased from the Dakota gasification plant, with an injection rate of 7 kt of CO_2 per day (PTRC 2011). Since 2005, the Midale site has injected more than 3 Mt of CO_2, with an injection rate of 1800 t of CO_2 per day (PTRC 2004).

6 *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.

Table 3–15 **CO_2 Import and Capture Quantities**

	CO_2 Quantity, kt												
CO_2 Capture Source	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018
Imported	NO	NO	1800	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Domestic Capture	NO	NO	NO	NO	NO	NO	NO	NO	100	800	1900	1600	1700

Note:
NO Not occurring.

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

	GHG Emissions, kt CO_2												
GHG Source Category	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018
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	0.27

Note:
NO Not occurring.

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.

The net emission impact of GHG emissions from all of these operations is included in Canada's inventory as part of the Energy Industries (1.A.1) and Oil and Natural Gas (1.B.2) categories.

3.4.1. Transport of CO_2—Pipelines (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 EOR facility at 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.

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 Cenovus EOR facility 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. 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 pipelines, currently under construction in Alberta, as they come on-line.

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.

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

Year	1990	2005	2011	2012	2013	2014	2015	2016	2017	2018
Ethanol Consumed (ML)	7	253	2 336	2 341	2 441	2 392	2 432	2 516	2 517	2 592

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)[7] 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 higher heating value (HHV)7 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.

7 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.

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

Year	1990	2005	2011	2012	2013	2014	2015	2016	2017	2018
Biodiesel Consumed (ML)	NO	NO	716	729	805	802	813	785	848	901

CHAPTER 4

INDUSTRIAL PROCESSES AND PRODUCT USE
(CRF SECTOR 2)

4.1. Overview

This chapter covers 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 alternatives 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 considered under the Energy sector.

Greenhouse gas emissions from the IPPU sector contributed 56.3 Mt to the 2018 national GHG inventory (Table 4–1), compared with 56.9 Mt in 1990. The 2018 IPPU emissions represented 7.7% of total Canadian GHG emissions in 2018. 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.

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

4.2.1. Category Description

Portland cement constitutes more than 90% of the cement produced in Canada, while the rest is masonry and other cement (Statistics Canada no date [b]). The Cement category considers emissions associated with the production of clinker, the precursor of Portland cement, and excludes other cement production (IPCC 2006). There are 24 cement kilns in Canada within 16 separate facilities, all of which use dry kilns. These facilities are located in British Columbia, Alberta, Ontario, Quebec and Nova Scotia.[1] Total clinker production capacity in Canada is approximately 16 Mt/year.

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

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

Greenhouse Gas Category	GHG Emissions (kt CO_2 eq)											
	1990	1995	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018
INDUSTRIAL PROCESSES AND PRODUCT USE	**56 900**	**58 300**	**56 600**	**51 400**	**55 100**	**59 300**	**56 800**	**54 700**	**54 300**	**55 200**	**54 000**	**56 300**
Mineral Products	**8 410**	**9 110**	**10 250**	**7 850**	**7 970**	**8 480**	**7 750**	**7 830**	**8 070**	**7 940**	**8 470**	**8 850**
Cement Production	5 760	6 460	7 600	6 040	6 060	6 560	5 980	5 950	6 260	6 190	6 750	7 170
Lime Production	1 790	1 890	1 740	1 400	1 460	1 480	1 390	1 500	1 400	1 360	1 390	1 360
Mineral Product Use	860	750	910	410	450	440	380	380	410	390	330	320
Chemical Industry	**17 570**	**18 520**	**10 420**	**6 400**	**7 110**	**7 460**	**7 330**	**7 210**	**7 600**	**7 710**	**6 940**	**7 660**
Ammonia Production	2 770	2 940	2 710	2 490	2 880	3 000	2 950	2 540	2 850	2 790	2 560	2 440
Nitric Acid Production	970	960	1 200	1 060	1 120	1 070	990	1 020	1 120	1 040	930	1 100
Adipic Acid Production	10 300	10 310	2 550	-	-	-	-	-	-	-	-	-
Petrochemical and Carbon Black Production (includes Carbide Production)	3 520	4 310	3 960	2 850	3 110	3 390	3 400	3 650	3 630	3 880	3 450	4 120
Metal Production	**23 770**	**23 490**	**20 230**	**16 220**	**17 070**	**16 890**	**14 790**	**15 010**	**14 460**	**15 400**	**15 120**	**14 970**
Iron and Steel Production	10 480	11 470	10 310	9 170	10 080	10 180	8 040	8 930	8 520	9 270	8 980	9 330
Aluminium Production	10 330	10 010	8 680	6 870	6 810	6 470	6 530	5 830	5 720	5 990	6 010	510
SF_6 Used in Magnesium Smelters and Casters	2 960	2 010	1 230	190	180	250	210	250	230	130	130	130
Production and Consumption of Halocarbons, SF_6 and NF_3	**980**	**500**	**5 110**	**7 740**	**8 600**	**9 090**	**10 080**	**10 960**	**11 050**	**11 320**	**11 530**	**12 550**
Non-Energy Products from Fuels and Solvent Use	**5 800**	**6 320**	**9 980**	**12 800**	**13 970**	**16 850**	**16 300**	**13 250**	**12 590**	**12 230**	**11 290**	**11 550**
Other Product Manufacture and Use	**370**	**390**	**530**	**430**	**400**	**500**	**560**	**480**	**570**	**630**	**660**	**740**

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	2011	2012	2013	2014	2015	2016	2017
INDUSTRIAL PROCESSES AND PRODUCT USE												
Current (2020) submission	56.9	58.3	54.0	56.6	51.4	55.1	59.3	56.8	54.7	54.3	55.2	54.0
Previous (2019) submission	56.6	57.8	53.2	55.6	50.6	54.1	58.2	55.3	52.7	52.9	54.5	53.8
Net change in emissions	+0.3	+0.5	+0.8	+1.0	+0.8	+1.0	+1.1	+1.5	+2.0	+1.4	+0.7	+0.2
Mineral Products												
Current (2020) submission	8.4	9.1	10.0	10.3	7.9	8.0	8.5	7.8	7.8	8.1	7.9	8.5
Previous (2019) submission	8.4	9.1	10.0	10.3	7.8	8.0	8.5	7.8	7.8	8.1	7.9	8.5
Net change in emissions	-0.0	-0.0	+0.0	-0.0	+0.0	+0.0	-0.0	-0.0	+0.0	+0.0	-0.0	-0.0
Chemical Industry												
Current (2020) submission	17.6	18.5	8.8	10.4	6.4	7.1	7.5	7.3	7.2	7.6	7.7	6.9
Previous (2019) submission	17.3	18.0	8.0	9.5	5.5	6.1	6.4	6.4	6.0	6.5	6.6	5.9
Net change in emissions	+0.3	+0.5	+0.8	+0.9	+0.9	+1.0	+1.1	+0.9	+1.2	+1.1	+1.2	+1.1
Metal Production												
Current (2020) submission	23.8	23.5	23.4	20.2	16.2	17.1	16.9	14.8	15.0	14.5	15.4	15.1
Previous (2019) submission	23.8	23.5	23.4	20.2	16.2	17.1	16.9	14.8	15.0	14.5	15.5	15.7
Net change in emissions	+0.0	+0.0	+0.0	+0.0	-0.0	-0.0	+0.0	+0.0	-0.0	-0.0	-0.1	-0.5
Production and Consumption of Halocarbons, SF_6 and NF_3												
Current (2020) submission	1.0	0.5	2.8	5.1	7.7	8.6	9.1	10.1	11.0	11.0	11.3	11.5
Previous (2019) submission	1.0	0.5	2.8	5.1	7.8	8.6	9.1	9.4	10.1	11.0	12.0	12.6
Net change in emissions	+0.0	-0.0	+0.0	+0.0	-0.0	-0.0	+0.0	+0.6	+0.9	-0.0	-0.7	-1.0
Non-Energy Products from Fuels and Solvent Use												
Current (2020) submission	5.8	6.3	8.5	10.0	12.8	14.0	16.8	16.3	13.3	12.6	12.2	11.3
Previous (2019) submission	5.8	6.3	8.4	10.0	12.8	14.0	16.8	16.3	13.2	12.2	11.8	10.5
Net change in emissions	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.4	+0.4	+0.8
Other Product Manufacture and Use												
Current (2020) submission	0.4	0.4	0.6	0.5	0.4	0.4	0.5	0.6	0.5	0.6	0.6	0.7
Previous (2019) submission	0.4	0.4	0.6	0.5	0.4	0.4	0.5	0.6	0.5	0.6	0.7	0.7
Net change in emissions	+0.0	-0.0	-0.0	+0.0	+0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0

Notes:
Totals may not add up due to rounding.

In 2018, the category accounted for 7170 kt (or 1.0%) of Canada's total emissions, with about a 25% growth in emissions since 1990 (Table 4–1).

The emissions resulting from 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 calculated 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, Volume 3). Since plant-level data on the composition of carbonate raw materials is unavailable, the application of a Tier 3 method is not possible.

Equation 4–1

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

EF_{cl}	=	annual emission factor based on clinker production, 0.5260 kt CO_2/kt clinker
M_{cl}	=	clinker production data, kt
CF_{ckd}	=	factor that corrects for the loss of cement kiln dust and by-pass dust, fraction (1.012)
EF_{toc}	=	emission factor for CO_2 emissions from organic carbon in the raw feed, 0.0115 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. However, the Cement Association of Canada (CAC) has provided national aggregated data expressed as an annual calcination emission factor (EF_{cl}) and annual amounts of bypass dust and CKD for 1990, 2000 and 2002–2014 (CAC 2014). These same quantities have been estimated for the remaining reporting years (1991–1999, 2001, 2015–2018). 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.

The calcination CO_2 emission factor (EF_{cl}) varies from year to year and is based on the available data for 1990, 2000 and 2002–2014. For the unknown data years (1991–1999, 2001), an average is taken from the years before and after the unknown data point. Starting in 2015, the calcination emission factor has not been updated by the CAC and as a result, it has been assumed to be the same as that for 2014. The correction factor for CKD/bypass dust is calculated by the CAC to be 1.012 and is based on the average CKD data from years 1990, 2000 and 2002–2014.

The CAC reports that the raw material contains 0.2% organic carbon and assumes a raw meal/clinker ratio of 1.57. Again, both values are based on data from 1990, 2000 and 2002–2014. These assumptions, combined with the molecular weight ratios of CO_2 to C (44.01/12.01), result in the organic carbon emission factor (EF_{toc}) of 0.0115 (kt CO_2/kt clinker).

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 1997–2018 was obtained from Statistics Canada (Statistics Canada 1990–2004; Statistics Canada no date [a]).

Provincial/territorial emissions are estimated based on clinker capacity of cement plants across Canada. The source of 1990–2006 data was the *Canadian Minerals Yearbook* (NRCan 1990–2006). In subsequent years (2007–2013), information has been provided directly by Natural Resources Canada via personal communication.[2] Capacity data has not been made available for 2014–2018 and has therefore been assumed to be the same as the 2013 data.

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 various parameters in Equation 4–1. The error associated with the non-response rate of the Statistics Canada survey for clinker production data has been also considered in the uncertainty estimate. The Tier 1 uncertainty associated with the CO_2 estimate for clinker production has been calculated to be ±12.5%. The uncertainty value is applicable to all years of the time series. Equation 6.4 of the IPCC Good Practice Guidance (IPCC 2000) has been consistently 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.

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

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 Chapter 6, Volume 1 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006).

4.2.5. Category-Specific Recalculations

National clinker production data for 2017 was updated, which resulted in a small downward recalculation of less than 1 kt CO_2 eq.

4.2.6. Category-Specific Planned Improvements

2017 and 2018 plant-specific clinker production collected through ECCC's Greenhouse Gas Reporting Program, instead of clinker capacity of cement plants across Canada, will be used to estimate provincial/territorial emissions. Clinker production capacities from 2014 onwards have been assumed to stay constant at 2013 levels.

2017 and 2018 plant-specific data on cement kiln dust and on organic carbon in the raw feed obtained through the same program will be examined closely to explore the possibility of using these to update the current CF_{ckd} correction factor and the EF_{toc} emission factor.

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 Canadian lime production that is dolomitic and high-calcium for all inventory years. There exists no information on hydraulic lime production in Canada, and as a result its proportion of total lime production is assumed to be zero.

The Lime Production category contributed 1357 kt (0.2%) to Canada's total emissions in 2018, a 24% decrease from 1990.

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 and are included in the Limestone and Dolomite Use subcategory (section 4.4).

4.3.2. Methodological Issues

A Tier 2 methodology is used to estimate the CO_2 emissions from Lime Production where the country-specific emission factors were applied to national activity data (IPCC 2006). The country-specific emission factors for high-calcium lime and dolomitic lime were developed on the basis of the information on Canadian lime compositions collected from the Canadian Lime Institute[3] and are provided in Annex 6. Data on total national lime production, hydrated lime production and lime plant calcining capacities was obtained from the *Canadian Minerals Yearbook* (NRCan 1990–2006)[4] for the period up to and including 2006. In subsequent years, information was provided directly by Natural Resources Canada via personal communication.[5] The most recent lime production data is preliminary and subject to revision in subsequent publications.

Canadian lime plants are classified into three types based on their final products: dolomitic lime only, high-calcium lime only, and both high-calcium and dolomitic lime. In the absence of disaggregated data on the breakdown of lime types, an 85/15 value for high-calcium/dolomitic lime has been used for lime plants producing both high-calcium and dolomitic lime, resulting in the breakdown provided in Table 4–3. National CO_2 emissions were calculated by applying the Canadian emission factors to the estimated yearly national lime production data, by lime type.

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

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

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

Table 4–3 **Split between Dolomitic and High-Calcium Lime Production in Canada (1990–2018)**

Year	% Split	
	Dolomitic Lime	High-Calcium Lime
1990–1992	14%	86%
1993–1999	16%	84%
2000–2002	8%	92%
2003–2008	9%	91%
2009–2018	7%	93%

The water content of Canadian hydrated lime is estimated to be 28.25%.[6] 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 the two lime types: high-calcium and dolomitic. Corresponding emission factors are subsequently applied.

The 2006 IPCC Guidelines default lime kiln dust (LKD) correction factor of 2% is also applied throughout the time series.

Provincial CO_2 emissions are derived from national emissions on the basis of the calcining capacity of each province/territory. The *Canadian Minerals Yearbook* provided data on calcining capacity for the years 1990–2006; in subsequent years (2007–2013), the data was provided directly by Natural Resources Canada via personal communication.[7] The calcining capacities have not been updated since 2014 and are assumed to stay at 2013 levels.

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 and dolomitic lime in 1999–2000.[8] The slight decrease in the share of dolomitic lime in 2008–2009 is attributed to a closure of a plant in Ontario that produced only dolomitic lime.

4.3.3. Uncertainties and Time-Series Consistency

A Monte Carlo uncertainty assessment was performed for the Lime Production category. It took into account the uncertainties associated with the production data, emission factors, correction factors for hydrated lime and LKD, and percentage split between the two types of lime. The uncertainty associated with the category as a whole has been evaluated at ±14.7%. The uncertainty value is applicable to all years of the time series.

The emission factors and estimation method are consistent throughout the time series. The source of activity data has changed over the time series from the Canadian Lime Institute to Natural Resources Canada, as described in section 4.3.2.

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

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

4.3.5. Category-Specific Recalculations

National lime production data for 2017 was updated, which resulted in a small upward recalculation of 11 kt CO_2 eq.

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), 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 2018, the aggregate category accounted for 325 kt (or 0.04%) of Canada's total GHG emissions, with a decrease of approximately 62% in total emissions since 1990. Non-metallurgical Magnesium Production accounted for 36% of Mineral Product Use emissions, whereas Limestone and Dolomite Use, Other Uses of Soda Ash and Glass Production contributed 33%, 16% and 15% of emissions, respectively.

Glass Production (CRF Category 2.A.3)

The 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 this category. Calcination of carbonates in the clay results in process emissions of CO_2.

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

7 Panagapko D. 2013. Personal communication (email to Edalatmanesh M, Environment and Climate Change Canada, dated November 6, 2013).

8 Panagapko D. 2013. Personal communication (email to Edalatmanesh M, Environment and Climate Change Canada, dated November 6, 2013).

To assess the significance of CO_2 emissions from production of ceramics, emissions were estimated for 2005 to 2007 and for 2011 to 2018. For 2005 to 2007, national total annual amounts of clay used for ceramics were obtained from the *Canadian Minerals Yearbook* (NRCan 1990–2008). A tier 1 method as per 2006 IPCC Guidelines (i.e. equation 2.14 in volume 3 of the Guidelines) was used for these years (IPCC 2006). A default carbon content of 10% was applied to the annual amount of clay used to determine the mass of carbonate consumed (M_c). "M_c" for each year of 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 2018, process emission estimates were obtained from major Canadian manufacturers of structural clay products via the GHGRP. The emission assessment performed showed that the CO_2 emissions were below 0.05 percent of Canada's national total GHG emissions and did not exceed 500 kt CO_2 eq. As such, CO_2 emissions from ceramic production are considered "insignificant" under paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines, and are reported, as of 2020 inventory submission, as "NE" (with an explanation provided) in the CRF reporter as per the ERT's recommendation.

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

Second to glass production, 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 during different periods over the years 1990–2007. Two of the facilities closed, one in 1991 and the other in 2007; one facility remains in production.

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 CRF category 2.A.4.d Limestone and Dolomite Use are associated with other applications, such as its use in pulp and paper mills as makeup lime, and other chemical uses, including wastewater treatment and FGD.

4.4.2. Methodological Issues

Glass Production (CRF Category 2.A.3)

National CO_2 emissions 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 glass production.

The quantity of soda ash consumed in glass production is estimated by applying the ratio of soda ash used for glass production in the United States to the total Canadian consumption. The quantity of limestone consumed in glass production is based on limestone production statistics collected by Natural Resources Canada.[9]

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

CO_2 process emissions from ceramics production are considered as "insignificant." Details are provided 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 has been obtained from Global Trade Information Services (GTIS 1995–2006, 2007–2009) and Statistics Canada's Canadian International Merchandise Trade Database (Statistics Canada 2010–2018). 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, flue gas desulphurization and others. 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 carbon available in the magnesite, and

9 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.

assumes the purity of magnesite to be at 97% (AMEC 2006). The emission factor is multiplied by facility-specific activity data to produce provincial and national CO_2 emission estimates.

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.[10] The activity data for 2006 and 2007 has been estimated from the average ratio of magnesite consumed to magnesia produced between 1990 and 2005.

10 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.

The third plant has been operational for the full reporting period (1990–2018) and its annual activity data is sourced from British Columbia's Ministry of Energy and Mines (British Columbia Geological Survey 2018).

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).

Table 4–4 **High Calcium and Dolomite Consumption in Canada**

Year	2.C.1 Iron and Steel		2.A.3 Glass Production	2.A.4.d Other Process Uses of Carbonates		
	High-Calcium Limestone (kt)	Dolomite (kt)	High-Calcium Limestone (kt)	High-Calcium Limestone (kt)		
				Pulp and Paper Mills	Non-ferrous Smelters	Other Chemical Uses
1990	459	197	171	214	16	846
1991	344	147	169	220	162	964
1992	393	169	154	231	167	264
1993	139	59	161	224	176	244
1994	133	57	146	234	154	587
1995	215	92	146	130	181	436
1996	208	89	146	134	164	711
1997	232	100	181	117	158	915
1998	274	118	158	89	129	857
1999	274	118	137	96	101	522
2000	476	204	51	118	39	928
2001	334	143	44	69	94	680
2002	181	77	46	57	55	927
2003	197	85	18	62	46	939
2004	146	63	18	75	51	1109
2005	151	65	18	80	47	1175
2006	140	60	18	173	57	1057
2007	69	30	32	41	64	1178
2008	223	95	12	15	65	1182
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	82	35	0	43	27	189

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 has been gathered from the *Canadian Minerals Yearbook* (NRCan 1990–2006). For subsequent years, information has been provided directly by Natural Resources Canada via personal communication. Moreover, data for stone used as flux in iron and steel furnaces for all years is disaggregated into limestone and dolomite on the basis of a 70/30 split (AMEC 2006). Table 4–4 exhibits the split between consumption of high-calcium limestone and dolomite in the iron and steel sector, glass production and other process uses of carbonates. National CO_2 emissions are estimated by multiplying the quantities of limestone and dolomite consumed by the corresponding emission factors. The emissions are subsequently allocated to the respective reporting categories of Glass Production (CRF category 2.A.3), Iron and Steel Production (CRF category 2.C.1, refer to section 4.10), and 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.

On the basis of Canadian information,[11] 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 2018 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.

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

A Tier 1 uncertainty assessment was performed for the category of Soda Ash Use. It considered uncertainties associated with the production (for years before 2001), import and export data. The uncertainty associated with the category as a whole for the time series ranged from ±7.6% to ±6.1%.

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.

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

The Tier 1 uncertainty assessment for the category of 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.

11 Cook S. 2013. Personal communication to Edalatmanesh M, Environment and Climate Change 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 Other Uses of Soda Ash, updates to the activity data for 1995 and 1996 resulted in a small downward recalculation of less than 1 kt CO_2 eq. For Limestone and Dolomite Use, updates to the activity data for 2017 resulted in a decrease of approximately 52 kt CO_2 eq.

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 2400 kt (0.3%) of Canada's emissions in 2018, and its level of emissions has remained relatively constant since 1990.

There are currently nine ammonia production plants[12] operating in Canada, located in Alberta, Saskatchewan, Manitoba and Ontario. Eight of these plants use steam-methane reformers to produce ammonia; they 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 4–2). 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 2.D.3. Other uses of urea (e.g., its use as an ingredient in manufacturing of resins, plastics or coatings) was determined to be a significant source of emissions and is reported in CRF 2.B.10.

4.5.2. Methodological Issues

The Ammonia Production category estimates CO_2 emissions resulting from the feedstock use of natural gas and considers emissions that are recovered for use in urea production. A Tier 2 country-specific method is applied in accordance with the 2006 IPCC Guidelines (IPCC 2006). The 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. The annual ammonia production data for 1990–2004 were gathered in a study conducted by Cheminfo Services (2006); those for 2005–2009 were collected by Environment Canada through a voluntary data submission process with the fertilizer industry; and those for 2008–2018 were obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey (Statistics Canada no date [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 other ones stopped operating in 2005). Seven of these nine plants (two of these with 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 these two plants did not use SMR. At the plant level, the variability of the ammonia-to-feed fuel conversion factor is very steady; it varies less than 0.001% from one year to another over the five years. Similarly, the average value varies less than 0.001% from one year to another over the five years.

The amount of natural gas used as feed is multiplied by the respective province's natural gas carbon content factor (CC_j) to determine the resulting CO_2 emissions generated. The amount of CO_2 recovered for urea production is then subtracted from the process-related emissions (Equation 4–2). Using the 2006 IPCC Guidelines, 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. The resulting recovery factor ($RFCO_2$) is therefore 0.728 kg CO_2/kg urea.

12 https://ammoniaindustry.com/tag/canada/, https://fusiontables.google.com/data?docid=1vXUF9q5X0vbWID_JAzpxaByp28lwlr3gs0y2zg8#rows:id=1

Equation 4–2 **CO_2 Emissions from Ammonia Production**

$$E_{CO_2} = \sum_i AP_i \cdot FF_i \cdot CC_j - RF_{CO_2} \cdot UP_i$$

E_{CO_2}	=	emissions of CO_2, kt
AP_i	=	ammonia production of facility i, kt
FF_i	=	ammonia-to-feed fuel conversion factor of facility i, m^3 natural gas/t NH_3
CC_j	=	carbon content factor of the fuel in province j, kt CO_2/m^3 of natural gas
RF_{CO_2}	=	factor for CO_2 recovered for urea production, 0.728 kg CO_2/kg urea
UP_i	=	urea production of facility i, kt

Urea production data for 2008–2018 was retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. 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.

Finally, the quantity of natural gas used to produce hydrogen for ammonia production was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double counting, the natural gas amounts allocated by Statistics Canada for hydrogen production are systematically removed from the non-energy use of natural gas reported under the Non-Energy Products from Fuels and Solvent Use category.

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

4.5.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Ammonia Production. The assessment took into account the uncertainties associated with the ammonia and urea production data, ammonia-to-feed fuel conversion factor and the carbon content of natural gas. The uncertainty values associated with CO_2 emissions from the category as a whole vary over time from 6.7% to 9.3% in accordance with changes in natural gas volumes consumed for ammonia production and with changes in urea production.

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

There were no recalculations attributed to this specific category.

4.5.6. Category-Specific Planned Improvements

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

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

4.6.1. Category Description

The Nitric Acid Production category accounted for 1 098 kt (0.15%) of Canada's emissions in 2018, a 13% increase from 1990.

There exist two basic types of nitric acid production technology: 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 reaction and absorption stages. High-pressure process plants can function with a non-selective catalytic reduction (NSCR) or selective catalytic reduction (SCR) system. The emission abatement systems are classified as "non-selective" when natural gas is used as a reductant to reduce all nitrogen oxides (NO_x). In contrast, a "selective" catalytic reduction (SCR) uses ammonia, which selectively reacts only with nitrogen oxide (NO) and nitrogen dioxide (NO_2) gases, and not with nitrous oxide (N_2O), hence a higher N_2O emission factor. Most Canadian plants (as of 2018, five out of six) operate with a high-pressure design and have NSCR abatement technology installed.

The second type of nitric acid production technology design, i.e. dual pressure, uses low pressure for the reaction stage and higher pressure for the absorption stage. To increase the efficiency of the absorption stage, dual-pressure plants can "extend" the absorption tower by adding more trays. This is referred to in Table A6.2–3 as "absorption Type 1." Alternatively, plants can have in place a second tower to allow "double absorption." This is referred to in Table A6.2–3 as "absorption Type 2" (Cheminfo Services 2006).

4.6.2. Methodological Issues

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

1. Plant-specific production data and plant-specific emission factors (i.e. Tier 3 type method) when these were available from companies; or
2. Plant-specific production data and production technology-specific emission factors that are national average values (i.e. Tier 2 type method) when plant-specific emission factors were not available; or
3. Estimated production data and national average technology-specific emission factors (i.e. Tier 1 type method) when limited or no plant-specific data was available (only one plant).

More specifically, the Tier 2 method was applied to all five facilities currently in operation in Canada (one of which has two production technologies) for almost all years.

Plant-specific emission factors were also applied to two of the plants for certain years: plant one—2000 to 2004 and plant two—1990 to 2004. It should be noted that to make sure that confidential plant-level production data are fully protected, it is not possible for Canada to specifically associate EFs with the plants.

The applicability of the emission factors indicated in Table A6.2–3 was assessed in the 2006 Cheminfo study. During this study, plants were asked to provide plant-specific emission factors if available. A plant that accounted for over 80% of the emissions confirmed that the Extended Absorption "Type 1" and SCR emission factors were provided by the equipment vendor. Other plants were able to provide plant-specific emission factors for some years but not others. The remaining plants applied emission factors presented in Table A6.2–3. The 2000 IPCC emission factor of 8.5 kg N_2O/ HNO_3, not the emission factor from the 2006 IPCC Guidelines, was applied because the former was confirmed in the 2006 Cheminfo study.

When facility-level production data is unavailable, production is estimated on the basis of the overall capacity utilization of other known plants. The estimated production is multiplied by the most appropriate industry-typical emission factor. For 1990–2004, the raw activity data and plant-specific emission factors (when available) were obtained through the 2006 Cheminfo study (Cheminfo Services 2006). For 2005–2011, the data was reported by companies to Environment and Climate Change Canada on a voluntary basis in conjunction with Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. For 2012–2018, production data was obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

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 and facility-specific nitric acid production data and emission factors. The uncertainty values associated with N_2O emissions from the category as a whole vary slightly over time from 2.0% to 2.5%, with the emission factors being the largest contributors.

The same emission factors are consistently applied over the time series. The activity data source is provided in section 4.6.2.

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

The Nitric Acid Production category has undergone informal quality control checks throughout the emission estimation process. This includes checking for errors in production data, for example, by comparing data with that from previous years, checking for transcription errors and checking units.

4.6.5. Category-Specific Recalculations

There have been no recalculations for this category.

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 owner. 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 emission estimation method calculated emissions that occur when the abator is operating separately from emissions that occur when the abator is not operating due to maintenance or technical problems (Equation 4–3).

Equation 4–3

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

N_2O Emissions with Abator:

Equation 4–4

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

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, which are 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 4–5

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

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 align with Tier 3 and Tier 2 methods (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

Canada had a single operational soda ash production facility between 1990 and 2001. There has been no production in Canada since 2001.

4.8.2. Methodological Issues

Canadian soda ash production halted in 2001. A Tier 1 method has been applied to estimate the CO_2 emissions generated from the ash production process for the applicable reporting years (1990–2001). The net CO_2 emissions are assumed to be negligible because the CO_2 coming from the Solvay process was recovered for re-use (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. It is mainly used 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).

Based on the 2010 Cheminfo study, there is one TiO_2 producer in Canada. It has been using both chloride and sulphate processes for making TiO_2. During the study, production capacity data for both process types was provided, allowing for the assessment of significance of emissions of 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 were insignificant. More specifically, they represented less than 0.01% 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). As per the ERT's recommendation, CO_2 emissions of this category are reported as "NE" and an explanation is provided in the CRF reporter as of the 2018 NIR submission.

Methanol Production (CRF Category 2.B.8.a)

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, CH_4 and N_2O) emissions come mainly from process off-gas that is separated from methanol and combusted on-site for energy recovery. The process off-gas contains excess CO, CO_2 and light hydrocarbons. Additional CH_4 emissions can occur in venting of process gases containing CH_4 from the methanol distillation train and methanol storage tanks and from fugitive emissions from equipment leaks (Cheminfo Services 2010). N_2O emissions are reported in CRF category 2.B.10 Other (Methanol Production—N_2O Emissions).

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

There were five ethylene facilities in operation in Canada between 1990 and 2018, one of which began operating in 1994 and another of which was 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.c)

Three ethylene dichloride production (EDC) facilities operated in Canada for different periods between 1990 and 2006; all plants are currently closed, with the last one closing in 2006.

Two processes had been used 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.d)

Ethylene oxide is a chemical intermediate that is used in the manufacture of glycols, including monoethylene glycol. There were five ethylene oxide facilities operated in Canada between 1990 and 2018, four of which are currently operational. CO_2 emissions are by-product from the direct oxidation of the ethylene feedstock and are dependant upon 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.f)

Four facilities produced carbon black in Canada between 1990 and 2018, 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” in the CRF.

Styrene Production (CRF Category 2.B.8.g)

Three styrene facilities produced styrene in Canada between 1990 and 2018, 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.

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

During the manufacture of HCFC-22, trifluoromethane (HFC-23 or CHF_3) is generated as a by-product (IPCC 2000). Two HCFC-22 producers (Dupont Canada and Allied-Signal) operated in Canada during 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 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 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 category of other uses of urea takes into account potential emissions from urea used as an ingredient in the manufacturing of resins, plastics or 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, with the quantity used for agriculture, as well as 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)

A Tier 1 method (i.e. with the application of Tier 1 IPCC default emission factors) was 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 therefore used to estimate total CH_4 emissions from carbide production:

Equation 4–6

$$\text{Total } CH_4 \text{ emissions (t)} = \sum^{y}[(\textbf{SiC capacity} \times \textbf{capacity utilization} \times \textbf{Emission Factor\_SiC}) + (\textbf{CaC}_2 \textbf{ capacity} \times \textbf{capacity Emission Factor\_CaC}_2)]$$

y	=	companies
$SiC \text{ or } CaC_2 \text{ capacity}$	=	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 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.a)

When available, CO_2, CH_4 and N_2O, facility-reported emissions data was included in this submission. The remaining emissions were estimated using a Tier 2 approach where reported facility production data and emissions were used to derive a country-specific emission factor for CO_2, CH_4 and N_2O. National methanol production values are taken from Camford's CPI Product Profile for 1990–1999 and estimated on the basis of assumed capacity utilization for 2000–2006 (Cheminfo Services 2010).

Methanol production restarted in Canada in 2011 in a facility that had previously been included in the inventory. The same country-specific emission factors were applied to the facility's publicly reported production data for 2011 (Cheminfo Services 2015). For 2012–2018, production data is obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

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

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,[13] 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[14] 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 2008–2018, 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, emissions are estimated on the basis of the estimated ethylene production (allocated to each non-reporting facility by share of capacity) and the corresponding emission factors.

13 Cheminfo Services 2010

14 Cheminfo Services 2015

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

CH_4 emissions from ethylene dichloride (EDC) production for 1990–2006 were developed through a consulting study. Since all EDC plants are currently closed and no survey response could be provided for historical data, a Tier 1 calculation approach (i.e. annual production * 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 C_2+ Petrochemical Report. The default process CH_4 emission factor for EDC as applied comes from Table 2–10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), under the name dichloroethylene. The Canadian C_2+ Petrochemical Report 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. For the purpose of emission estimation at the provincial level, the annual EDC production was allocated by Cheminfo Services to each plant on the basis of the capacity share (calculated from production capacity data reported by companies during the Cheminfo Services [2010] study).

Ethylene Oxide (CRF Category 2.B.8.d)

CO_2 and CH_4 emissions from the production of ethylene oxide were estimated using a 2006 IPCC Tier 1 method, which involved multiplication of annual production quantity by the default emission factors. The appropriate Tier 1 CO_2 and CH_4 emissions 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 each plant was chosen from the list of emission factors for oxygen process and based on its catalyst selectivity. The CH_4 emission factor used was the one for “non thermal treatment” as process configuration. Production data for the years 1990 to 2009 were obtained through the Canadian C_2+ Petrochemical Report, as part of the 2010 Cheminfo Study. For years 2016 onwards, the activity data source was Statistics Canada’s Industrial Chemicals and Synthetic Resins Survey. Production data from 2010 to 2015 were linearly interpolated to complete the time series.

Carbon Black Production (CRF Category 2.B.8.f)

CH_4 and N_2O emissions from carbon black production were estimated in 2010 through a consulting study. A survey was sent to the three operating carbon black facilities requesting 1990–2009 data on carbon black capacity and production, and on process GHG emissions. 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 2010–2018 is obtained from Statistics Canada’s Industrial Chemicals and Synthetic Resins Survey.

Styrene Production (CRF Category 2.B.8.g)

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. Methane (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 C_2+ 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 2012–2018, 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.

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.[15]

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 the one of U.S. for this category, the Canadian methodology (see equation below) was derived from that described in the U.S. National GHG Inventory[16].

Equation 4–7

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

Urea production data for 2008–2018 was retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. 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. Emissions from the production of urea have been accounted for CRF category 2.B.1 Ammonia Production.

Import and export data for urea and urea-ammonium-nitrate from 1990–2018 were obtained from Statistics Canada's Canadian International Merchandise Trade Database[17].

The data for quantities of urea and urea-ammonium-nitrate used as a fertilizer were obtained from the AFOLU sector and lastly, urea used as an additive in catalytic converters was calculated based on the estimated emissions which are discussed in section 4.13 and reported in CRF 2.D.3.

It is assumed that any urea that is not used as a fertilizer, as an additive for selective catalytic converters or exported in the same year, is used as an ingredient in manufacturing of resins, plastics or coatings. It is also assumed that all the carbon contained in the urea used for other uses is released in the same year as its production or import.

To estimate the CO_2 emitted from other uses of urea, an emission factor of 0.733 kg CO_2 emitted/ kg of urea used is applied. This factor is the stoichiometric quantity of CO_2 required to produce urea, assuming the complete conversion of ammonia and CO_2 to urea (IPCC 2006).

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

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

17 Statistics Canada, Canadian International Merchandise Trade Database http://www5.statcan.gc.ca/cimt-cicm/home-accueil?lang=eng.

The same factor is used as the emission factor based on the assumption that all CO_2 used to manufacture urea gets emitted back upon the use of that urea.

4.9.3. Uncertainties and Time-Series Consistency

Carbide Production (CRF Category 2.B.5)

A Tier 1 uncertainty assessment was performed for the category of Carbide Production (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 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.a)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the subcategory of Methanol Production 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.b)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010, 2015) for the subcategory of Ethylene Production 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.c)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the subcategory of Ethylene Dichloride Production 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.d)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the subcategory of Ethylene Oxide Production 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 range from ±30.8% to ±38.2% for CH_4 emission estimates, and from ±7.9% to ±9.2% for CO_2 emission estimates.

Carbon Black Production (CRF Category 2.B.8.f)

A Tier 1 uncertainty assessment was performed by Cheminfo Services for the subcategory of Carbon Black Production 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.g)

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010) for the subcategory of Styrene Production 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 ±19% 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. The major source of uncertainty could be the Tier 1 default emission factor, because the correlation between the quantity of HFC-23 emitted and the HCFC-22 production rate can vary with plant infrastructure and operating conditions (IPCC 2000). 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 subcategory of other uses of urea 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 ±6.2% to ±7.4%.

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

Emission estimates of the other two GHGs (i.e. CH_4 and N_2O) for the same categories and CO_2 emission estimates for the category of *Titanium Dioxide Production* have undergone informal quality control checks.

4.9.5. Category-Specific Recalculations

There were no recalculations performed for these categories.

4.9.6. Category-Specific Planned Improvements

There are no improvements planned for CRF category 2.B, Chemical Industry.

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

4.10.1. Category Description

The Iron and Steel Production category contributed 9333 kt (1.3%) to Canada's total emissions in 2018, an 11% decrease from 1990.

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; and
- 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 Canada-specific circumstances in the emission factor for coke (EF_{met_coke}), and carbon content of pig iron.

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

Equation 4–8

$$E_{CO2\ PI} = \left(EF_{met\_coke} \times M_{met\_coke}\right) + \left(M_{ore} \cdot CC_{ore} - P_{PI} \cdot CC_{PI}\right) \times \left(\frac{44}{12}\right)$$

E_{CO2_PI}	=	process emissions from pig iron production, kt
EF_{met_coke}	=	year-specific emission factors (t CO_2/ t metallurgical coke used) obtained from the Cheminfo Services (2010) study
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, ore, pig iron; in the case of ore, this value is zero according to IPCC (2000)
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 this category's emission estimates, it was assumed that the reductant used in the Canadian industry is 100% metallurgical coke (Cheminfo Services 2010). The carbon content in ore is almost zero (IPCC 2000). 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 1990–2018). 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) and from the Canadian Steel Producers Association (CSPA) for 2013–2018. The emission factors for coke use (EF_{met_coke}) 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. Canada-specific coke carbon content is not available for 2010–2018; as a result, the 2009 coke carbon content is assumed for 2010–2018 (being a calcined product, carbon content of coke is not expected to vary greatly). The coke carbon contents were then applied to the coke use data provided by Statistics Canada. With respect to the carbon content of pig iron, CSPA[18] provided an industry-average content value.

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

Equation 4–9

$$E_{CO2\_steel} = \left[CC_{iron} \cdot M_{iron} + CC_{scrap\ steel} \cdot M_{scrap\ steel} - CC_{BOF} \cdot M_{BOF} - CC_{EAF} \cdot M_{EAF}\right] \cdot \frac{44}{12} + EF_{EAF} \cdot P_{EAF} + EF_{BOF} \cdot P_{BOF}$$

E_{CO2_steel}	=	process emissions from steel production, kt
CC_j	=	carbon content of i, %— where j is the pig iron charged, or scrap steel charged in either the electric arc furnace (EAF) or basic oxygen furnace (BOF)
M_j	=	mass of j used, kt
$44/12$	=	ratio of the molecular weight of CO_2 to the molecular weight of carbon
EF_k	=	emission factors (t CO_2/ t steel produced) obtained from the Canadian Steel Producers Association
P_k	=	steel production by either EAF or BOF, kt

According to Equation 4–9 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 and electric arc furnaces (EAFs). It should be noted that the amount of pig iron fed to steel furnaces (used in Equation 4–9) is not equal to the amount of total pig iron production (used in Equation 4–8). 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 charged to steel furnaces, on total steel production and on the amount of steel produced in EAFs was obtained from Statistics Canada for 1990–2003 and 2004–2012 (Cat. No. 41-001 and 41-019, respectively) and from CSPA for 2013–2018. The values of the carbon contents and emission factors presented in were provided by the CSPA.[19]

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

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

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.

For more specific information on the Canadian Iron and Steel sector, refer to Annex 3.3. For information regarding emission factors and carbon contents considered in the CO_2 emission estimate for CRF category 2.C.1, Iron and Steel Production, refer to Annex 6.

CH_4 emissions were estimated on the basis of the mass of metallurgical coke used (Statistics Canada 1990-2018) multiplied by an emission factor. The emission factor value for CH_4 emissions from coke use in the iron and steel industry is not presented in this report to protect the confidentiality of the data.

Data on provincial level metallurgical coke use from RESD (Statistics Canada 1990–2018) 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, emission factor of coke, data on pig iron and steel production, carbon contents 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 ±5.35% and ±405%, respectively, resulting in an overall uncertainty of ±5% for the category as a whole.

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

There were minor corrections in carbon content values of crude steel produced in BOF and in EAF that impacted the entire time series, as well as revisions to the RESD activity data for 2016 and 2017. The largest recalculation of this category was due to a revision in limestone data from Statistics Canada for 2017 (-403 kt of CO_2 eq).

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 4.13).

As supporting information (to disaggregate RESD fuel data) becomes available, it is planned to allocate the aforementioned emissions to the CRF category 2.C.1, Iron and Steel Production.

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

4.11.1. Category Description

The Aluminium Production category accounted for 5500 kt (0.8%) of Canada's emissions in 2018, representing an overall decrease in emissions of 47% since 1990.

Emissions from the combustion of fossil fuels used in the production of baked anodes are covered in the Energy sector, but emissions arising specifically from the combustion of volatile matter released during the baking operation and from the combustion of baking furnace packing material are accounted for under the Aluminium Production category (IPCC 2006).

In addition to CO_2 emissions, primary aluminium smelting is a source of carbon tetrafluoride (CF_4) and carbon hexafluoride (C_2F_6), both of which are included in this submission. This submission also includes a small amount of SF_6 that is emitted from its use as cover gas as well as a degassing (purifying) agent at some aluminium plants that produce high magnesium-aluminium alloys.[20] The consumption of SF_6 is highly variable depending on whether either 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 trend in the Canadian aluminium industry has been towards shutting down older smelters using Søderberg technology, modernizing facilities and improving production efficiency. Of the 10 plants currently in operation, none use Søderberg technology (the last Søderberg aluminium smelter shut down in 2015).[21]

4.11.2. Methodological Issues

As of data year 2013, the Canadian aluminium companies, operating in Quebec and British Columbia, have developed and reported their GHG emissions under the methodological protocols and reporting rules of the Western Climate Initiative.[22] 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.

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 1, 2 and 3. For example, the largest Canadian producer of aluminium reported that its 2008 emissions were developed using plant-specific parameters; for earlier years, and where plant-specific data was not available, companies have used Quebec's Framework Agreement or International Aluminium Institute (IAI) EFs as the default (Alcan 2010). Since 2015, all facility-reported process-related estimates of CO_2, PFCs and SF_6 are Tier 3 plant-level estimates using plant-specific parameters.[23]

4.11.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Aluminium Production (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 ±3%, 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 the same as that of the 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

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

21 https://www.ec.gc.ca/epe-epa/default.asp?lang=En&n=5BE979CD-1

22 http://www.westernclimateinitiative.org/

23 Banville J-F. 2017. Personal communication (email received from Banville J-F to Au A, Environment and Climate Change Canada, April 7, 2017). Aluminium and Iron Ore Pelletizing Sectors.

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 was shut down in the first quarter of 2007. Another magnesium producer, Métallurgie Magnola, existed between 2000 and 2003, but was shut down 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.[24] 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. Timminco was also closed in August 2008.

There were 11 magnesium casting facilities 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 SO_2. Two facilities have ceased their casting operations over the last few years. During the 2005–2008 period, only seven facilities 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). In 2010, another facility moved its operations to the United States.

It is estimated that the remaining magnesium casting facilities in operation released about 134 kt CO_2 eq (<0.1% of Canada's emissions in 2018).

Note that 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 2018 inventory submission.

4.12.2. Methodological Issues

SF_6 emissions from magnesium production for 1999–2007 were directly reported by the companies (Norsk Hydro, Timminco Metals and Métallurgie Magnola Inc.) to Canada's National Pollutant Release Inventory (NPRI). Emission estimates used in this report are obtained from the NPRI's online database (Environment Canada 1990-2007). For previous years (i.e. 1990–1998), the data was provided voluntarily by the producers to Environment Canada through personal communication. Since there was no reported 2008 data for Timminco, its 2008 SF_6 value was estimated on the basis of its 2007 data and the number of months of operation in 2008 (i.e. 7 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 emissions of SF_6 = consumption of SF_6. However, they used different methods for estimating their SF_6 consumption. Norsk Hydro confirmed the use of the weight difference method,[25] 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.[26] 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.

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

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

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

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 used for calculating SF_6 emissions from casting facilities assumes all SF_6 used as a cover gas is emitted to the atmosphere. To estimate SF_6 use for the entire time series, results of a previous study (Cheminfo Services 2002) were used in combination with the data received from the Cheminfo Services (2005b) study and additional assumptions. For facilities that had SF_6 data for only one year, it was assumed that their SF_6 use stayed constant during the other operating years at the level of the year for which the actual SF_6 data was obtained. For casters that had data for more than one year, linear interpolation between two data points was applied to estimate SF_6 consumption for the other years.

For 2005–2007, consumption data was provided by all seven operating casting facilities through a voluntary data submission process. They were used for the calculation of emissions. For 2008, data was made available by six out of the seven casting facilities through the voluntary data submission process. For the remaining facility, 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 facilities. For 2014-2018, SF_6 use data were provided by three out of five operating magnesium casting facilities through a voluntary data collection. Due to the unavailability of data for a few facilities, the SF_6 emission and production values for these facilities for data years 2010 to 2018 is extrapolated using provincial gross output values.

The technique applied to estimate emissions from magnesium casting for 1990–2004 and 2008–2009 is considered to be of Tier 2 type (IPCC 2006).

4.12.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of Magnesium Casting. It took into account the uncertainty associated with the SF_6 data reported by each facility. The uncertainty for the category as a whole was estimated at ±6.8%. It should be noted that the uncertainty assessment was done for only one year of the time series (2018).

As the last magnesium production facility was closed in August 2008, it became difficult to gather the data needed for the Tier 1 uncertainty assessment of the Magnesium Production category. Hence, considering the fact that the same emission estimation method (i.e. emissions = consumption of SF_6) was applied to both categories of Magnesium Casting and Magnesium Production, it was assumed that the Magnesium Production category would have the same uncertainty (±6.8%) as the Magnesium Casting category.

The data source remains consistent over the time series. The methodology, which equates consumption of SF_6 as a cover gas by magnesium casters to emissions of SF_6, is applied over the time series with some assumptions for some historical years, as discussed in the methodology section.

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

The category of Magnesium Production 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. To detect large fluctuations (e.g., in production or in implied emission factors), there is a step (step 4.4) in Canada's current QC process.

The category of Magnesium Casting has undergone informal quality control checks.

4.12.5. Category-Specific Recalculations

Emission estimates for 2010 to 2017 were recalculated for this category due to new SF_6 use data provided by the operating magnesium casting facilities and updates in gross output data. The changes were between -138 kt to +4 kt.

4.12.6. Category-Specific Planned Improvements

A voluntary data collection to obtain up-to-date SF_6 use data (covering data years 2014 to 2018) from magnesium casting facilities was started in 2019. Follow-ups have been made with facilities that had not submitted data. The data to be obtained from these facilities will be assessed for quality for an eventual use in future inventory submissions.

4.13. Overall Category Planned Improvements (CRF Category 2.C.5 and 2.C.6)

Emissions from lead and zinc production occurs in Canada due to the use of reductants in the sintering or smelting processes. Currently, CO_2 emissions are reported under category 2.D.3 Non-energy Products from Fuels and Solvent Use since disaggregation is not currently possible. Future improvements include identifying the type of production processes in Canada and disaggregating emissions, if possible, based on the type of reductant used in lead and zinc production.

4.14. Non-Energy Products from Fuels and Solvent Use and Use of Urea in SCR 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.

The Non-Energy Products from Fuels and Solvent Use category contributed 11 545 kt (1.6%) to Canada's total emissions in 2018, a 99% increase from 1990.

Efforts have been made to examine the possibility of disaggregating lubricating oils and greases from Non-Energy Products from Fuels and Solvent Use, 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)

Catalytic converters that employ urea to help reduce NO_x emissions are referred to as selective catalytic reduction (SCR) catalysts. CO_2 can be emitted from use of urea-based additives in catalytic converters and it is considered as 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 for energy unit-based EFs. The fractions or percentages of carbon stored were IPCC default values (IPCC/OECD/IEA 1997, IPCC 2006). The result of (1 minus percentage of carbon stored) gives what is called the "oxidized during use" (ODU) factor. Emissions of CH_4 for CRF category 2.D.3 are included under category 2.B.8 Petrochemical and Carbon Black production and emissions of N_2O are included in 2.B.10 other (chemical industry). Emissions factors for CH_4 and N_2O are located in Table A6.2-4 in Annex 6.

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 4–5.

Fuel quantity data for non-energy fuel usage was reported by the RESD (Statistics Canada 1990–2018). 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.

Table 4–5 **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*

Note:
* other products include waxes, paraffin and unfinished products (items which cannot be identified in end-product terms).

For example, to estimate emissions coming from non-energy use or oxidation of petroleum products, such as lubricating oils and greases, RESD data was multiplied by the potential CO_2 emission factor and by the ODU factor (which is 1 minus percentage of carbon stored).

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.

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles

(CRF Category 2.D.3)

The 2006 IPCC Guidelines recommends 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.[27]

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 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 category of *Non-Energy Products from Fuels and Solvent Use*, CO_2 emissions were recalculated upwards throughout the times series. The main reasons for recalculations between 2015 and 2017 were revisions of activity data, as well as a correction to a calculation error for 2016 and 2017. Updating of emissions factors for coal also contributed to minor recalculations for the whole time series. The overall impact of all revisions ranges from 1 kt to 800 kt.

Revised activity data caused a minor upward recalculation of 1.3 kt in 2017, for the category of use of urea in SCR vehicles.

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

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 emissions factors are still valid and update them if necessary. In addition, as supporting information becomes available (i.e. information that would allow disaggregation of fuel data and allocation to the appropriate source category) for other (more specific) categories (e.g., iron and steel production), emissions in the Non-Energy Products from Fuels and Solvent Use category will be revised to avoid double counting of emissions and to improve transparency in the inventory.

There is no planned improvement for estimating CO_2 from use of urea in SCR vehicles.

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

4.15.1. Category Description

Industrial processes related to the electronics industry in Canada include the use of PFCs, SF_6 and NF_3 in semiconductor manufacturing, electrical environmental testing, gross leak testing and thermal shock testing. This category does not include emissions of SF_6 used in electrical equipment or PFCs used for electrical insulation and as dielectric coolant as these are included under Other Product Manufacture and Use (CRF category 2.G).

It is estimated that emissions from the electronics industry in Canada account for about 4 kt CO_2 eq in 2018.

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 4.16). 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 chambers.

The IPCC Tier 2 methodology, as shown in Equation 4–10, was used to estimate PFC emissions from the semiconductor manufacturing industry:

Equation 4–10

$$E_{SC} = E_{FC} + E_{CF_4}$$

E_{SC} = total PFC emissions from semiconductor

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)

Default Tier 2 emission factors used in the mentioned IPCC 2006 equations 6.2 and 6.3 are found in Table 6.3 of the 2006 IPCC Guidelines.

As no information on emission control technologies for these processes in Canada was available, it was assumed that no emission control technologies were used. The heel (h) value was assumed to equal 0.1, as suggested in the 2006 IPCC Guidelines.

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 user indicated usage of NF_3 in 2013 and a gas distributor identified an additional purchaser in 2010. 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.

To determine NF_3 use throughout the time series, various assumptions needed to be made. For years 1990–2009, using the 2010 value from the (unidentified) purchaser as the reference endpoint, the midpoint of the 1986 data range was linearly interpolated. The 2006 IPCC Tier 2a equation was then applied to the 1990-2009 NF_3 interpolated values. For 2010-2013, the use reported by the purchaser for 2010 was assumed to stay constant. Also, as the process used by the 2010 purchaser is unknown, it was assumed the IPCC 2006 Tier 2a method was applicable. For years 2014 onwards, the emission estimation relied solely on data reported by the user, which was assumed to be constant. Because the NF_3 user was involved in an etching process, the IPCC 2006 Tier 2b was applied.

In all cases, NF_3 usage was assumed, as opposed to NF_3 remote usage, based on the definitions stated in the 2006 IPCC Guidelines. The corresponding default emission factors were therefore chosen and a default heel value of 10% was used. It was also assumed that no emission control technologies were employed.

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 chemical vapour deposition (CVD) processes does not produce any fluorocarbon by-product. A Tier 2A estimate was conducted using IPCC 2006 Volume 3, equation 6.2.

The heel value (h) provided and confirmed by two major SF_6 gas distributors, Air Liquide and Praxair, was 12%.[28] The IPCC 2006 default emission factor (1-U) of 0.2 was used and it was assumed that there has been no emission control technology applied by this industry.

Since sales data was obtained from major Canadian gas suppliers for the period 1995–2003 only, it was assumed that the quantity sold per year during 1990–1994 was at the 1995 level. The amount of SF_6 sold to semiconductor manufacturers in 2004–2009 was estimated by multiplying the total SF_6 imported (from Statistics Canada) by the sales distribution data (in %) received from SF_6 distributors (Cheminfo Services 2005a). No SF_6 sales data was collected for the years 2010–2018. The average quantity of SF_6 sold annually to the semiconductor manufacturing industry for 2004–2009 was used for 2010 and 2011 data years. For the 2012–2018 data years, the gross output (GO) economic data for NAICS 334 (Computer and Electronic Products Manufacturing) were used as proxy variable to estimate the amount of SF_6 sold to the semiconductor industry.

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 data for years 1998–2000).

PFC Emissions from Other Emissive Applications (CRF Category 2.E.5)

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 4.16). PFC usage was last reported in a voluntary data collection survey for 2008 data, identifying a minor amount of PFCs used for emissive applications in the electronics industry. In a survey conducted in 2010 collecting 2009 data, major gas distributors did not report any PFC use in emissive applications. No other surveys were conducted for years after 2010. As such, emissions were assumed to be zero for years 2010-2018. Emissive sources in Canada include electrical environmental testing, gross leak testing and thermal shock testing. The IPCC Tier 1a methodology was used to estimate emissions at the application level. Default emission factors from the IPCC 2000 Good Practice Guidance document were 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

A Tier 1 uncertainty assessment was performed for PFC consumption as a whole. 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 ranges from ±10% to ±24%.

The 2006 IPCC Guidelines show the relative error for Tier 2b etching with NF_3 to be a factor of three (300%), as per IPCC 2006, Volume 3, Table 6.9.

A Tier 1 uncertainty assessment was performed for the category of SF_6 emissions from semiconductor manufacturing (±45%).

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

Categories under Electronics Industry have undergone informal quality control checks.

4.15.5. Category-Specific Recalculations

There has been minor recalculations in the category SF_6 emissions from semiconductor manufacturing, ranging from about +0.04 kt CO_2 eq to +0.1 kt CO_2 eq (+2% to +8%) between the years 2013 to 2017, as a result of an update in gross output data.

4.15.6. Category-Specific Planned Improvements

The last PFC and SF_6 data set collected was in 2010 and the last NF_3 data set collected was in 2014. A voluntary data collection to obtain up-to-date PFC, SF_6 and NF_3 use and sales data (covering data years 2014 to 2018) was started

28 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.

in 2019. Information on implemented emission control technologies for the semiconductor industry in Canada will be collected. The data obtained from facilities will be assessed for quality for an eventual implementation in future inventory submissions.

4.16. Product Uses as Substitutes for ODS (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 ODS, 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 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. All HFCs consumed in Canada are imported in bulk or in manufactured items and products (e.g. refrigerators).

HFC releases contributed 12 540 kt CO_2 eq (1.7%) to Canada's total emissions in 2018, a 2730% increase from 1995.

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. 2017 and 2018 activity data were collected in 2018 and in 2019, 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, 2018 and 2019 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 2018 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 4–6. No data was collected for 2016.

There are two facilities in Canada that can destroy HFCs and other substances, but no data is 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 aerosols, foam blowing, fire extinguishing, solvents, and miscellaneous sub-applications, default emission factors from the 2006 IPCC guidelines (IPCC 2006, Volume 3) 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 section 7.1.2.1 of the 2006 IPCC Guidelines, under Approaches for Emission Estimates (IPCC 2006). For the calculation of the net

Table 4–6 **HFCs Used in Canada and Years for which Activity Data is Available**

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

consumption of a HFC in a specific sub-application, IPCC equation 7.1 (IPCC 2006) has been adapted to the Canadian context and used. Refer to Annex 3.3 for additional details on methodology.

The approach/model tracks the lifecycle of each HFC by sub-application and year, then estimates annual emissions for each applicable lifecycle stage (assembly of the product, in-service operation of the product and end-of-life decommissioning). The model also calculates the annual quantity of each HFC that remains in products (in stock) after assembly, in-service and end-of-life losses. In this way, the model is a mathematically expanded version of the method discussed in IPCC section 7.1.2.2 (IPCC 2006, Volume 3) and subsequent sections. 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 details in Annex 3.3.

4.16.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for HFC consumption. 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 (IPCC 2006, Volume 3) 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 the time series ranged from ±34% to ±50%.

The inclusion of the mandatory survey information would be expected to similarly maintain this uncertainty. The uncertainty associated with this category has not been updated.

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 Chapter 6, Volume 1 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

4.16.5. Category-Specific Recalculations

The emissions from all sub-applications have been recalculated as a result of updated 2014 and 2016 mandatory surveys of HFC bulk imports, exports and sales by HFC type and market segment. The updated 2014 and 2016 mandatory surveys affect the 2005–2017 emission estimatess, with the largest increase of 0.7 Mt CO_2 eq in 2014 and the largest decrease of 1.0 Mt CO_2 eq in 2017.

4.16.6. Category-Specific Planned Improvements

Research into the commercial and industrial refrigeration emission factors, market share and other characteristics in Canada will be examined for application in future inventories. A data gap exists with the 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. Additionally, 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 ODS (CRF Category 2.F, PFCs)

4.17.1. Category Description

Perfluorocarbon (PFC) consumption began in Canada in 1995. Similar to HFCs, PFCs are also used as substitutes for ozone-depleting substances (ODS) being phased out under the Montreal Protocol (IPCC 2006). However, the use of PFCs are very limited compared to HFCs in Canada. Current applications which use PFCs as a substitute for ODS include: Refrigeration and Air Conditioning, Foam Blowing Agents, Aerosols and Solvents.

PFC releases contributed to about 2.2 kt CO_2 eq in 2018, a 75% decrease from 1995.

4.17.2. Methodological Issues

The IPCC Tier 1a/2a methodologies were used to estimate emissions from the consumption of PFCs in various applications for the years 1995 to 2018. Details of the method 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 collection of 2003–2007 PFC use data from major distributors of PFCs 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 collected in 2009 and 2010. No data on PFC use was collected for 2010–2018. The 2010 PFC use data was extrapolated from the 2009 PFC use data using 2009 and 2010 economic gross output data of applicable economic sectors. The 2011–2018 PFC use data was then extrapolated from the 2008, 2009 and 2010 estimates by least squares linear regression.

Refrigeration and Air Conditioning (CRF Category 2.F.1, PFCs)

IPCC Tier 2a methodology, i.e. equations 12, 13 and 14 from Volume 3, Chapter 7, section 7.5 of the 2006 IPCC Guidelines, were used to estimate the emissions from the assembly, operation and disposal of the sub-applications: industrial refrigeration, commercial refrigeration, stationary air conditioning systems and mobile air conditioning systems.

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 Annex 6.

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 loss 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 and from the disposal of mobile air conditioning systems between 1995 and 2006 since these systems have an average lifetime of 15 and 12 years, respectively (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 lifetime has been past; 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 lifetimes have been reached and the remaining PFCs in the systems are disposed of. Emissions from the refrigeration and air conditioning sub-applications are likely to be over-estimated since various regulatory requirements currently existing in Canada would prohibit the release of PFCs.

Foam Blowing Agents (CRF Category 2.F.2, PFCs)

IPCC Tier 1a methodology was applied using IPCC 2006 default emission factors since activity data at the sub-application level was not available. 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).

Aerosols (CRF Category 2.F.4, PFCs)

Major gas distributors have not provided any data regarding PFCs used in aerosols in EC's PFC surveys, last conducted in 2009. As a result, PFC emissions from aerosols applications were assumed to be negligible. A survey was conducted in 2019 to obtain 2014-2018 PFC data. Emissions are expected to be negligible since data for PFCs used in aerosols has not been provided from major gas distributors in past surveys.

Solvents (CRF Category 2.F.5, PFCs)

The IPCC Tier 1a methodology presented in the 2006 IPCC Guidelines was used to estimate PFC emissions from solvents. A product lifetime of 2 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. Main sub-applications include electronics cleaning, laboratory solvents, and carrier solvent for various products (e.g. protective coating, mold release agents, lubricants).

Emission factors applied for the application of PFCs used as ODS substitutes are presented in Annex 6.

4.17.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for PFC consumption. Similar to HFC consumption, the 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 ±10% to ±24%.

4.17.4. Category-Specific QA/QC and Verification

The category of PFC consumption has undergone informal quality control checks.

4.17.5. Category-Specific Recalculations

There have been minor recalculations ranging from -0.5 kt to +1 kt across the time series due to an update in gross output data, floor space data and emission factors for assembly loss and leakage during operation for PFCs from refrigeration and air conditioning (IPCC 2006).

4.17.6. Category-Specific Planned Improvements

Voluntary collection of up-to-date PFC data, covering reporting years 2014 to 2018, started in September 2019. Data gathered will be analyzed for potential integration into future NIRs, and the implementation year in the NIR will depend on the findings of the data analyses.

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 SF_6 in electrical equipment (CRF category 2.G.1), 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 PFC emissions from other contained product uses (CRF category 2.G.4) such as an electronic insulator or a dielectric coolant in power transformers, which are not ODS substitutes or electronics industry-related.

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).

N_2O is used in a limited number of applications, with anaesthetic use representing the vast majority of consumption in Canada. Use as a propellant in food products is the second largest type of end use in Canada. 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).

Of all applications in which N_2O can be used, only the two major types are emissive. When N_2O is used as an anaesthetic, it is assumed that none of the N_2O is metabolized (IPCC 2006). In other words, the used N_2O quickly leaves the body in exhaled breath (i.e. is emitted) as a result of the poor solubility of N_2O in blood and tissues. When N_2O is used as a propellant, only emissions coming from N_2O used in whipped cream are estimated, because the amounts of N_2O employed in other food products and in non-food products are considered negligible, according to the food industry and the gas producer and distributors. When the cream escapes from the can, the N_2O gas expands and whips the cream into foam. As none of the N_2O is reacted during the process, it is all emitted to the atmosphere (Cheminfo Services 2006).

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 706 kt (<0.1%) to Canada's total emissions in 2018, an 89% increase from 1990.

4.18.2. Methodological Issues

SF_6 Emissions from Electrical Equipment (CRF Category 2.G.1)

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.

A modified Tier 3 method was used to estimate SF_6 emissions from electrical equipment in utilities for certain years (i.e. 2006–2018) 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 2006–2018 were provided by the Canadian Electricity Association (CEA), Hydro-Québec and BC Hydro, which collectively represent electricity companies across Canada. BC Hydro was a member of CEA, prior to 2017 and Hydro- Québec has joined CEA in 2017. The emission data submitted by the CEA, Hydro-Québec and BC Hydro 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, Hydro-Québec 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 2006–2018 period was the sum of all provincial estimates. The Protocol is the result of a collaborative effort between Environment Canada, the 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 nameplate capacity less recovered quantity for disposal emissions or to simply nameplate capacity for failure emissions). A more detailed description of the methodology is provided in Annex 3.3.

Estimates were not available from the 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).

N_2O 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 years 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 2006–2018 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 no date [d]).

PFC Emissions from Other Contained Product Uses (CRF Category 2.G.4)

Data on PFCs used in other contained products were last gathered in 2010 from EC's PFC surveys. The IPCC Tier 2 emission factors (IPCC 2000) for other contained product uses are: a leakage rate of approximately 1% during the manufacturing process

and an annual leakage rate of 2% during their lifetime (IPCC 2000). These emission factors are applied to the PFC data to estimate PFC emissions from contained sources, as per equation 3.54 of the IPCC 2000 Good Practice Guidance.

4.18.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the category of SF_6 from Electrical Equipment. It should be noted, though, 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).

A Tier 1 uncertainty assessment was performed for the category of PFC consumption as a whole. The 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 ±10% to ±24%.

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 ±19%. 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.

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

The categories of SF_6 Consumption in Electrical Equipment, N_2O Emissions from Medical Applications and Propellant Usage, and PFC Emissions from Other Contained Product Uses have undergone informal quality control checks.

4.18.5. Category-Specific Recalculations

There were recalculations of less than 1 kt CO_2 eq for SF_6 emissions from electrical equipment for 2016 and 2017 due to updates in activity data.

As a result of a methodology change (from 1996 IPCC to the 2006 IPCC methodology), 1991–2017 N_2O emissions from Product Use were recalculated. The impacts of recalculations ranged from -82 kt CO_2 eq to +39 kt CO_2 eq. It is important to note that the overall trend remains the same despite small changes in annual emissions.

4.18.6. Category-Specific Planned Improvements

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 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.

CHAPTER 5

AGRICULTURE (CRF SECTOR 3)

5.1. Overview

The Agriculture sector has contributed 8% of Canada's total greenhouse gas emissions (GHGs) annually since 1990, and emissions within the sector increased by 27% between 1990 and 2018. Emission sources from the Agriculture sector include the Enteric Fermentation (CH_4) and Manure Management (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 liming 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). Emissions of GHGs 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, mink, 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. On the other hand, approximately 75% of dairy cattle, 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 100 million poultry. Beef cattle and swine populations peaked in 2005 at 15 million head each. Since 2005, beef populations decreased to 11 million head, while swine populations decreased to 12.5 million head in 2010 but have since been on the rise and are currently at 14 million head. Since 1990, poultry populations have increased to 154 million. Dairy cattle populations have decreased steadily since 1990 to less than 1 million head in 2018.

Since 1990, cropping practices have changed in Canada, with canola production increasing from 3 Mt to 21 Mt, corn production from 7 Mt to 14 Mt, and soybean production from 1.3 Mt to 7.7 Mt. From 1990 to 2002, wheat production fell off sharply, decreasing from 32 Mt to 16 Mt. However, since then, production has risen again, and reached 30 Mt in 2018. With the changes in crop production, inorganic nitrogen consumption has more than doubled from 1.2 Mt N in 1990 to 2.6 Mt N in 2018, the area under summerfallow decreased by 7.4 million hectares (Mha) and land under conservation tillage increased by 17 Mha.

As a result of those changes, Canada's total greenhouse gas (GHG) emissions from the Agriculture sector increased from 47 Mt CO_2 eq in 1990 to 59 Mt CO_2 eq in 2018 (Table 5–1). This difference represents an increase of 27% from 1990, mainly due to an increase in the use of inorganic nitrogen fertilizers (121%), as well as higher populations of beef cattle and swine (5% and 38% increases, respectively) and changes in feeding and manure handling practices in the dairy and swine industries.

1 In common reporting format (CRF) tables, bison emissions are reported under the Intergovernmental Panel on Climate Change (IPCC) category "buffalo" though 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 2018, and mean estimates lie within an uncertainty range of -16% to +20%. Over the 1990 to 2018 time series, mean CH_4 emissions are estimated to have increased by 3.2 Mt CO_2 eq, a 13% 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 21 Mt CO_2 eq in 1990 and 29 Mt CO_2 eq in 2018; mean estimates lie within an uncertainty range of -27% to +29%. Over the time series, mean N_2O emissions increased by 8.0 Mt CO_2 eq, an increase of 38%.

Emissions from the Agriculture sector peaked in 2005, and decreased to 55 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. These trends, in combination with high crop production in recent years, have caused emissions to increase from their low point in 2011 to 59 Mt CO_2 eq in 2018.

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	2012	2013	2014	2015	2016	2017	2018
Agriculture TOTAL[a]	**47 000**	**57 000**	**60 000**	**57 000**	**59 000**	**58 000**	**58 000**	**59 000**	**60 000**	**59 000**
Enteric Fermentation (CH_4)	**22 000**	**28 000**	**31 000**	**25 000**	**25 000**	**24 000**	**24 000**	**24 000**	**24 000**	**24 000**
Dairy Cattle	4 000	3 400	3 200	3 100	3 200	3 200	3 200	3 200	3 300	3 400
Beef Cattle[b]	18 000	23 000	26 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000
Others[c]	730	1 100	1 300	1 100	1 100	1 100	1 100	1 100	1 100	1 100
Manure Management	**6 100**	**8 000**	**8 800**	**7 700**	**7 800**	**7 700**	**7 800**	**7 900**	**8 000**	**7 900**
Dairy Cattle CH_4	430	560	680	850	870	870	870	880	890	920
N_2O	520	460	350	260	270	270	260	260	260	270
Beef Cattle[b] CH_4	810	1 100	1 200	1 100	1 000	1 000	1 000	1 000	1 000	1 000
N_2O	1 900	2 700	3 000	2 400	2 300	2 300	2 300	2 300	2 300	2 300
Swine CH_4	1 000	1 500	1 800	1 500	1 500	1 500	1 600	1 700	1 700	1 700
N_2O	120	90	80	60	60	60	60	60	60	60
Poultry CH_4	160	190	190	190	190	200	200	200	200	200
N_2O	430	530	540	570	580	590	600	610	610	610
Others[d] CH_4	40	50	60	50	50	50	50	40	40	40
N_2O	100	150	180	160	150	150	140	130	130	120
Indirect Source of N_2O	600	780	840	690	690	690	700	710	710	700
Agricultural Soils (N_2O)	**17 000**	**19 000**	**19 000**	**22 000**	**24 000**	**23 000**	**24 000**	**24 000**	**25 000**	**25 000**
Direct Sources	14 000	16 000	15 000	18 000	20 000	19 000	20 000	20 000	21 000	20 000
Synthetic Nitrogen Fertilizers	5 700	7 500	6 900	10 000	11 000	11 000	11 000	11 000	12 000	11 000
Organic Nitrogen Fertilizers	2 100	2 400	2 500	2 300	2 300	2 300	2 300	2 400	2 400	2 400
Crop Residue Decomposition	4 400	4 600	4 900	5 300	6 500	5 700	5 900	6 500	6 500	6 300
Cultivation of Organic Soils	60	60	60	60	60	60	60	60	60	60
Mineralization of Soil Organic Carbon	490	520	500	630	670	710	760	810	870	930
Conservation Tillage[e]	-300	-740	-850	-1 200	-1 500	-1 300	-1 400	-1 400	-1 300	-1 400
Summerfallow	1 300	1 000	740	470	480	380	330	270	220	130
Irrigation	280	320	330	360	400	390	390	410	330	400
Manure on Pasture, Range and Paddock	220	250	260	220	210	210	210	200	200	200
Indirect Sources	2 800	3 400	3 400	3 800	4 200	4 000	4 100	4 200	4 300	4 200
Crop Residue Burning (CH_4 & N_2O)	**220**	**130**	**40**	**40**	**50**	**50**	**60**	**50**	**50**	**50**
Lime and Urea Application (CO_2)	**1 200**	**1 600**	**1 400**	**2 300**	**2 700**	**2 500**	**2 600**	**2 500**	**2 500**	**2 600**

Notes:
a. Totals may not add up due to rounding.
b. Beef Cattle includes dairy heifers.
c. Others, Enteric Fermentation, includes buffalo, goat, horse, lamb, llama/alpaca, sheep and swine, deer/elk, wild boars.
d. Others, Manure Management, includes bison, goat, horse, lamb, llama/alpaca, sheep, fox, mink, 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 63 kt CO_2 eq lower in 1990, 97 kt CO_2 eq lower in 2005 and 1,525 kt CO_2 eq lower in 2017 compared with the previous submission, for recalculations of 0.1%, 0.2% and -2.5%, respectively (Table 5–2).

Recalculations were the result of the implementation of a methodology for estimating N_2O emissions from the application of biosolids to agricultural soils (Table 5–3 and see Annex 3.4) and updates to activity data. Activity data updates include revisions to inorganic N fertilizer shipment data for years 2013 to 2017, crop production in 2017 and corrections to the spatial distributions of livestock and crop areas.

Activity data for lime application is available with a 3-year lag and, as a result, the value for 2017 was updated for the 2020 submission and held constant for 2018. Rice is not produced in Canada and is not a source of CH_4 emissions. Prescribed burning of savannas is not practiced 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.

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

Table 5–2 **Quantitative Summary of Recalculations for the Agriculture Sector in 2020 NIR**

		Recalculations (kt CO_2 eq)							
		1990	2000	2005	2013	2014	2015	2016	2017
Previous submission (2019 NIR), kt CO_2 eq		47 000	57 000	60 000	59 000	58 000	58 000	59 000	60 000
Current submission (2020 NIR), kt CO_2 eq		47 000	57 000	60 000	59 000	58 000	58 000	59 000	58 000
Change due to continuous improvement or refinement:									
New methodology for calculating emissions from Biosolids		**77**	**93**	**110**	**110**	**120**	**150**	**160**	**140**
Agricultural Soils	kt CO_2 eq	77	93	110	110	120	150	160	140
	%	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2
Revision of Activity Data		**-13**	**-10**	**-15**	**-37**	**-51**	**-78**	**-35**	**-1 700**
Manure Management	kt CO_2 eq	-9	-7	-7	-14	-15	-13	-10	-11
	%	-0.02	-0.01	-0.01	-0.02	-0.03	-0.02	-0.02	-0.02
Agricultural Soils	kt CO_2 eq	-5	-3	-8	-23	-36	-65	-24	-1 600
	%	-0.01	-0.01	-0.01	-0.04	-0.1	-0.1	0.0	-2.8
Crop Residue Burning	kt CO_2 eq	0	0	0	0	0	0	0	0.2
	%	0	0	0	0	0	0	0	0.0004

Table 5–3 **Qualitative Summary of the Revisions to Methodologies, Corrections and Improvements Carried out for Canada's 2019 Submission**

Correction or Improvement	Recalculation Categories Affected	Years Affected
1. New methodology for estimating N_2O emissions from the application of biosolids to agricultural soils	N_2O emissions from direct and indirect emissions from agricultural soils	1990–2017
2. Revision of Activity Data (Inorganic N fertilizer shipments, crop production, distribution of crops and livestock)	N_2O emissions from direct and indirect emissions from manure management systems and agricultural soils. CH_4 and N_2O emissions from crop residue burning.	1990–2017

to western Canada. Other animals that produce CH_4 by enteric fermentation, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boar 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 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 1990–2018 time period are reflected in a 21% increase in CH_4 emission factors from this animal category. As milk production increases, the requirement of energy for lactation (NE_l) becomes greater and requires increased food consumption.

In beef cattle, changes in mature body weight influence maintenance and growth energy (NE_m and NE_g) requirements and, as a consequence, feed consumption. From 1990 to 2003, larger breeds became popular and emission factors increased by 7.4% during that period. Since then, 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 enteric fermentation continue to be estimated using the IPCC Tier 1 methodology. The poultry, rabbits and fur-bearing animal categories are excluded from enteric fermentation estimates 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

Using a Monte Carlo technique, an uncertainty analysis was performed on the methodology used to estimate methane emissions from agricultural sources. 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), though some additional parameters and updates were included in this analysis. For 2017, 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 Boadi et al. (2004) methodology.

The uncertainty range for CH_4 emissions from enteric fermentation was similar in 1990 and 2018, and mean estimates lie within a range of -17% to +22% (Table 5–4). Over the time series of 1990 to 2018, mean emissions are estimated to have increased by 1.8 Mt CO_2 eq, an 8% increase. The observed increase falls within an uncertainty range of +4% to +13%.

The uncertainty in emissions was mainly associated with the calculation of the emission factor. The range of uncertainty around the calculation of the Non-dairy Cattle Tier 2 emission factors was the highest

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 (1000 head)		971	920 (-5.2%)	1 022 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		140	119 (-15%)	167 (+19%)
	Emissions (Mt CO_2 eq)		3.4	2.8 (-16%)	4.1 (+20%)
Non-dairy Cattle	Population (1000 head)		11 019	10 808 (-1.9%)	11 243 (+2.0%)
	Tier 2 Emission Factor (kg/head/year)		71	60 (-15%)	84 (+18%)
	Emissions (Mt CO_2 eq)		20	17 (-16%)	24 (+21%)
Other Animals	Emissions (Mt CO_2 eq)		1.1	0.87 (-18%)	1.3 (+18%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	22	19 (-16%)	27 (+21%)
		2018	24	21 (-14%)	28 (+17%)
	Trend	1990–2018	1.8 (+8.0%)	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 2018.

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 2018.

(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 (Ym) 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 (1990–2018), 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: (i) publishable records that represent production data for genetically elite animals within the Canadian herd from 1990 to present, and (ii) 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.

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 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 2020 NIR submission (Table 5–5).

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 collected to update the timeline for changes to dairy feed in recent years.

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—Direct N_2O	1990	2019	3070	-8	-0.3	Long term (1990–2017)	
		2020	3062			11	11
	2005	2019	4109	-7	-0.2		
		2020	4102			Short term (2005–2017)	
	2017	2019	3400	-10	-0.3	-17	-17
		2020	3390				
Manure Management—Indirect N_2O	1990	2019	614	-0.6	-0.1	Long term (1990–2017)	
		2020	613			15	15
	2005	2019	839	-0.5	-0.1		
		2020	838			Short term (2005–2017)	
	2017	2019	708	-0.7	-0.1	-16	-16
		2020	707				

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. Over the medium term, the results of this study will be analyzed to attempt to integrate the new information 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 upon 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 landbase. Feedlot beef production results in large volumes of drylot 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 boar, 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 digestible energy (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. The VS for swine was 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 management 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 management systems is provided in Annex 3.4, section A3.4.3.3.

Increases in cattle emission factors over the 1990–2018 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 methane emissions from agricultural sources using the Monte Carlo technique included methane emissions from manure management. 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 estimate of 3.8 Mt CO_2 eq from manure management CH_4 emissions from Canadian livestock in 2018 lies within an uncertainty range of -32% to +27% (Table 5–6). The emission estimate from manure management in 1990, 2.5 Mt CO_2 eq, has a slightly larger uncertainty range, -33% to +38%, due to greater uncertainty associated with the type of manure management systems in 1990. The estimate of a 57% increase in mean emissions between 1990 and 2018 lies within an uncertainty range of +45% to +66%.

As was the case with enteric fermentation, 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 have not yet been performed; however, since the MCF factor is driving uncertainty for manure management, it is not suspected that changes to the these models would have a large impact on national manure management uncertainty. However, the introduction of an AWMS time series for the dairy and swine sectors may play an important role in influencing the trend uncertainty for manure management emissions.

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2018), with the exception of milk production for dairy 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 (1000 head)		971	920 (-5.2%)	1022 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		38	21 (-45%)	52 (+37%)
	Emissions (Mt CO_2 eq)		0.92	0.51 (-45%)	1.26 (+37%)
Non-dairy Cattle	Population (1000 head)		11 019	10 808 (-1.9%)	11 243 (+2.0%)
	Tier 2 Emission Factor (kg/head/year)		3.7	2.8 (-25%)	5.4 (+45%)
	Emissions (Mt CO_2 eq)		1.0	0.7 (-27%)	1.53 (+51%)
Swine	Population (1000 head)		14 063	13 729 (-2.4%)	14 403 (+2.4%)
	Tier 2 Emission Factor (kg/head/year)		4.7	2.2 (-54%)	6.9 (+45%)
	Emissions (Mt CO_2 eq)		1.7	0.9 (-49%)	2.36 (+42%)
Other Animals	Emissions (Mt CO_2 eq)		0.25	0.17 (-31%)	0.28 (+14%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	2.5	1.4 (-44%)	3.3 (+36%)
		2018	3.8	2.8 (-28%)	4.7 (+23%)
	Trend	1990–2018	1.4 (+57%)	1.1 (+45%)	1.6 (+66%)

Notes:

a. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2018.

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 2018.

5.3.1.4. QA/QC and Verification

Methane emissions from manure management have undergone Tier 1 QC checks as described in the QA/QC plan (see section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data and methodologies are documented and archived in electronic form. The IPCC Tier 2 CH_4 emission factors for manure management practices by all animal categories derived from Marinier et al. (2004) have been reviewed by independent experts (Patni and Desjardins 2004). These documents have been archived in electronic form.

Internal Tier 2 QC checks carried out in 2010–2011 included a complete review and rebuild of calculation methodology, input data and review and compilation of Canadian research on manure management (MacDonald and Liang 2011). No specific bias can be clearly identified in the IPCC Tier 2 model parameters due to the high variability in research results and the lack of supporting information for research carried out on manure storage installations. There is no clear standard for evaluating whether IPCC parameters are appropriate for estimating emissions from manure management systems in the Canadian context. More standardized and detailed research is required in Canada to improve upon the current Tier 2 methodology. Details of this review can be found in Annex 3.4, section A3.4.3.7.

5.3.1.5. Recalculations

Methane emissions from manure management were not recalculated in this submission (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 recent publications on livestock management (Sheppard et al. 2009a, 2009b, 2010, 2011a, 2011b; Sheppard and Bittman 2011, 2012), have provided the basis for a new manure management time series for dairy and swine production in Canada, and work is being considered for other major livestock categories. Further refinements to parameters used in the calculation of VS based on changes in animal feed are being considered for implementation in the medium-term.

5.3.2. N_2O Emissions from Manure Management (CRF Category 3.B [b])

5.3.2.1. Source Category Description

The production of N_2O during storage and treatment of animal waste occurs during nitrification and denitrification of nitrogen contained in the manure. Nitrification is the oxidation of ammonium (NH_4+) to nitrate (NO_3-), and denitrification is the reduction of NO_3- to N_2O or N_2. Manure from the Non-dairy Cattle, Sheep and Lamb, Goat and 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. Nitrous oxide emissions from urine and dung deposited by grazing animals are reported separately (see section 5.4.1.4).

5.3.2.2. Methodological Issues

Nitrous oxide 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; nitrogen retention is calculated using milk production and cattle weight statistics. 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 Enteric Fermentation estimates (section 5.2) and for CH_4 Emissions from 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 enteric fermentation and manure management CH_4 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 3.4 Mt CO_2 eq from manure management in 2018 lies within an uncertainty range of 1.9 Mt CO_2 eq (-43%) to 5.1 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 (1990–2018).

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 have been very few published data on N_2O emissions from manure management 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 upon 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 changes to the spatial distribution of livestock. The net impact of these changes was a decrease of 8 kt CO_2 eq in 1990, 7 kt CO_2 eq in 2005 and 10 kt CO_2 eq in 2017. The recalculations did not alter the short-term or long-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 as no country-specific leaching loss factors are available.

Emission factors of N_2O from NH_3 volatilization and leaching of N during 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. Most uncertain quantities 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 cannot be implemented for this submission. 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 (1990–2018).

5.3.3.4. QA/QC and Verification

These categories have 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 both paper and electronic form.

5.3.3.5. Recalculations

Indirect N_2O emissions from manure management were recalculated due to changes in the spatial distribution of livestock that resulted in a decrease in emissions of 0.6 kt CO_2 eq in 1990, 0.5 kt CO_2 eq in 2005 and 0.7 kt CO_2 eq in 2017. 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. Over the medium term, the Non Dairy Tier 2 parameters will be reviewed and revised as necessary, based on the more recent information.

5.4. N_2O Emissions from Agricultural Soils (CRF Category 3.D)

Emissions of N_2O from agricultural soils consist of direct and indirect emissions. The emissions of N_2O 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 summerfallow, 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: i) 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 ii) the leaching and runoff of inorganic fertilizer, manure 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 three country-specific sources of emissions/removals: tillage practices, summerfallow and irrigation. Emissions/removals from these sources are estimated on the basis of nitrogen inputs from the application of organic and inorganic nitrogen fertilizers and crop residue nitrogen.

5.4.1.1. Inorganic Nitrogen Fertilizers

5.4.1.1.1. Source Category Description

Inorganic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen undergoes transformations, such as nitrification and denitrification, which can release N_2O. Emission factors associated with fertilizer application depend on many factors, such as soil types, climate, topography, farming practices and environmental conditions (Gregorich et al. 2005; Rochette et al. 2008b).

5.4.1.1.2. Methodological Issues

Canada has developed a country-specific, Tier 2 methodology to estimate N_2O emissions from inorganic nitrogen fertilizer application on agricultural soils, which takes into account moisture regimes 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 fertilizer sales. All inorganic nitrogen fertilizers sold by retailers are assumed to be applied for crop production 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 country-specific methodology (Rochette et al. 2008b) 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.

The estimate of N_2O emissions of 11 Mt CO_2 eq from the application of fertilizers on agricultural soils in 2018 lies within an uncertainty range of 7.5 Mt CO_2 eq (-35%) to 17 Mt CO_2 eq (+43%) (Table 5–7). The main source of uncertainty in the calculation is associated with the parameters (slope and intercept) of the regression equation relating emission factors to the ratio of precipitation to potential evapotranspiration (P/PE).

The same methodology and emission factors are used for the entire time series (1990–2018).

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, but there is a close agreement between the IPCC default emission factor of 1% (IPCC 2006) and 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).

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		3.4	1.9 (-43%)	5.1 (+51%)
Indirect Emissions		0.70	0.28 (-60%)	1.2 (+70%)
Agricultural Soils (N_2O)		**25**	**16 (-36%)**	**37 (+52%)**
Direct N_2O Emissions from Managed Soils		20	15 (-28%)	27 (+34%)
	Inorganic Nitrogen Fertilizers	11	7.5 (-35%)	16 (+43%)
	Organic Nitrogen Fertilizers	2.4	1.6 (-33%)	3.4 (+41%)
	Crop Residues	6.3	4.1 (-35%)	9.1 (+45%)
	Cultivation of Organic Soils	0.061	0.013 (-79%)	0.12 (+96%)
	Mineralization Associated with Loss of Soil Organic Matter	0.93	0.61 (-35%)	1.4 (+45%)
	Urine and Dung Deposited by Grazing Animals	0.20	0.082 (-60%)	0.36 (+75%)
	Soil N Mineralization/Immobilization	-0.91	-0.51 (-44%)	-1.4 (+55%)
Indirect N_2O Emissions from Managed Soils		4.2	1.7 (-60%)	7.2 (+70%)
	Atmospheric Deposition	1.2	0.31 (-75%)	2.6 (+110%)
	Leaching and Runoff	3.0	0.60 (-80%)	6.0 (+100%)

Notes:
a. Mean value reported from database.
b. Values in parentheses represent the uncertain percentage of the mean.

5.4.1.1.5. Recalculations

Two changes contribute to recalculations; revision of the fertilizer shipment data for the years between 2013 and 2017 and addition of biosolids to the organic nitrogen sources. Changes to quantities of organic N results in adjustments to spatial distributions of inorganic N and thus in recalculations of soil N_2O emissions from inorganic nitrogen fertilizers.

Recalculations in inorganic nitrogen fertilizers due to the changes in organic fertilizer quantities decreased emissions by 1 kt CO_2 eq in 1990, 0 kt CO_2 eq in 2005 and -1359 kt CO_2 eq in 2017. Overall, the recalculation decreased the long-term emission trend from an increase of 105% to 81% and the short-term emission trend from an increase of 70% to 51%.

5.4.1.1.6. Planned Improvements

A compilation of soil N_2O flux data since 1990 collected mainly through published literature is ongoing to identify key factors, including soil properties, climatic conditions, and management practices, explaining N_2O emissions from agricultural soils in Canada and to re-evaluate the empirical relationship between N_2O emission factors, growing season precipitation and potential evapotranspiration.

5.4.1.2. Organic Nitrogen Fertilizers Applied to Soils

5.4.1.2.1. Source Category Description

The application of organic nitrogen sources as fertilizer to agricultural soils can increase the rate of nitrification and denitrification and result in enhanced N_2O emissions. Emissions from this category include (i) all manure managed by drylot, liquid and other animal waste management systems and (ii) human biosolids managed by municipal wastewater treatment plants.

5.4.1.2.2. Methodological Issues

Like the methodology used to estimate emissions from inorganic nitrogen fertilizers, the method used to estimate N_2O emissions from organic manure applied to agricultural soils is a country-specific IPCC Tier 2 method that takes into account moisture regimes (long-term growing season precipitation and potential evapotranspiration) and topographic conditions. Emissions are calculated by multiplying the amount of organic nitrogen applied to agricultural soils by an emission factor 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. Based on provincial regulations and crop requirements, biosolids were applied to ecodistricts and subsequent emissions were calculated using the country-specific Tier 2 emission factors.

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 country-specific methodology (Rochette et al. 2008b) used to develop N_2O emission factors, as noted in section 5.4.1.1.3.

The estimate of N_2O emissions of 2.4 Mt CO_2 eq from manure spreading of Canadian livestock wastes in 2018 lies within an uncertainty range of 1.6 Mt CO_2 eq (-33%) to 3.4 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 P/PE regression equation for estimating N_2O emission factors, animal N excretion rates, emission factor modifiers for texture ($RF_{TEXTURE}$), tillage (RF_{TILL}) and N content of the biosolids.

The same methodology and emission factors are used for the entire time series (1990–2018).

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 both paper and electronic form.

5.4.1.2.5. Recalculations

The inclusion of biosolids, as noted in section 5.3, altered the organic manure distribution and quantities and as a result, the N_2O emissions from organic manure N applied to soils.

Total recalculations resulted in an increase in emissions of 52 kt CO_2 eq in 1990, 80 kt in 2005 and 108 kt CO_2 eq in 2017 (a relative change of 2.6 to 4.8%) (Table 5–8). These recalculations increased the long-term emission trend from an increase of 13% to 16% between 1990 and 2017 and decreased the short-term emission trend between 2005 and 2017 from a decrease in emissions of 8% to 7%.

5.4.1.2.6. Planned Improvements

Through a compilation of soil N_2O flux data from published literature, Canada aims to differentiate N_2O emission factors between organic and inorganic N sources. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

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 residue multiplied by the 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 inorganic fertilizer nitrogen application based on moisture regimes and topographic conditions.

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. 2008b) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emissions of 6.3 Mt CO_2 eq from crop residue decomposition in 2018 lies within an uncertainty range of 4.1 Mt CO_2 eq (-35%) to 9.1 Mt CO_2 eq (+45%) (Table 5–7). The main sources of uncertainty in the calculation of emissions from crop residue decomposition include the slope of the P/PE regression equation for estimating N_2O emission factors and emission factor modifiers for texture ($RF_{TEXTURE}$) and tillage (RF_{TILL}).

The same methodology and emission factors are used for the entire time series (1990–2018).

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.

Table 5–8 **Recalculations of N_2O Emission Estimates and Their Impact on Emission Trends from Fertilizer Application, Manure Spreading, 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 Category Emissions (%)	Old Trend (%)	New Trend (%)
Inorganic Nitrogen Fertilizers	1990	2019	5 721	-1	0.0	Long term (1990–2017)	
		2020	5 720			105	81
	2005	2019	6 891	0	0.0		
		2020	6 891			Short term (2005–2017)	
	2017	2019	11 732	-1359	-11.6	70	51
		2020	10 374				
Organic Nitrogen Fertilizers	1990	2019	2 009	52	2.6	Long term (1990–2017)	
		2020	2 061			13	16
	2005	2019	2 467	80	3.2		
		2020	2 548			Short term (2005–2017)	
	2017	2019	2 274	108	4.8	-8	-7
		2020	2 382				
Crop Residue Decomposition	1990	2019	4 415	0	0.0	Long term (1990–2017)	
		2020	4 415			47	48
	2005	2019	4 852	0	0.0		
		2020	4 851			Short term (2005–2017)	
	2017	2019	6 502	16	0.3	34	34
		2020	6 519				

5.4.1.3.5. Recalculations

Recalculations were the result of a minor correction to activity data for crop production in the year 2017. Emissions remained unchanged 1990 and 2005, and increased by 16 kt CO_2 eq in 2017. As a result of these changes, the long-term emission trend increased from a 47% increase to a 48% increase, and the short-term trend remained unchanged at 34%.

5.4.1.3.6. Planned Improvements

Through a compilation of soil N_2O flux data from published literature, Canada aims to differentiate N_2O emission factors between organic and inorganic N sources. Further uncertainty work will be carried out, over the medium term, to capture the most recent changes in the agricultural soil emission model and to establish trend uncertainty.

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 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 were 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 enteric fermentation and manure management 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 2018 lies within an uncertainty range of 0.082 Mt CO_2 eq (-60%) to 0.36 Mt CO_2 eq (+75%) (Table 5–7).

The same methodology and emission factors are used for the entire time series (1990–2018).

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

There were no recalculations in this source of emission estimates.

5.4.1.4.6. Planned Improvements

There is no immediate plan in place aimed at improving 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 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 for 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 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 2018 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: FLCL already reported under LULUCF), perennial above-ground biomass and cultivation of histosols. A data set 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 inorganic fertilizer application, organic manure applied as fertilizer and crop residue decomposition. Emission factors are based on precipitation and potential evapotranspiration data 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

Revisions to activity data for management practices altered the amount of soil organic matter and, as a consequence, the total quantity of nitrogen lost.

The recalculations resulted in small increases in emissions of 1 kt CO_2 eq in 1990, a decrease of 3 kt CO_2 eq in 2005, and an increase of 0.4 kt CO_2 eq in 2017. The long-term trend decreased from 79% to 78%, and the short-term trend increased from 76% to 77%.

5.4.1.5.6. Planned Improvements

Through a compilation of soil N_2O flux data from the published literature, Canada aims to differentiate 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 1990–2017 (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 the uncertainty in the default emission factor.

The estimate of N_2O emissions of 0.061 Mt CO_2 eq from organic soils in 2018 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 (1990–2018).

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 aimed at improving emission estimates from 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 result 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), but increases N_2O emissions for the non-Prairie regions of Canada (Rochette et al. 2008a). The net result across the country is a small 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 modifications of emission factors for inorganic fertilizers, manure 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 (F_{TILL}), defined as the ratio of mean N_2O fluxes on NT or RT to mean N_2O fluxes on IT (N_2O_{NT}/N_2O_{IT}), represents the effect of NT or RT on N_2O emissions (see Annex 3.4).

5.4.1.7.3. Uncertainties and Time-Series Consistency

For N_2O emissions from the adoption of conservation tillage practices, the uncertainty analysis considered the uncertainty in tillage practice areas, manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emission reductions of -1.4 Mt CO_2 eq (Table 5–9) from conservation tillage practices in 2018 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 (1990–2018).

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

Corrections to inorganic nitrogen fertilizer activity data and the addition of biosolids N to agricultural soils modified the total amount of N subjected to tillage practices. Minor revisions to crop and livestock activity data redistributed nitrogen among different ecodistricts on the landscape and modified the types and areas on which tillage practices were carried out.

The changes reduced the impact of tillage adoption on N_2O emissions by 0.3 kt CO_2 eq in 1990, increased it by 0.8 kt CO_2 eq in 2005 and decreased estimates by 112 kt CO_2 eq in 2017. These recalculations increased the impact of tillage adoption on the trend from 335% to 373% in the long-term and from 51% to 65% in the short-term (Table 5–9).

5.4.1.7.6. Planned Improvements

Through a compilation of soil N_2O flux data from published literature, Canada aims to update the method for estimating the impact of tillage practices on soil N_2O emissions. Work is ongoing to develop level and trend uncertainty estimates using the IPCC Tier 2 method. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.8. N_2O Emissions Resulting from Summerfallow

5.4.1.8.1. Source Category Description

This category is not derived from additional nitrogen input but reflects changes in soil conditions that affect N_2O emissions. Summerfallow (SF) is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several soil factors may stimulate N_2O emissions relative to a cropped situation, such as higher soil water content, higher soil temperature, and greater availability of soil carbon and nitrogen (Campbell et al. 1990, 2005).

5.4.1.8.2. Methodological Issues

Experimental studies have shown that N_2O emissions in fallow fields are not statistically different from emissions on continuously cropped fields (Rochette et al. 2008b). Omitting areas under SF in calculations of N_2O emissions because no crops are grown or fertilizer applied could

Table 5–9 **Recalculations of N_2O Emission Estimates and Their Impact on Emission Trends from Conservation Tillage Practices, Summerfallow and Irrigation**

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 (%)
Conservation Tillage Practices	1990	2019	-296	-0.3	0.1	Long term (1990–2017)	
		2020	-296			335	373
	2005	2019	-850	0.8	-0.1		
		2020	-849			Short term (2005–2017)	
	2017	2019	-1 287	-112	8.7	51	65
		2020	-1 399				
Summerfallow	1990	2019	1 302	3	0.3	Long term (1990–2017)	
		2020	1 305			-83	-85
	2005	2019	741	1.4	0.2		
		2020	743			Short term (2005–2017)	
	2017	2019	218	-26	-12	-71	-74
		2020	193				
Irrigation	1990	2019	280	0.7	0.2	Long term (1990–2017)	
		2020	281			18	37
	2005	2019	331	0.9	0.3		
		2020	332			Short term (2005–2017)	
	2017	2019	330	54	17	0	16
		2020	384				

lead to underestimating total N_2O emissions. The emissions from SF land are therefore calculated through a country-specific method by summing emissions from fertilizer nitrogen, manure nitrogen application to annual crops and crop residue nitrogen for a given ecodistrict and multiplying the sum by the proportion of that ecodistrict area under summerfallow (Rochette et al. 2008b). A more detailed description of the approach is provided in Annex 3.4.

5.4.1.8.3. Uncertainties and Time-Series Consistency

For N_2O emissions from summerfallow, the uncertainty analysis considered the uncertainty in summerfallow areas, manure management factors defined in sections 5.3.2.3 and 5.4.1.2.3, crop residue decomposition defined in section 5.4.1.2.3, and the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emissions of 0.27 Mt CO_2 eq from summerfallow land in 2017 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). Summerfallow emissions were derived from soil emission calculations, and uncertainty is therefore influenced by all factors identified 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 (1990–2017).

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, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.8.5. Recalculations

Similar to section 5.4.1.7.5, summerfallow emissions were impacted by corrections to inorganic nitrogen fertilizer activity data and land application of biosolids, combined with minor revisions to the distribution of crops and livestock, resulting in recalculations in this section.

As a result of these changes, emissions associated with summerfallow increased by 3 kt CO_2 eq in 1990, 1 kt CO_2 eq in 2005 and decreased by 26 kt CO_2 eq in 2017 (Table 5–9). Emission trends decreased slightly, from a decrease of 83% to 85% in the long term and from a decrease of 71% to 74% in the short term.

5.4.1.8.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.9. N_2O Emissions from Irrigation

5.4.1.9.1. Source Category Description

As in the case of tillage practices and summerfallow, 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.

5.4.1.9.2. 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 amounts of precipitation plus those of irrigation water are equal to the potential evapotranspiration at the 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 = 1 (precipitation/potential evapotranspiration, EF_{BASE} = 0.017 N_2O-N/kg N) for the irrigated areas of a given ecodistrict. To improve transparency, the effect of irrigation on soil N_2O emissions is also reported separately from other source categories.

5.4.1.9.3. 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 country-specific methodology (Rochette et al. 2008b) used to develop N_2O emission factors as noted in section 5.4.1.1.3.

The estimate of N_2O emissions of 0.38 Mt CO_2 eq from irrigated land in 2018 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 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, in particular the slope and intercept of the P/PE regression equation.

The same methodology and emission factors are used for the entire time series (1990–2018).

5.4.1.9.4. 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 both paper and electronic form.

5.4.1.9.5. Recalculations

Emissions from irrigation are linked to all soil emission calculations. The inclusion of estimates for biosolids as a source of organic N, revisions to activity data for inorganic fertilizer and crop production, and small changes to the distribution of crops resulted in recalculations to emissions linked to irrigation.

These changes increased emissions slightly by 1 kt CO_2 eq in 1990, 1 kt CO_2 eq in 2005 and 54 kt CO_2 eq in 2017, with a relative change of 0.2%, 0.3% and 16%, respectively. These recalculations increased the estimate of the change in emissions associated with irrigation in the long term from 18% to 37% and in the short term from 0% to 16% (Table 5–9).

5.4.1.9.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. Further uncertainty work will be carried out to establish trend uncertainty 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 both inorganic fertilizer and manure 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. Even though 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. The default IPCC emission factor, 0.01 kg N_2O-N/kg N, is used to derive the N_2O emission estimate (IPCC 2006).

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 1.2 Mt CO_2 eq from volatilization and redeposition in 2018 lies within an uncertainty range of 0.31 Mt CO_2 eq (-75%) to 2.6 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%).

The same methodology and emission factors are used for the entire time series (1990–2018).

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 the addition of biosolids as a source of organic N applied to agricultural soils, and due to revisions to activity data including inorganic nitrogen fertilizer shipments, livestock populations, crop areas, and crop production.

These recalculations increased emissions by 9 kt CO_2 eq or 1.1% in 1990, 13 kt CO_2 eq or1.2% in 2005, and decreased by 27 kt CO_2 eq or 2.2% in 2017. (Table 5–10). The short-term trend decreased from 10% to 7% and long-term from 49% to 47%.

5.4.2.1.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source.

5.4.2.2. Nitrogen Leaching and Runoff

5.4.2.2.1. Source Category Description

When inorganic fertilizer, manure 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).

Table 5–10 **Recalculations of N_2O Emission Estimates and Their Impact on Emission Trends from Indirect Emissions of Agricultural Soils, 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 Category Emissions (%)	Old Trend (%)	New Trend (%)
Atmospheric Deposition	1990	2019	821	9	1.1	Long term (1990–2017)	
		2020	830			49	44
	2005	2019	1 108	13	1.2		
		2020	1 121			Short term (2005–2017)	
	2017	2019	1 223	-27	-2.2	10	7
		2020	1 197				
Nitrogen Leaching and Runoff	1990	2019	1 952	8	0.4	Long term (1990–2017)	
		2020	1 960			56	46
	2005	2019	2 275	11	0.5		
		2020	2 286			Short term (2005–2017)	
	2017	2019	3 041	-170	-5.6	34	26
		2020	2 871				

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 Prairie region of Canada. 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 Mt CO_2 eq from nitrogen leaching and runoff in 2018 lies within an uncertainty range of 0.61 Mt CO_2 eq (-80%) to 6.1 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 (1990–2018).

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

As was the case with volatilization, recalculations occurred as a result of biosolid N application to agricultural soils, and revision to activity data including inorganic nitrogen fertilizer shipments, livestock populations, crop areas, and crop production.

The recalculations decreased emissions by 8 kt CO_2 eq or 0.4% in 1990 and by 11 kt CO_2 eq or 0.5% in 2005 and increased emissions by 170 kt CO_2 eq or 5.6% in 2017. These recalculations caused a change of 56% to 46% in long-term trends and 34% to 26% in short-term trends.

5.4.2.2.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source.

5.5. CH_4 and N_2O Emissions from Field Burning of Agricultural Residues (CRF Category 3.F)

5.5.1. Source Category Description

Crop residues are sometimes burned in Canada, as a matter of convenience and for the purpose of disease control through residue removals. However, this practice has declined in recent years because of concerns over soil quality and environmental issues. Crop residue burning 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.

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

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

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

CH_4 and N_2O emissions from field burning of agricultural residues have 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

In this submission, minor recalculations occurred as a result of changes to crop residue as described in section 5.4.1.3. These changes resulted in an increase of 0.2 kt CO_2 eq in in 2017.

5.5.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from 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.

5.6.2. 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 that are 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 of 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 (1990–2017).

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 recalculations involved in emission estimates for this source category.

5.6.6. Planned Improvements

There is no immediate plan in place aimed at improving 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 2018 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.

5.7.4. 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

There were no recalculations involved in emission estimates for this source category.

5.7.6. Planned Improvements

There is no immediate plan in place aimed at improving 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); additional emissions of methane (CH_4), nitrous oxide (N_2O) and carbon monoxide (CO)[1] due to controlled biomass burning; CH_4 and N_2O emissions from wetland drainage and rewetting due to peat extraction; and N_2O released following Land converted 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 a net removal of 60 Mt[3] in 1990, 13 Mt in 2005 and 13 Mt in 2018. When applied to the national totals, they decrease the total Canadian GHG emissions by 9.9%, 1.7% and 1.8% in 1990, 2005 and 2018, respectively. 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 category has the largest influence on sectoral totals. The net fluxes are negative (removals) for all years of the time series. When interannual variations and trends in the net flux from the managed forest associated with wildfires and other natural disturbances are removed from reporting, net removals from Forest Land decrease from 200 Mt in 1990 to 140 Mt in 2007.

The decrease in removals reflects the influence of forest harvesting and, to a certain extent, an interaction with insect disturbances in Western Canada. After 2007, net overall removals have fluctuated, increasing to 150 Mt in 2009 when harvest rates reached the lowest point in the 29-year time series, and declining slightly to a minimum value of 140 Mt in 2018.

Emissions from the Harvested Wood Products[4] category, which is closely linked to Forest Land, have varied through 1990–2018 (see section 6.4), but have remained relatively constant at 1990 levels in recent years (Table 6–1). They are influenced primarily by the trend in forest harvest rates during the reporting period and the long-term impact of harvest levels before 1990, as some HWP from harvest prior to 1990 are disposed of during the reporting period. As a result, annual emissions fluctuated between 120 Mt in 2009 (lowest harvest year) and 150 Mt in 1995.

The combined net flux from Forest Land and Harvested Wood Products from forest harvest—not including HWP resulting from forest conversion activities since 1990—amounted to net removals of 14 Mt in 2018, which includes net removals of 140 Mt from Forest Land and net emissions of 126 Mt from HWP.

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

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 to estimates and activity data have been rounded according to the rounding protocol described in Annex 8, except in cases where consistency with the explanations provided needed to be ensured.

4 Includes harvested wood products from Forest Land conversion.

Table 6–1 **LULUCF Sector Net GHG Flux Estimates, Selected Years**

Sectoral Category		Net GHG Flux (kt CO_2 eq)[b]							
		1990	2005	2013	2014	2015	2016	2017	2018
Land Use, Land-Use Change and Forestry TOTAL[a]		**-60 000**	**-13 000**	**-25 000**	**-25 000**	**-18 000**	**-19 000**	**-16 000**	**-13 000**
a.	**Forest Land**	**-200 000**	**-150 000**	**-150 000**	**-150 000**	**-140 000**	**-140 000**	**-140 000**	**-140 000**
	Forest Land remaining Forest Land	-200 000	-140 000	-150 000	-150 000	-140 000	-140 000	-140 000	-140 000
	Land converted to Forest Land	-1 100	- 950	- 590	- 540	- 500	- 440	- 390	- 330
b.	**Cropland**	**8 100**	**-11 000**	**-10 000**	**-9 500**	**-8 600**	**-7 700**	**-6 800**	**-6 200**
	Cropland remaining Cropland	-1 300	-15 000	-13 000	-12 000	-11 000	-10 000	-9 700	-8 800
	Land converted to Cropland	9 500	3 900	2 700	2 800	2 700	2 800	2 900	2 700
c.	**Grassland**	**0.6**	**0.9**	**1.9**	**0.8**	**1.2**	**1.2**	**1.2**	**1.2**
	Grassland remaining Grassland	0.6	0.9	1.9	0.8	1.2	1.2	1.2	1.2
	Land converted to Grassland	NO	NO	NO	NO	NO	NO	NO	NO
d.	**Wetlands**	**5 300**	**3 100**	**3 100**	**3 100**	**2 900**	**2 900**	**3 000**	**2 600**
	Wetlands remaining Wetlands	1 500	2 600	2 400	2 400	2 500	2 600	2 600	2 400
	Land converted to Wetlands	3 800	480	670	710	410	330	350	210
e.	**Settlements**	**2 100**	**2 100**	**2 300**	**2 300**	**2 200**	**2 100**	**1 900**	**1 800**
	Settlements remaining Settlements	-3 900	-4 100	-4 100	-4 100	-4 100	-4 100	-4 100	-4 100
	Land converted to Settlements	6 000	6 100	6 400	6 400	6 400	6 200	6 000	5 900
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**	**140 000**	**130 000**	**130 000**	**130 000**	**130 000**	**130 000**	**130 000**
	Forest Conversion[c]	*21 000*	*16 000*	*15 000*	*15 000*	*15 000*	*15 000*	*14 000*	*14 000*
	Indirect CO_2[d]	*790*	*820*	*630*	*560*	*570*	*530*	*510*	*490*
	Natural Disturbances[e]	*-22 000*	*46 000*	*43 000*	*160 000*	*240 000*	*120 000*	*220 000*	*250 000*

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.

variability that largely mask trends in forest management activities. Since 1990 emissions and removals from natural disturbances have ranged from removals of 50 Mt in 1992 to emissions of 230 Mt in 2018. Emissions and removals have tended to be higher since the mid-2000s compared to the early part of the inventory reporting period (Figure 6–3) 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 practices and reduction in the use of summerfallow, have resulted in a decrease in emissions from Cropland in the 1990–2006 period, from emissions of 8.1 Mt in 1990 to net removals of 12 Mt in 2006. A decline in emissions from Forest Land converted to Cropland also contributes to this trend. After 2006, net removals remained relatively constant until 2011, but have since gradually declined to 6.2 Mt in 2018, largely as a result of the conversion of perennial lands to annual crop production, a decrease in the adoption rate of conservation tillage, and the fact that soil C in lands previously converted to conservation tillage is approaching equilibrium.

Over the 1990–2018 period, net fluxes in the Wetlands category (peat extraction and flooded lands) fluctuated between 2.6 Mt (2018) and 5.4 Mt (1993). Emissions from flooded lands in 2018 accounted for 39% of all emissions in the Wetlands category, compared to 82% in 1990. Emissions from Land converted to Wetlands decreased over the reporting period from 3.8 Mt to 0.2 Mt.

Net emissions reported in the Settlements category fluctuated between 1.5 Mt (1996) and 2.3 Mt (2007), mainly driven by rates of conversion from forested land that accounted for 5.9 Mt in 2018. Relatively steady removals of around 4.0 Mt per year from the growth of urban trees offset these emissions by an average of 68% over the reporting period.

Forest conversion is not a reporting category per se since it overlaps with the subcategories of Land converted to Cropland, Land converted to Wetlands, Land converted to Settlements and Harvested Wood Products. Greenhouse gas emissions due to forest conversion decreased from 21 Mt in 1990 to 14 Mt in 2018, including the emissions from HWP resulting from forest conversion activities since 1990. This decline in emissions includes

decreases of 4.1 Mt, 1.8 Mt and 0.4 Mt in immediate and residual emissions from Forest Land converted to Cropland, Wetlands and Settlements, respectively, as well as a small decrease of 0.4 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. 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 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 and Settlements due to correction of volume-to-biomass parameters used in modelling forests in Western Canada, new estimates for the drainage of forested wetlands and improvements in the estimated removals by urban trees (Table 6–3).

Small recalculations also occurred in Cropland, Wetlands and Harvested Wood Products categories and in land categories associated with forest conversion, as a result of updates in activity data related to harvest, peat extraction and forest conversion activities as well as indirect impacts resulting from changes in the forest ecosystem model.

The cumulative impact of all these recalculations (Table 6–2) decreased the estimates of net removals by 8.6 Mt (-13%) for 1990, 8.6 Mt (-40%) for 2005 and 7.3 Mt (-31%) for 2017.

Table 6–2 **Summary of Recalculations in the LULUCF Sector**

Sectoral Category			1990	2005	2013	2014	2015	2016	2017
Land Use, Land-Use Change and Forestry TOTAL[a, b]		**kt**	**8 600**	**8 600**	**7 300**	**7 100**	**7 000**	**6 900.0**	**7 300**
		%	**-13%**	**-40%**	**-22%**	**-22%**	**-28%**	**-27%**	**-31%**
a.	**Forest Land**	**kt**	**11 000**	**10 000**	**8 800**	**8 600**	**8 600**	**8 400**	**8 200**
		%	**-5.0%**	**-6.6%**	**-5.5%**	**-5.4%**	**-5.7%**	**-5.5%**	**-5.4%**
	Forest Land remaining Forest Land	kt	11 000	10 000	8 800	8 600	8 600	8 400	8 200
		%	-5.0%	-6.6%	-5.6%	-5.4%	-5.7%	-5.5%	-5.4%
	Land converted to Forest Land	kt	-	-	-	-	-	-	-
		%	-	-	-	-	-	-	-
b.	**Cropland**	**kt**	**- 130**	**32**	**0.0**	**6.3**	**12**	**63**	**22**
		%	-1.5%	-0.3%	0.0%	-0.1%	-0.1%	-0.8%	-0.3%
	Cropland remaining Cropland	kt	16	38	29	10	- 4.4	- 18	- 19
		%	-1.2%	-0.3%	-0.2%	-0.1%	0.0%	0.2%	0.2%
	Land converted to Cropland	kt	- 140	- 6.0	- 29	- 3.9	16	81	42
		%	-1.5%	-0.2%	-1.0%	-0.1%	0.6%	3.0%	1.5%
c.	**Grassland**	**kt**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		%	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Grassland remaining Grassland	kt	-	-	-	-	-	-	-
		%	-	-	-	-	-	-	-
d.	**Wetlands**	**kt**	**8.8**	**11**	**2.4**	**3.9**	**- 3.0**	**14**	**- 190**
		%	0.2%	0.4%	0.1%	0.1%	-0.1%	0.5%	-6.0%
	Wetlands remaining Wetlands	kt	-5.5	- 2.6	- 2.0	- 1.4	- 1.0	23	- 200
		%	-0.4%	-0.1%	-0.1%	-0.1%	0.0%	0.9%	-7.2%
	Land converted to Wetlands	kt	14	13	4.4	5.3	- 2.0	-9.0	14.0
		%	0.4%	2.9%	0.7%	0.7%	-0.5%	-2.7%	4.1%
e.	**Settlements**	**kt**	**-1 700**	**-1 700**	**-1 500**	**-1 600**	**-1 600**	**-1 600**	**-1 700**
		%	**-45%**	**-45%**	**-40%**	**-41%**	**-42%**	**-44%**	**-47%**
	Settlements remaining Settlements	kt	-1 500	-1 600	-1 700	-1 700	-1 700	-1 700	-1 700
		%	64%	68%	71%	71%	71%	71%	71%
	Land converted to Settlements	kt	- 210	- 78	180	130	64	70	50
		%	-3.3%	-1.3%	2.9%	2.1%	1.0%	1.1%	0.8%
g.	**Harvested Wood Products**	**kt**	**-190.0**	**- 7.9**	**31**	**73.0**	**37**	**15.0**	**910**
		%	-0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.7%
	Forest Conversion[c]	kt	*- 500*	*- 89*	*150*	*140*	*49*	*120*	*88*
		%	*-2.3%*	*-0.6%*	*1.0%*	*0.9%*	*0.3%*	*0.8%*	*0.6%*

Notes:
a. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.
b. Hyphen (-) indicates no recalculations
c. Not a reporting category.

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 has established governance mechanisms for LULUCF sector reporting through memoranda of understanding (MOU) with Agriculture and Agri-Food Canada 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.

Planned improvements include continued refinements to the isolation of anthropogenic emissions and removals in 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.

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.

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 provides more detail on the implementation of the “managed forests” definition.

Table 6–3 **Summary of Changes in the LULUCF Sector**

List of Changes	Change Category	Years Affected
Forest Land		
Correction volume-to-biomass parameters used in modelling forests in Western Canada	Methodological Updates	Complete time series
Conventional harvest volumes updated based on recent National Forestry Database (NFD) forest harvest statistics	Activity data updates	2017–2018
New forest drainage estimates	Address ERT Recommendation	Complete time series
Forest conversion activity data updates for 2005–2018	Activity data updates	2005–2018
Cropland		
Reconciliation of inconsistencies between AAFC and STATCAN provincial census data, and fix error in fruit trees AD	Activity data updates	Complete time series
Changes in C available in deforested lands for agriculture after CBM updates	Methodological Updates	Complete time series
Grassland		
No recalculations		
Wetlands		
Updates of 2017 AD from NRCan for peat extraction	Activity data updates	2017–2018
Changes in C available in deforested lands for hydro-reservoirs after CBM updates	Methodological Updates	Complete time series
Settlements		
Improvements in estimates of urban trees	Continuous Improvement	Complete time series
Updates in deforestation AD for years 2005-2017 related to mining, transportation and hydro infrastructure	Activity data updates	2017–2018
Harvested Wood Products		
Changes in C inputs after CBM updates	Methodological Updates	Complete time series
Conventional harvest volumes updated based on recent NFD forest harvest statistics	Activity data updates	2017–2018
Forest conversion activity data updates for 2005–2018	Activity data updates	2005–2018
Update on residential firewood consumption and industrial fuelwood data	Activity data updates	2017–2018

Agricultural land comprises both Cropland and agricultural Grassland. 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). Agricultural Grassland 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 agricultural 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 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 lands (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 2018. The diagonal cells related to Forest Land and 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 emissions have occurred. Forest Land includes all managed forest areas comprising areas with anthropogenic impacts for which GHG estimates are reported in CRF Tables 4.A and 4(V), and areas with natural disturbance impacts (see Table 6–5). Grassland converted to Settlements refers to land conversion of unmanaged tundra to Settlements in Northern Canada (section 6.8.2.2). Column totals equal the total land area as reported in the CRF for each category. The full time series of the land use and land-use change matrix is available in Table 4.1 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 and removals are detected for this sector. More details on the spatial estimation and reporting framework can be found in Annex 3.5.

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. Hence, 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 CRF tables 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; this area is currently reported to fulfill the requirement of the UNFCCC Reporting Guidelines and reports the total land mass area of the country in the Land Transition Matrix.

Table 6–4 **Land Use and Land-Use Change Matrix for the 2018 Inventory Year (Areas in kha)**

	Final Land Use					
Initial Land Use	Forest Land[a]	Cropland	Grassland[b]	Wetlands[c]	Settlements[c]	Other
Forest Land	225 736	12	NO	0.0	22	NO
Cropland	NE	47 328	NO	NE	11	NO
Grassland	NO	5.7	6 354	NE	0.9	NO
Wetlands	NO	NE	NO	483	NE	NO
Settlements[b]	NO	NE	NO	NO	951	NO
Other	NO	NO	NO	0.5	NO	NE

Notes:

NE Not estimated

NO Not occurring

Non-diagonal cells refer to annual rates of land-use change, i.e., total land converted during the latest inventory year.

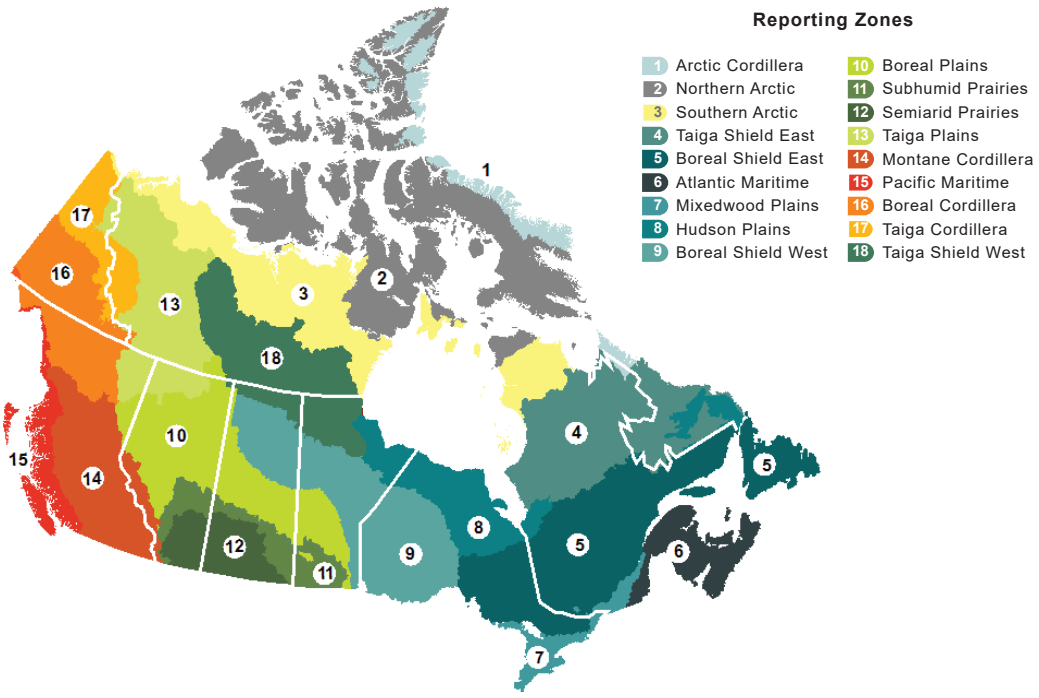
Areas presented in this table are not rounded to keep consistency within the table between numbers with different orders of magnitude, and with areas reported in the CRF Tables. However, caution is advised when interpreting these estimated areas due to the uncertainty associated with these values.

a. Includes all managed forest areas.

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**



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 2018b). 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 2018, the net GHG balance of managed Forest Land amounted to removals of 140 Mt (Table 6–1 and CRF Table 4), while emissions from wood products originating from Canada's managed forests amounted to 130 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. For the purpose of UNFCCC reporting, managed Forest Land is divided into the subcategories Forest Land remaining Forest Land (230 Mha, net removals of 140 Mt in 2018) and Land converted to Forest Land (0.03 Mha, net removals of 0.3 Mt in 2018).

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, and some of this C 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 planning, harvest operations and subsequent forest regeneration are the primary direct human influences on emissions and removals in forests. Forest harvest transfers C to Harvested Wood Products (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

Table 6–5 **Forest Land Remaining Forest Land Areas, GHG Fluxes and C Transfers, Selected Years**

Subcategories	1990	2005	2013	2014	2015	2016	2017	2018
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	56 000	56 000	57 000	57 000	57 000	58 000
Net Flux (kt CO_2 eq)[a, b]	**-220 000**	**-98 000**	**-110 000**	**12 000**	**94 000**	**-23 000**	**77 000**	**110 000**
Reported Estimates[c]	-200 000	-140 000	-150 000	-150 000	-140 000	-140 000	-140 000	-140 000
Indirect CO_2[d]	*370*	*570*	*400*	*330*	*380*	*340*	*330*	*320*
Emissions/removals from lands impacted by Natural Disturbances	-22 000	46 000	43 000	160 000	240 000	120 000	220 000	250 000
Wildfires—Immediate emissions[e]	38 000	67 000	59 000	180 000	250 000	130 000	230 000	260 000
Post-wildfire CO_2 emissions and removals[e]	-61 000	-52 000	-50 000	-47 000	-40 000	-38 000	-32 000	-27 000
Insects—emissions and removals[f]	660	32 000	34 000	31 000	29 000	27 000	24 000	22 000
Other natural disturbances—emissions and removals[g]		17	- 0.3	- 0.7	- 1.0	- 1.3	- 1.6	- 1.2
Carbon Transferred to HWP (kt C)[h]	***47 000***	***56 000***	***44 000***	***43 000***	***45 000***	***45 000***	***45 000***	***45 000***

Notes

Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

a. Negative sign indicates removal of CO_2 from the atmosphere.

b. Net flux corresponds to the sum of net GHG balance due to forest management activities and emissions/removals due to natural disturbances, 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 slah burning after forest harvest are reported in CRF table 6.

e. Immediate emissions include direct and indirect CO_2 and non-CO_2 emissions resulting from the immediate impact of wildfires. Post-wildfire CO_2 emissions are associated to the long term effect of wildfires on dead and soil organic matter, it includes small emissions associated to insect infestations on wildfire-impacted areas. Removals of CO_2 are associated to natural stand regeneration following wildfire.

f. Includes emissions due to insect infestations, mainly residual, and removals associated to 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.

biomass as young trees accumulate little biomass in the first 30 to 40 years. The combination of emissions and removals in Forest Land and emissions of C harvested from the forest represents the net flux between managed forests and the atmosphere (Figure 6–2).

Reported estimates for the net removals from Forest Land exclude the impacts of non-anthropogenic natural disturbances (wildfires, insect infestations and windthrow, Table 6–5).[5] Net removals from Forest Land decreased from 200 Mt in 1990 to 140 Mt in 2007 and remained relatively constant thereafter (Figure 6–2). The decrease in removals that occurred between 2000 and 2007 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, increasing emissions from decomposition. In 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.

The total net flux in managed forests shown in Table 6–5 is calculated by adding reported estimates of emissions and removals caused by human activities, including indirect CO_2, to emissions and removals that occur in areas dominated by the impact of uncontrollable natural disturbances. When emissions and removals from lands impacted by natural disturbances are included, net fluxes in managed forests go from net removals of 220 Mt in 1990 and 98 Mt in 2005 to net emissions of 110 Mt in 2018. Variations in net fluxes largely depend on the occurrence of natural disturbances in a given year.

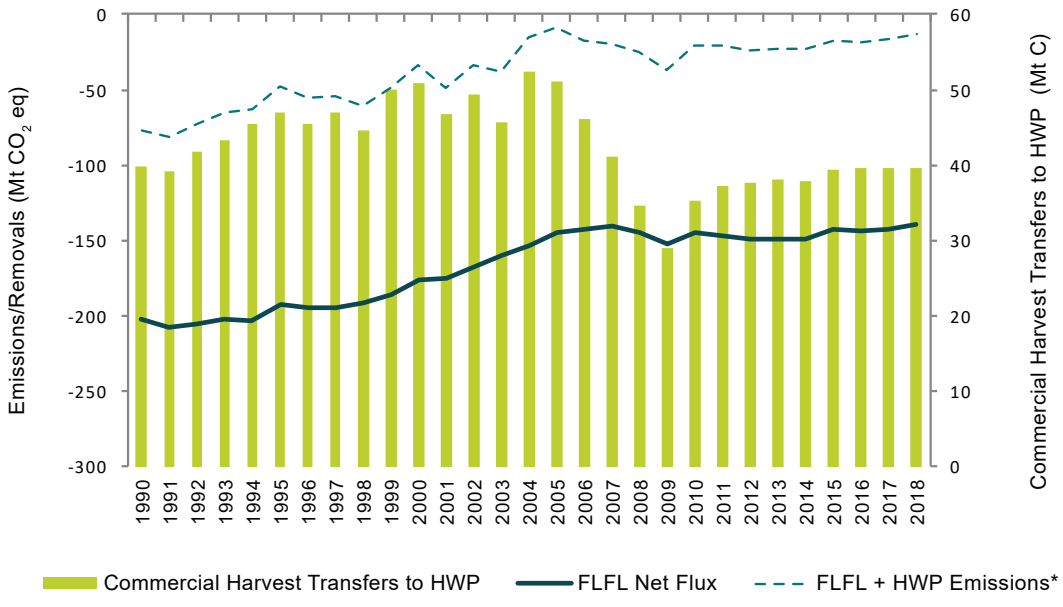
6.3.1.2. Methodological Issues

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 (NFCMARS) 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 carbon (C) stocks, stock changes and CO_2 emissions and removals. The model uses regional ecological and climate

5 Impacts of natural disturbances with greater than 20% tree mortality.

6 Average age of the forest in this context is referring to the age class structure of the forest and carbon uptake refers to net primary production.

Figure 6–2 **Emissions and Removals Related to Forest Land**



* Includes emissions from HWP originating from harvesting and salvage logging after natural disturbances.

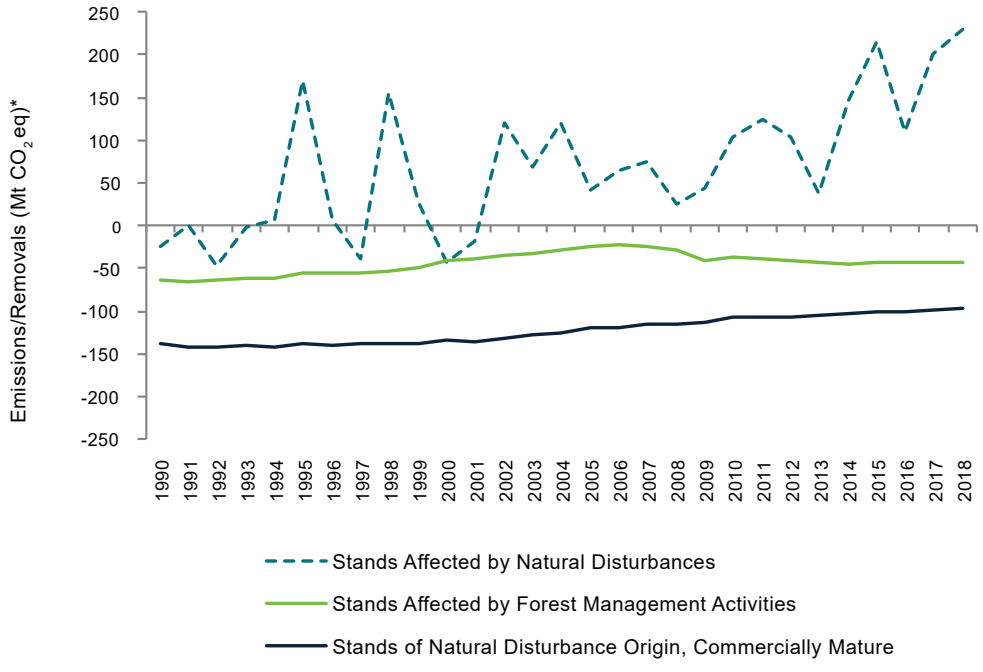
parameters to simulate C transfers among pools, to harvested wood products and to the atmosphere. A more detailed description of forest C modelling can be found in Annex 3.5.2.1.

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). It is understood that in Canada, natural disturbances are responsible for significant emissions and subsequent removals when forests regrow after the disturbances occur (Table 6–5). However, Canada has developed a Tier 3 approach to isolate the effect of anthropogenic activities on managed forests. This approach is based on the monitoring of forest stands impacted by anthropogenic and natural drivers separately (Figure 6–3). For transparency, all emissions and removals are presented in this report, but reporting is based on stands associated with anthropogenic drivers in an effort to better capture emissions and removals (Figure 6–3) more closely linked to land management decisions and to provide information to better inform policy. A full accounting of natural disturbances and C balance in managed forests can be found in the State of the Forest Report (NRCan 2018c). Emissions and removals from stands dominated by the impacts of recent natural disturbances are not reported until the stands have reached commercial maturity for a given region; however they are displayed in Table 6–5 for reference and transparency purposes. When stands have reached a regionally determined minimum operable age and, as a consequence, are considered within forest management planning or are directly affected by forest management activities, they are reclassified as stands under anthropogenic influence. Direct forest management activities include commercial clear-cut and partial harvest, commercial and pre-commercial thinning, and salvage logging. Additional information on the estimation approach is provided in Annex 3.5.2.4 and in Kurz et al. (2018).

Carbon stock changes in managed forests are reported in CRF Table 4.A, by reporting zone. 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 dead organic matter upon stand mortality. Therefore, individual C stock changes give no indication of the net fluxes between C pools in managed forests and the atmosphere.

Harvesting wood from managed forests results in both 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

Figure 6–3 **Emissions and Removals in Forest Land Remaining Forest Land by Stand Component**



* Not including indirect CO_2.

reported in the Harvested Wood Products category, and the emissions from the C that decomposes on site are reported in Forest Land. 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 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), for the first time in this submission. 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.

Calculations of direct and indirect soil N_2O emissions from net soil organic carbon (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 in 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 the entire managed forests of Canada 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 2020 submission (covering the entire 1990–2018 time series). Confidence intervals are obtained for each inventory year by randomly sampling 10 000 combinations of all the project runs for that year. Separate uncertainty estimates are produced for each gas. In years where there are not substantial changes, such as in this submission, no comprehensive uncertainty analysis using Monte Carlo simulation is performed. 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 uncertain range of the CO_2 estimates is 77 Mt in 1990, 83 Mt in 2005 and 84 Mt in 2018 (Table 6–6). On average, uncertainty was ±58 Mt of the median result from 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 A3.5.2.7 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 global uncertainty estimates of the Forest Land Category.

Time-Series Consistency

All estimates have been developed in a consistent manner, but some sources of activity data do not provide full coverage for the entire reporting period. Estimates of wildfire areas burned in the managed forest for the 1990–2003 period were derived from the Canadian National Fire Database (CNFDB),[7] which comprises information from provincial resource management agencies, compiled and updated by the Canadian Forest Service. Estimates of area burned for the period 2004–2018 were obtained from the National Burned Area Composite (NBAC).[8] This composite of data is derived from various remote sensing sources, monitoring data collected by provincial resource management agencies, and a rule set that, for each fire, identifies the most accurate available data source. An analysis of the period of overlap in the data shows that the differences between the two time series are small

7 http://www.nrcan.gc.ca/node/13159

8 http://www.nrcan.gc.ca/node/13159

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[1] (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
CO_2	1990	- 203	- 270	33	- 192	-5.0
	2005	- 146	- 205	40	- 122	-17
	2018	- 140	- 193	38	- 109	-22
CH_4	1990	0.4	0.3	-23	0.64	59
	2005	0.6	0.5	-17	1.04	80
	2018	0.4	0.3	-24	0.81	126
N_2O	1990	0.2	0.1	-25	0.31	65
	2005	0.3	0.2	-18	0.52	81
	2018	0.2	0.1	-27	0.39	137

Note:

a. Uncertain 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 2018.

and not biased. The processes used to quantify the area burned estimates in NBAC generate improved estimates of the area burned of individual fires, because, in general, more detailed information about unburned areas within the fire perimeter is generated. Individual fire events may thus generate less burned area, but the total number of events included in the NBAC can be higher.

The forest inventory data incorporated in the analyses were not all collected in the same year across the country. Annex 3.5 explains how forest inventory data from various sources were processed to provide complete, coherent and consistent forest data for 1990.

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; an issue logging system identifies each issue and facilitates tracking and managing its resolution. 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 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). Data sets from the NFI of C stocks 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 aboveground biomass, deadwood, litter and mineral soil pools was 7.5%, 30.8%, 9.9% and 8.4%, respectively. The contribution of aboveground biomass and deadwood to the error in ecosystem subtotal pools was small. However, the contribution from soils was large. The error in aboveground biomass and deadwood pools compared favourably to the standards proposed in the IPCC guidelines (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 NIR approach for estimating anthropogenic emissions and removals was reviewed by an international panel of forest scientists convened by Environment and Climate Change Canada 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 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 important recalculations in this reporting category due to a correction in the coefficients used to convert wood volume-to-biomass for certain stand types in forests of Western Canada. Volume-to-biomass conversion parameters were revised following a standard QA/QC procedure. Details on the conversion parameters of merchantable volume to above-ground biomass used for C modelling can be found in Annex 3.5.2.1. These corrections impacted estimates of standing stocks, growth rates and carbon transfers for these specific stands.

Other minor recalculations were due to: i) changes in the CBM-CFS3 executable to address differences in model results when running on Windows10 versus Windows7, and to enhance diagnostics; ii) updates in activity data related to harvest for 2017 and forest conversion activities for 2005–2017; and iii) inclusion of new estimates associated to drainage of forested wetlands.

The combined effect of these changes resulted in a decrease of net removals by 11 Mt (-5.0%), 10 Mt (-6.6%) and 8.2 Mt (-5.4%) in 1990, 2005 and 2017 respectively (see Figure 6–4).

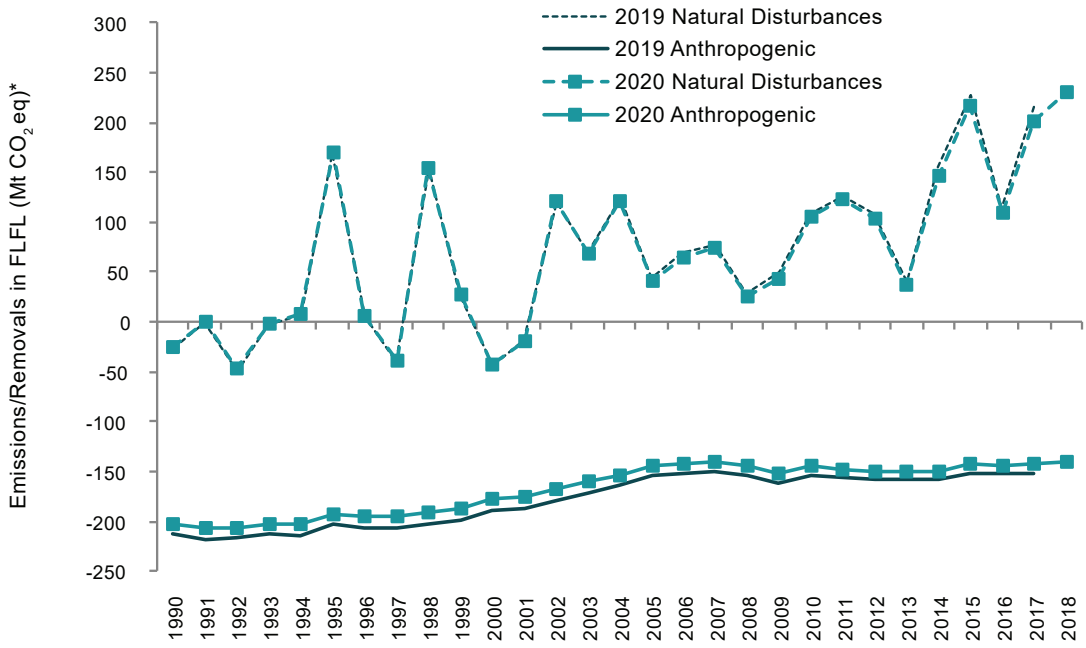
Activity Data Updates

Commercial forestry activities (clear-cut harvesting, commercial thinning and slash burning) for 2017 were updated on the basis of National Forestry Database statistics to replace the estimated activity levels used for 2017 in the 2019 NIR. Residential firewood consumption targets were revised for 2017. Deforestation activity estimates for the 2005–2017 period were revised to capture new data related to mining activities in the reporting zones 14 (Montane Cordillera) and 15 (Pacific Maritime).

6.3.1.6. Planned Improvements

Planned improvements include updates to baseline inputs (data, processes and parameters) such as: i) activity data on fire and insect disturbances and further refinements to certain parameters in the CBM-CFS3 modelling framework, like the volume to biomass coefficients; ii) enhancements to activity data and parameters use to model bioenergy production and; iii) improvements to the modelling of hardwood forests of Eastern Canada to better represent partial harvesting in CBM-CFS3 and validate modelled trends using an independent earth observation (EO)-based validation analyses. 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**



* 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; hence, the category more precisely refers to 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 2018. The trend reflects the gradual transfer of lands afforested more than 20 years ago to the Forest Land remaining Forest Land category and a lack of recent data on rates of forest establishment. Nearly eighty percent 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 15% in the Prairie provinces (Boreal Shield West, Boreal Plains and Subhumid Prairies reporting zones) and the remaining 7.9% in Western Canada (Pacific Maritime and Montane Cordillera).

Net removals declined throughout the period, from 1.1 Mt in 1990 to 0.3 Mt in 2018. Net C accumulation largely occurs in biomass (77 Gg C in 2018—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, the subcategory 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

The Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative collected and compiled afforestation records for 1990–2002 (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). No new afforestation activity data were collected for the 2009–2018 inventory years.

GHG emissions and removals on lands newly converted to Forest Land were estimated using CBM-CFS3, as described in Annex 3.5. 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 scale 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 and entered into the CRF reporter.

6.3.2.5. Recalculations

There were no recalculations for this source category.

6.3.2.6. Planned Improvements

There is currently limited access to information on afforestation activity, but efforts are underway to obtain 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.

6.4. Harvested Wood Products (CRF Category 4.G)

6.4.1. Source Category Description

The Harvested Wood Products category is reported following 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 from it in that the HWP pool is treated as a C transfer related to forest harvest and hence does not assume instant oxidation of wood in the year of harvest (more details provided in Annex 3.5).

Emissions associated with this category result from the use and disposal of HWP manufactured from wood coming from forest harvest and forest conversion 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 mainly influenced by the trend in forest harvest rates and the long-term impact of harvest levels starting in the year that C begins to be stored in a pool of HWP that are in use. As a result, emissions fluctuated between 120 Mt in 2009 (lowest harvest year) and a peak of 150 Mt in 1995. In 2018, HWP amounted to total emissions of 130 Mt, similar to 1990 (Table 6–7).

Harvested Wood Products emissions are inextricably linked to emissions/removals from Forest Land, such that the sum of net emissions/removals from Forest Land and emissions from HWP provides an estimate of total net emissions/removals from the managed forest (Figure 6–2).

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 or forest conversion. The model tracks

Table 6–7 **Carbon Stocks in the HWP Pool and Emissions Resulting from Their Use and Disposal**

Source Subcategories / Commodities	1990	2005	2013	2014	2015	2016	2017	2018
Carbon Stocks (Mt C)[a]								
Inputs	48	58	45	44	46	46	46	46
Conventional Harvest[b]	40	51	38	38	39	40	40	40
Forest Conversion[b]	1.7	1.2	1.2	1.1	1.0	1.1	0.9	0.9
Residential Firewood[c]	6.9	5.2	5.4	5.4	5.4	5.4	5.4	5.4
Exports	19	31	21	21	21	21	21	21
Net Stocks[d]	330	520	570	570	580	590	590	600
Emissions (Mt CO_2)[a]	**130**	**140**	**130**	**130**	**130**	**130**	**130**	**130**
Domestic Harvest	85	67	66	65	65	66	67	66
Solid Wood—Sawnwood	5.4	5.7	6.4	6.5	6.5	6.6	6.8	6.9
Solid Wood—Wood Panels	2.7	3.2	4.0	4.0	4.1	4.2	4.3	4.4
Other Solid Wood Products	0.9	1.9	2.2	2.2	2.2	2.2	2.2	2.2
Paper and Market Pulp	8.3	0.7	2.5	2.8	3.0	3.0	2.7	2.6
Firewood—Residential and Industrial	45	50	46	46	46	46	45	45
Mill Residue[e]	23	5.0	4.9	3.9	3.7	3.6	5.8	5.8
Worldwide from Canadian Harvest	42	72	64	64	63	63	62	62
Solid Wood—Sawnwood	9.9	16	18	18	18	18	19	19
Solid Wood—Wood Panels	0.8	4.0	5.0	5.1	5.2	5.4	5.5	5.6
Other Solid Wood Products	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Paper and Market Pulp	31	50	39	39	38	37	36	36
Mill Residue[e]	0.5	2.1	2.1	2.0	1.8	1.7	1.7	1.7

Notes:

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 FLFL and in tables 4.B, 4.D and 4.D under subcategories related to Forest Conversion, if using the instant oxidation approach for HWPs. Includes a small proportion of carbon used for residential firewood.

c. Includes only carbon collected for residential firewood from the managed forest, as estimated by the CBM-CFS3 model, and assumed to be burned in the year of harvest. This C would be reported as C losses in CRF table 4.A under FLFL, 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.

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 harvested wood products model takes the C output from harvested wood from the ecosystem model, 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 bioenergy.

Inputs to the model (Table 6–7) include the annual mass of C from conventional contemporary harvest and residential firewood collection in Forest Land and a relatively small amount from forest conversion activities (around 2.4% of all inputs in any year) transferred from the CBM-CFS3 model (see section 6.3.1.2). 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 wood waste are provided by the Energy sector. Residential firewood data come from the 1996, 2006 and 2012 TNS Global/Canadian Facts Surveys, while data on industrial consumption of firewood comes 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.

For the amounts of C associated with volumes of residential firewood provided by the Energy sector, 87% of the total firewood volume is used as input to simulate the harvest of firewood from the managed forest. The remaining 13% of the Energy sector wood volumes comes from post-consumer products (details are provided in Annex 3.5).

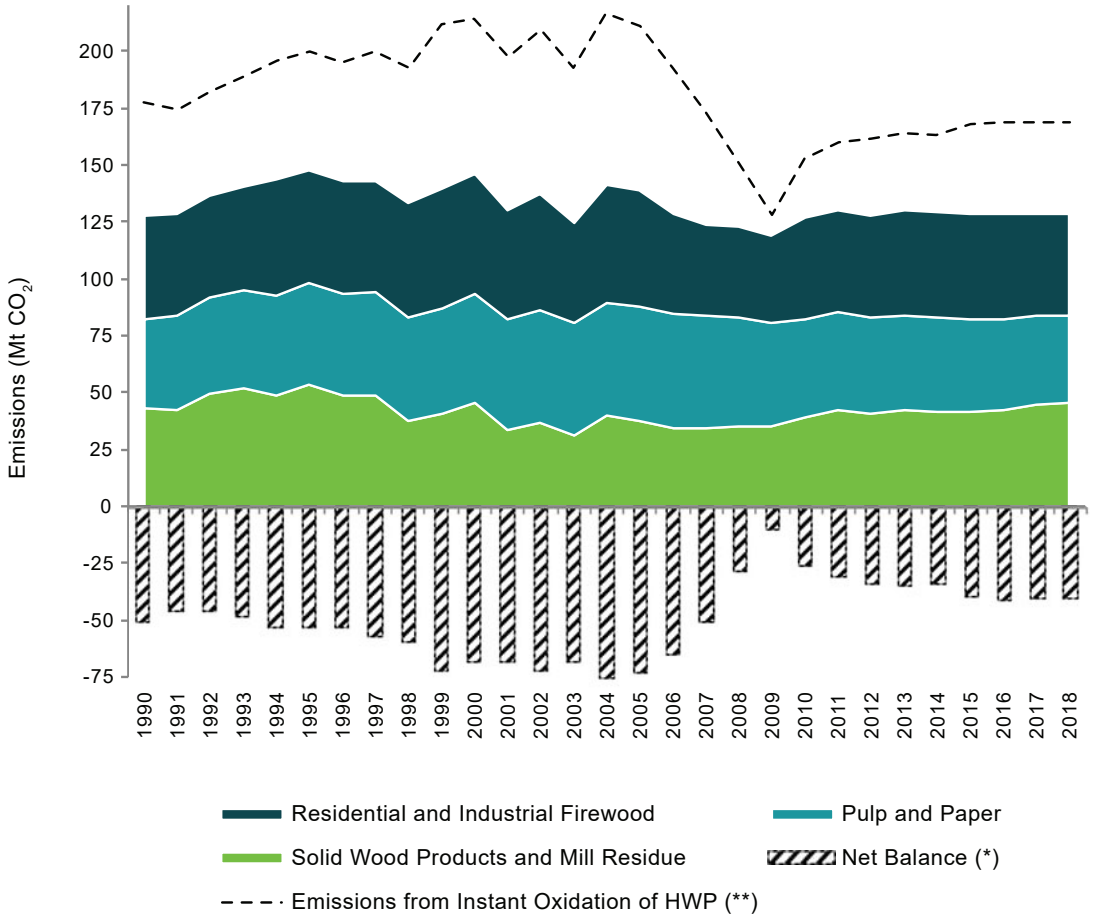
The trend in emissions from HWP disposal results from historical commodity production combined with the duration of the life cycle of various commodities (Table 6–7). The impact of any significant changes in harvest levels or in the mix of products is therefore redistributed over several subsequent years 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: i) 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; ii) 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 Vol, 4, Chapter 12 of the 2006 IPCC Guidelines for HWP with longer half-lives; iii) Column “E”, the 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; iv) Column “F”, for net E/R 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 fluctuating between -46 Mt in 1991 and 1992, and -75 Mt in 2004 (highest harvest year) (bars in Figure 6–5). 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 products that were disposed of in the reporting year. Conversely, 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.

This data series represents the C transferred annually from the forest into the HWP pool in units of CO_2, i.e. the emissions that would result from using an instant oxidation approach, and is presented only for reference purposes. Includes salvage logging after natural disturbances on Forest Land.

Figure 6–5 **Emissions from the HWP Pool Using the Simple Decay Approach**



* 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.

** This data series represents the carbon transferred annually from the forest into the HWP pool in units of CO_2, i.e. the emissions that would result from using an instant oxidation approach, and is presented only for reference purposes. Includes salvage logging after natural disturbances on Forest Land.

6.4.3. Uncertainties and Time-Series Consistency

In the assessment of the uncertainty of HWP, 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). In years where there are not substantial changes, no comprehensive uncertainty analysis using Monte Carlo simulation is performed. Instead, confidence intervals for each category for the current year of submission are extrapolated. More details are provided in Annex 3.5.

6.4.4. Recalculations

There were small recalculations in the HWP category driven by activity data updates for forest harvest, forest conversion and firewood, and by changes implemented in the forest ecosystem model that impacted the amount of C transferred to the HWP pool. As a result, total emissions from HWP were recalculated downward by 0.2 Mt (-0.1%) in 1990, 0.01 Mt (-0.01%) in 2005 and upward by 0.9 Mt (+0.7%) in 2017.

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	50	35	-30	63	26
	Forest Conversion—since 1990	3.0	2.7	-8.7	3.1	5.6
	Residential Firewood Collection	21	21	0.0	21	0.0
	Historical Harvest—before 1990	53	49	-4.5	59	3.4
2005	Conventional Harvest—since 1990	104	94	-9.2	111	7.0
	Forest Conversion—since 1990	3.0	2.7	-10	3.2	6.3
	Residential Firewood Collection	16	16	0.0	16	0.0
	Historical Harvest—before 1990	15	15	-8.9	16	10
2018	Conventional Harvest—since 1990	98	95	-3.0	101	2.8
	Forest Conversion—since 1990	2.6	2.6	-0.8	2.6	0.3
	Residential Firewood Collection	17	17	0.0	17	0.0
	Historical Harvest—before 1990	11	11	-5.6	12	4.3

6.4.5. Planned Improvements

Work is ongoing to improve activity data related to residential firewood harvest and use in Canada. It is likely that some of the residential firewood might come from woody biomass in areas outside the managed forest and outside lands affected by forest conversion. Improvements will be required to better distribute firewood harvest to their appropriate land use. Correction of key industrial firewood parameters and emissions factors being carried out in the Energy sector will likely impact CO_2 emissions from industrial firewood reported in the LULUCF sector in future submissions.

Further areas of research include the incorporation of the effects of wood and paper waste in solid waste disposal sites, the development of country-specific half-lives, the expansion of temporal coverage—which is currently limited by available data—and the development of a better regional representation of commodity production and foreign resolution (addition of more export regions).

6.5. Cropland (CRF Category 4.B)

Cropland covers approximately 47 Mha of the Canadian territory. In 2018, the net GHG balance in the Cropland category amounted to removals of 6.2 Mt (Table 6–1). For the purpose of reporting under the UNFCCC, Cropland is divided into Cropland remaining Cropland (net removals of 8.8 Mt in 2018) and Land (either forest or grassland) converted to Cropland (net emissions of 2.4 Mt and 0.3 Mt, respectively, in 2018). 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 Semi-arid Prairies, Subhumid Prairies and Boreal Plains reporting zones. Another 12% of cropland is found in the Mixedwood Plains reporting zone.

Cropland remaining Cropland 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 a forest. An enhanced Tier 2 approach is used for estimating CO_2 emissions from and removals by mineral soils triggered by changes in land management practices.

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 a net CO_2 removal of 1.2 Mt (Table 6–9). The soil C sink steadily increased to 16 Mt in 2006 and subsequently gradually decreased to 8.6 Mt in 2018. The increasing trend in removals in the first 17 years partly reflects the 95% reduction in summerfallow area from 1990 to 2018 and increased conservation tillage (from 11 Mha in 1990 to 28 Mha in 2018) (Campbell et al. 1996; Janzen et al. 1998; McConkey et al. 2003). Furthermore, the proportion of perennial crops to annual crops has increased since 1990, with the net change in crop mixture resulting in an emission of 2.2 Mt in 1990 and removals of 5.0 Mt in 2006.

Since 2006, however, there has been an increase in the proportion of annual crops in the crop mixture and decreased rates of adoption of conservation tillage. Furthermore, the soil sink from past management changes is approaching a steady state where organic C additions to the soil are balanced by losses of organic C as a result of decomposition. As a result, since 2006 net removals have decreased by roughly 7.0 Mt, mainly driven by the decrease in the proportion of perennial crops in the crop mixture.

Methodological Issues

According to the 2006 IPCC Guidelines, changes in SOC are driven by changes in soil management practices. Where no change in management is detected, 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* 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, such as changes in irrigation, manure application and fertilization, are also known to have positive impacts on SOC. Lack of activity data for these land management changes (LMCs) associated with specific crops prevented their inclusion in the inventory at this time. 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; and
- change in area of summerfallow.

Carbon emissions and removals were estimated by applying country-specific C emission and removal factors multiplied by the relevant area of land that underwent a management change. 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 LMC.

The impact of LMC 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 *Census of Agriculture* for estimates of areas of LMC (i.e. changes in tillage, types of crop and fallow)

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	2013	2014	2015	2016	2017	2018
Total Cropland remaining Cropland		**-1 300**	**-15 000**	**-13 000**	**-12 000**	**-11 000**	**-10 000**	**-9 700**	**-8 800**
Cultivation of histosols		**300**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Perennial woody crops		**- 410**	**- 450**	**-470**	**- 470**	**- 470**	**- 480**	**- 500**	**- 520**
Total mineral soils		**-1 200**	**-15 000**	**-13 000**	**-12 000**	**-11 000**	**-10 000**	**-9 500**	**-8 600**
Change in crop mixture	Increase in perennial	-4 300	-12 000	-11 000	-11 000	-11 000	-11 000	-11 000	-10 000
	Increase in annual	6 500	7 500	10 000	11 000	12 000	12 000	13 000	13 000
Change in tillage	Conventional to reduced	- 890	-1 100	- 830	- 790	- 760	- 720	- 690	- 660
	Conventional to no-till	- 440	-3 600	-3 800	-3 700	-3 700	-3 600	-3 600	-3 500
	Other	- 0.4	- 860	-1 100	-1 000	-1 000	-1 000	- 980	- 960
Change in summerfallow (SF)	Increase in SF	2 500	2 000	1 600	1 600	1 600	1 500	1 500	1 400
	Decrease in SF	-4 800	-8 500	-9 500	-9 500	-9 600	-9 700	-9 700	-9 800
Land conversion—Residual emissions[b]		170	1 700	1 800	1 800	1 800	1 800	1 700	1 700

Notes:

a. Negative sign indicates removal of CO_2 from the atmosphere.

b. 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.

which are not spatially explicit. The area of LMC was determined individually for 3404 SLC polygons having agricultural activities, each one with an agricultural area in the order of 1000–1 000 000 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 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 situation (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 specific instances, empirical data were used to complement the results of the CENTURY runs.

A more detailed description of methodologies for determining C factors and other key parameters can be found in Annex 3.5.

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 fallow, 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.[9]

The uncertainties associated with C change factors for fallow, 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. 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. However, a complete evaluation of uncertainty will not be carried out until significant changes are incorporated in the estimate methodology.

Consistency in the CO_2 estimates is ensured through the use of the same methodology for the entire time series of estimates (1990–2018).

Quality Assurance / Quality Control and Verification

Tier 1 QC checks implemented by Agriculture and Agri-Food Canada (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 and entered into the CRF reporter. In addition, the activity data, methodologies and changes are documented and archived in both paper and electronic form.

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 tillage were highly variable, particularly for Eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. For the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, and this compared favourably with the range of 0.46–0.56 Mg C/ha per year in the modelled factors in western Canadian soil zones. 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 per year empirical versus 0.74–0.77 Mg C/ha per year modelled). For conversion of crop fallow to continuous cropping, the modelled rate of C storage obtained (0.33 Mg C/ha per year) was more than twice the average rate of 0.15 ± 0.06 Mg C/ha per year derived from two independent

9 T. Huffman, Agriculture and Agri-Food Canada, personal communication to Brian McConkey, 2007.

assessments of the literature. This difference led to the decision to use empirically based factors for changes in summerfallow in the inventory. More details can be found in Annex 3.5.

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 will be addressed in future method improvement.

Recalculations

The agricultural mineral soil C sink was reduced by 4.3 kt in 2017 relative to what was reported in the 2019 NIR. This minor recalculation is a result of revisions to the EO Adjusted Interpolated *Census of Agriculture* to reconcile differences in crop area reporting between Statistics Canada provincial census data and AAFC's polygon-based area estimates and to fix errors in inventory activity data for fruit trees.

Changes were made in reported residual emissions resulting from Forest Land converted to Cropland for more than 20 years, as an indirect consequence of the random selection algorithms used by the forest ecosystem model to select forest land conversion sites. Changes to site selections slightly modified the total amount of biomass removed and the amount of deadwood and litter decaying on sites attributed to forest land conversion events.

These changes resulted in small decreases in net removals by 16 kt in 1990 and 4.3 kt in 2017, and an increase in net removals by 30 kt in 2005.

Planned Improvements

Improvements to the CENTURY model and the use of alternative models, such as DAYCENT and RothC, are being explored to improve the simulation of Canadian agricultural conditions.

6.5.1.2. CO_2 Emissions from Cultivation of Organic Soils

Category Description

In Canada, cultivated organic soils are defined as the conversion of organic soils to agriculture for 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 per year (IPCC 2006).

Areas of cultivated histosols are not provided by the *Census of Agriculture*; area estimates were based on the expert opinion of soil and crop specialists across Canada (Liang et al. 2004). The total area of cultivated organic soils in Canada (constant for the period 1990–2018) was estimated to be 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 (1990–2018).

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. 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.

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.

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 at 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 (1990–2018).

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

Work has begun to produce a circa 2010 mapping update for trees and shrubs in agricultural regions of Canada to improve the area estimates. Growth parameters for the biomass model will also be subject to review over the medium term.

6.5.2. Land Converted to Cropland (CRF Category 4.B.2)

This subcategory includes the conversion of Forest Land and Grassland to Cropland. Emissions from the conversion of Forest Land to Cropland account for more than 90% of the total annual emissions in this category, which decreased from 9.5 Mt in 1990 to 2.8 Mt in 2018. Emissions from the conversion of Grassland 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 an ongoing but declining practice in Canada, although agriculture remains an important cause of forest conversion (accounting for 36% of forest area conversion in 2018). The cumulative area of Forest Land converted to Cropland as reported in CRF Table 4.B was 1300 kha over the 20 years prior to 1990 and 310 kha over the 20 years prior to 2018. 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 2018, immediate emissions from this year's Forest conversion to Cropland accounted for 0.9 Mt, while residual emissions from events that occurred in the last 20 years accounted for 1.5 Mt.

Methodological Issues—Dead Organic Matter and Biomass Pools

Approximately 90% of emissions originate from the biomass and dead organic matter 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.

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. The soil emissions from Forest Land converted to Cropland 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). 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). Average N change was -5.2%, equivalent to a loss of approximately 0.4 Mg N/ha. For those comparisons where both N and C losses were determined, the corresponding C loss was 19.9 Mg C/ha. 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.

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 Forest Land converted 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 British Columbia) was grassland in the native condition. Hence, Forest Land converted to Cropland has been primarily forests on the fringe of former grassland areas.

The Canadian Soil Information System (CanSIS) 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 breaking 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: (i) logging and burning—immediate emissions from biomass and dead organic matter; (ii) organic matter decay and subsequent CO_2 emissions in the DOM pool; and (iii) net C losses from SOC. Note that 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.

Using the estimation approach, uncertainty estimates were derived independently for the biomass and dead organic matter 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 section 3.5.2.4 of Annex 3.5.

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 3.5.2.4.

Table 6–10 **Uncertainty Associated with CO_2 Emission Components and Non-CO_2 Emissions from Forest Land Converted to Cropland for the 2018 Inventory Year**

Emission Components	Emissions (kt CO_2 eq)	Uncertainty (kt CO_2 eq)
Immediate CO_2 emissions	768	±209
Residual CO_2 emissions from the DOM pool	1 302	±325
Residual CO_2 emissions from the soil pool	194	±120
CH_4 emissions	79	±21
N_2O emissions	47	±10

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 Agriculture and Agri-Food Canada, 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

There were no changes in the area of Forest Land converted to Cropland or the method for estimating emissions from the forest conversion to Cropland. However, changes implemented in the forest ecosystem model indirectly impact the amounts of biomass removed from deforested lands. These changes resulted in adjustments of emission estimates of -140 kt in 1990, -4.2 kt in 2005 and +2.3 kt in 2017.

Planned Improvements

Planned improvements described under section 6.9 will also affect this category.

6.5.2.2. Grassland Converted to Cropland (CRF Category 4.B.2.2)

Conversion of native grassland to Cropland occurs in the Prairie region of the country and generally results in losses of SOC and soil organic N and emissions of CO_2 and N_2O to the atmosphere. Carbon losses from the above-ground or below-ground biomass or DOM upon conversion are insignificant, based on findings from a recent work by Bailey and Liang (2013) on burning of managed grassland in Canada. 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 in 2018 from soils amounted to 270 kt, up from 260 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/kg C (see Annex 3.5).

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.

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 conversion to Cropland. The overall mean and uncertainty associated with emissions due to SOC losses from Grassland conversion to Cropland were estimated to be 219 ± 104 kt for the level uncertainty and -44 ± 21 kt for the trend uncertainty.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2018).

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 slight changes in the area of Grassland converted to Cropland due to updates in the cropland activity data. These changes decreased emission estimates by 5.0 kt in 1990, 1.8 kt in 2005 and increased by 39 kt in 2018.

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)

Agricultural grassland 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 (i.e. the land has never been cultivated). It occurs only in geographical areas where the grassland would not naturally grow into forest if abandoned, i.e. 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: Semi-arid Prairies (6.3 Mha), Montane Cordillera (87 ha) and Pacific Maritime (5 ha). As with Cropland, the change in management triggers a change in 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. The subcategory Land converted to Grassland, within the current definitional framework as explained in section 6.2, is reported as not occurring (Table 6–4).

6.6.1. **Grassland Remaining Grassland** (CRF Category 4.C.1)

6.6.1.1. **Category Description**

Fires sometimes occur on managed grasslands in Canada as 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 of CH_4 (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 (1990–2018).

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.

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 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 (Environment and Climate Change Canada 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 to 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 12 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 1.6 Mt in 2018 (Figure 6–6). 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.

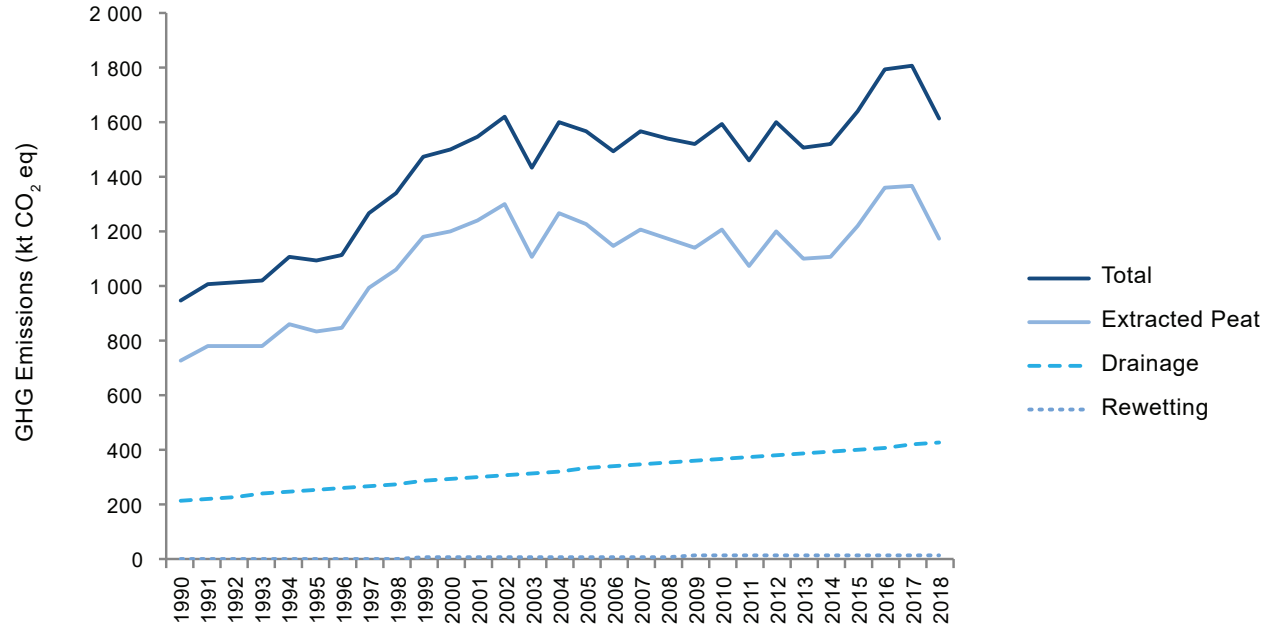
6.7.1.2. Methodological Issues

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). 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: active extraction, abandoned, rehabilitated and restored areas based on image interpretation and industry information. National peat production statistics were used to estimate the annual amount of extracted peat (NRCan 2018a). Emissions from peat extraction are reported under Land converted to Wetlands for the first year after conversion and under Wetlands remaining Wetlands thereafter. More information on estimation methodology can be found in Annex 3.5.

6.7.1.3. Uncertainty and Time-Series Consistency

There was no formal uncertainty assessment 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.

Figure 6–6 **Emissions from Peatlands Converted for Peat Extraction**



6.7.1.4. Quality Assurance / Quality Control and Verification

Section 1.3 in 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 mainly due to updated peat production statistics in 2017 and resulted in a decrease in emissions by 0.2 Mt for that year.

6.7.1.6. Planned Improvements

Refinements in the approach for estimating emissions and removals from non de-commissioned peat extraction sites will 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 Lands (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, 10 and 14 (i.e. Taiga Shield East, Boreal Shield East, Hudson Plains, Boreal 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 2018, 49% of the 41 kha of reservoirs flooded for 10 years or less were previously forested (mostly unmanaged forests). Total emissions from reservoirs declined from 4.4 Mt in 1990 to 1.0 Mt in 2018.

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 carbon pools were estimated as in all forest conversion events, using the CBM-CFS3 (refer to section 6.9 and Annex 3.5). Emissions from the burning and decay of all non-flooded dead organic matter are reported under Land converted to Wetlands for the first 10 years post-clearing and in Wetlands remaining Wetlands beyond this period. The construction of large reservoirs in northern Quebec (Toulnustuc, 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), 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 of this National Inventory Report contains more detail on this estimation methodology. The assessment includes CO_2 emissions only. Emissions from the surface of flooded lands are reported 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 2018.

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 Wetlands and Other Land converted to Wetlands.

It is important to note that fluctuations in the area of lands converted to flooded land (reservoirs) 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 (more than 10 years 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 Wetlands, refer to the corresponding subheading in section 6.9, Forest Conversion. Annex 3.5 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 in 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 Wetlands, 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

There were small recalculations in this source category (+13 kt in 2017) due to the indirect impact on the estimate of quantities of C stocks in lands deforested for hydro-reservoirs after revisions to the CBM-CFS3 (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 dissolved C 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 activity data are updated and validated will continue on an ongoing basis.

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 Lands converted to Settlements. Two types of Land conversion to Settlements were estimated: Forest Land converted to Settlements and Non-forest land converted to Settlements in the Canadian North. In 2018, 0.54 Mha of Lands converted to Settlements accounted for emissions of 5.9 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 4.0 Mt. Estimates are reported for nine of the southernmost reporting zones, where major urban centres are situated. The largest removals in 2018 were in the Mixedwood Plains (1.4 Mt) and Pacific Maritime (1.4 Mt) reporting zones, which together accounted for 70% of total removals.

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 an RU specific crown cover area growth rate (CRW) to yield an annual gross sequestration rate; net sequestration was estimated by applying a factor to the gross value. The CRW values for the 18 RUs (see Table A3.5-11) are derived as described in Steenberg et al. 2019. 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 driver of overall removal estimates. A more detailed description of this estimation methodology can be found in Annex 3.5.

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 (12%) was estimated from the weighted sampling error associated with each RU for the urban tree field data collected in Canada and any proxies used where information was not available. The total uncertainty associated with the estimates of the net CO_2 sequestration of urban trees is 19% for 1990 and 2012. Annex 3.5 provides more information.

The same methodology and coefficients are used for the entire time series of emission estimates (1990–2018).

6.8.1.4. Quality Assurance / Quality Control and Verification

Section 1.3 in 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 major recalculations in this category due to improvements that reflect Canadian-specific carbon sequestration rates instead of using a single US value adjusted only by growing season length for all of Canada. The current rates are derived from Canadian data collected in the field and are more consistent with the characteristics of Canadian urban forests as represented by simulations of the i-Tree model. The effect of these improvements was an annual increase in net removals in all reporting zones, with an increase of 1.5 Mt in 1990 to 1.7 Mt in 2017. The Pacific Maritime reporting zone had the largest increase in removals by 1.0 Mt in 2017 followed by the Atlantic Maritime, Mixedwood Plains and Boreal Shield East with individual increases of nearly 0.2 Mt each. More details are available in Annex 3.5, section A3.5.7.

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.

6.8.2. Land Converted to Settlements (CRF Category 4.E.2)

In 2018, emissions from Land converted to Settlements amounted to 5.9 Mt. While there are potentially several land categories, including forests that have been converted to Settlements, 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 of Forest Land converted to Settlements, as this has been the leading forest conversion type since 2000. On average, during the 1990–2018 period, 25 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.

The remainder of this section covers Non-forest land conversion to Settlements, which includes Grassland to Settlements conversion in the Canadian North as well as Cropland to Settlement conversion occurring in the agricultural regions of Canada.

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 Cropland converted 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. Annual conversion rates were estimated by calculating total areas of land converted between of 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, Montréal 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 Surface products from ArcGIS online services 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 Improvement

Future efforts to develop estimates for this category will focus on estimating emissions associated with the areas of change by determining above-ground biomass during pre-conversion as well as soil C loss.

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 2018, 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). Land-use change areas were estimated based on mapping from image interpretation for the years 1990, 2000 and 2010, as described in Annex 3.5.7.3.

Biomass factors were based on field sampling and cross-checked with values in the literature for the Canadian North (Annex 3.5.7.3).

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 was used to estimate uncertainty for this category. The uncertainty estimate for this category varies between 78% and 87% for the different reporting zones

10 http://www.arcgis.com/home/group.html?id=a74dff13f1be4b2ba7264c3315c57077#overview

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 in 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 Improvement

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

Forest conversion is not a reporting category, since it overlaps with the subcategories of Land converted to Cropland, Land converted to Wetlands, Land converted to Settlements and Harvested Wood Products. 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 2018, Forest Land converted to Cropland, Wetlands and Settlements amounted to total immediate and residual emissions of 11 Mt, down from 18 Mt in 1990. This decline includes a 5.2-Mt decrease in immediate and residual emissions from Forest Land converted to Cropland and a 1.8-Mt decrease in emissions from Forest Land converted to Wetlands (reservoirs). There was also a small decrease of 0.04 Mt in immediate and residual emissions from Forest Land converted 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 amounted to 2.6 Mt in 2018, down from 3.0 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 34 kha in 2018) 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.

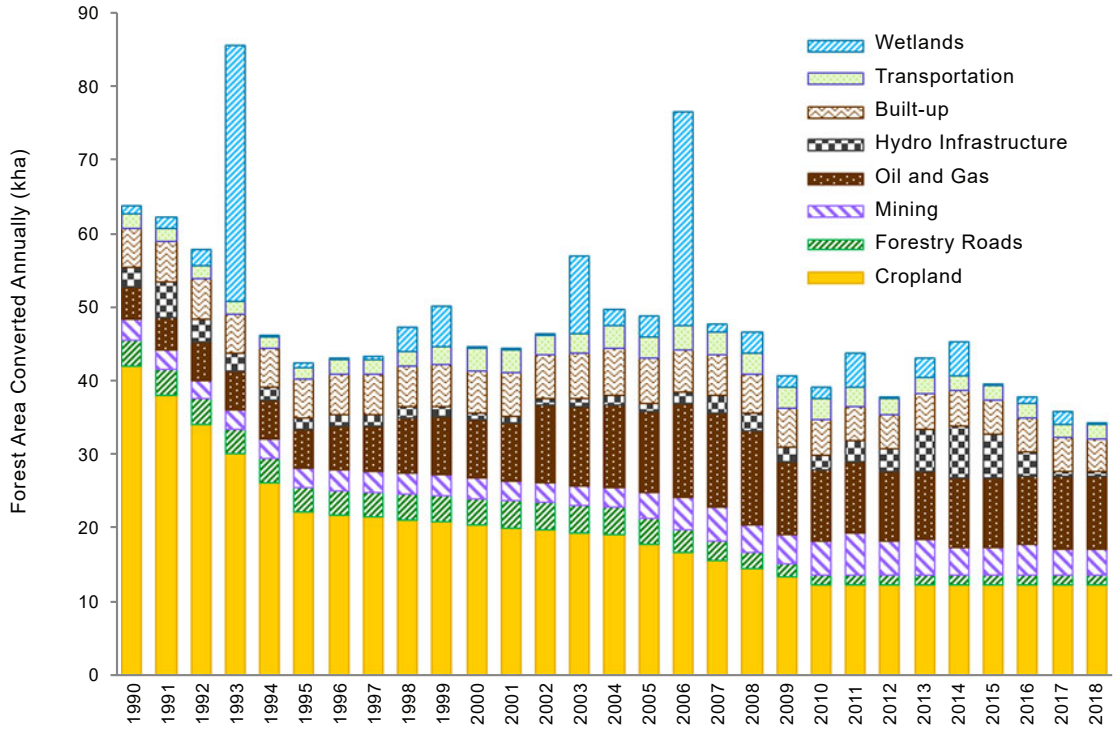
It is also important to note that immediate emissions from forest conversion, which occur upon the conversion event, are only a fraction of the total emissions due to current and previous forest conversion activities reported in any inventory year. In 2018, immediate emissions (2.0 Mt) represented only 18% of the total reported emissions due to forest conversion categories; the balance is accounted for by residual emissions due to current and prior events. Decay rates for dead organic matter 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 40% and 31%, respectively, of the cumulative area of forest conversion since 1990. Annual rates of Forest converted to Cropland show a steady decrease over the 1990–2010 period (Figure 6–7).

Conversely, annual rates of Forest Land converted to Settlements, which comprises forestry roads, mining, oil and gas, hydro infrastructure, transportation and built-up lands, increased from 21 kha in 1990 to 31 kha in 2006 and 2007, and then dropped to 22 kha in 2018 (Figure 6–7). Since 2000, the Settlements category has become the main driver of forest conversion, accounting on average for 60% of the total area converted annually, except for the years 2003 and 2006, when forest was cleared for important hydro development projects (Figure 6–7). This trend is reflective of resource development (e.g. forestry roads, hydro infrastructure, mining, oil and gas, and transportation), especially in the Boreal Plains region, which reached an annual 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 34% of the total forest area lost nationally in 2018.

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 6–7). However, because much of the pre-conversion C stocks are flooded, these episodic events may not release commensurate quantities of greenhouse gases.

Figure 6–7 **Annual Forest Conversion Areas per End Land Use**



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).

6.9.1. Methodological Issues

Forest conversion to other land categories has occurred in the past at high rates, but is a declining 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: systematic or representative sampling of remote sensing imagery, records, and 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.

All estimates of emissions from biomass and dead organic matter pools due to forest conversion were generated using the CBM-CFS3 (section 6.3.1.2), except when forests were flooded without prior clearing. 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 summarizes the estimation procedures.

6.9.2. 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 area for 2018 between 24 kha and 45 kha per year. 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 describes the main sources of uncertainty associated with area estimates derived from remote sensing.

6.9.3. 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 procedures, 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.

6.9.4. Recalculations

There were minor recalculations in forest conversion resulting in an overall net decrease of 11 kha in the estimated areas undergoing conversion for the 2005–2017 period. Most of the changes were due to updates in activity data related to mining in the reporting zones 14 (Montane Cordillera) and 15 (Pacific Maritime). In addition, changes implemented in the forest ecosystem model indirectly impacted the amounts of biomass removed from deforested lands. The combined effect of these changes resulted in small recalculations in the total, immediate and residual emissions from this source, ranging from -0.4 Mt in 1994 to +0.1 Mt in 2011.

Recalculations for the pre-2005 years were around 1% and were inherent in the random selection of forest stands by the forest ecosystem model algorithms, which resulted in modifications in the estimated amounts of biomass removed during conversion events and the amount of deadwood and litter decaying on deforested sites (see section 6.3.1.5 for further details).

6.9.5. Planned Improvements

The development of mapping data for forest conversion is ongoing, and a new anchor point started to be integrated into the forest conversion time series in this submission. Its integration will continue in upcoming submissions. Work is ongoing on processing Landsat and Sentinel imagery over Canada for the new mapping period 2013–2018. The medium- to long-term plan includes the review of 1970–2004 time series of deforestation areas as required resources become available.

CHAPTER 7

WASTE (CRF SECTOR 5)

7.1. Overview

The Waste sector in Canada includes emissions from the treatment and disposal of wastes, including solid waste disposal, composting and biological treatment of 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 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 2018, the greenhouse gas (GHG) emissions from the Waste sector contributed 17.7 Mt to total national emissions, compared with 20.7 Mt for 1990—a decrease of 3.1 Mt or 14.8% (Table 7–1). The emissions from this sector represented 3.4% and 3.5% of the overall Canadian GHG emissions in 1990 and 2018, respectively.

The chief contributor to the Waste sector emissions municipal solid waste disposal landfills, which, in 2018, amounted to 12.3 Mt CO_2 eq or 70% 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). The changes in methodology in the Waste sector are an updated degradable organic carbon content of landfilled waste and the separation of industrial wood waste landfilled to a new category (leaving municipal solid waste the sole component of the solid waste disposal category). 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 Emission Summary, Selected Years**

GHG Source Category	GHG Emissions (Mt CO2 eq)					
	1990	2005	2015	2016	2017	2018
Waste	20.7	19.9	18.0	18.0	17.9	17.7
Biological Treatment of Solid Waste	0.1	0.3	0.5	0.4	0.4	0.4
Incineration and Open Burning of Waste	0.5	0.6	0.4	0.4	0.4	0.4
Industrial Wood Waste Landfills	3.8	4.3	3.6	3.5	3.5	3.4
Solid Waste Disposal	15.4	13.7	12.3	12.4	12.5	12.3
Wastewater Treatment and Discharge	0.9	1.0	1.2	1.1	1.1	1.1

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	1993	1998	2005	2010	2015	2016	2017
Biological Treatment of Solid Waste								
Previous (2019) inventory submission	0.06	0.06	0.13	0.29	0.38	0.45	0.45	0.45
Current (2020) inventory submission	0.06	0.06	0.13	0.29	0.38	0.45	0.45	0.45
Net change in emissions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Incineration and Open Burning of Waste								
Previous (2019) inventory submission	0.48	0.56	0.63	0.62	0.48	0.44	0.43	0.43
Current (2020) inventory submission	0.47	0.55	0.61	0.58	0.45	0.40	0.39	0.39
Net change in emissions	0.00	-0.01	-0.02	-0.04	-0.03	-0.04	-0.04	-0.04
Industrial Wood Waste Landfills								
Previous (2019) inventory submission								
Current (2020) inventory submission	3.85	4.21	4.44	4.28	3.98	3.62	3.55	3.47
Net change in emissions								
Solid Waste Disposal								
Previous (2019) inventory submission	17.90	17.66	17.85	18.27	16.45	16.73	16.66	16.70
Current (2020) inventory submission	15.42	15.37	11.44	13.74	11.25	12.32	12.43	12.49
Net change in emissions	-2.48	-2.29	-6.41	-4.53	-5.21	-4.41	-4.22	-4.21
Wastewater Treatment and Discharge								
Previous (2019) inventory submission	0.85	0.88	0.93	0.99	1.09	1.17	1.18	1.19
Current (2020) inventory submission	0.92	0.92	0.96	1.00	1.11	1.15	1.14	1.13
Net change in emissions	0.06	0.04	0.03	0.01	0.02	-0.01	-0.03	-0.06

Note:
Totals may not add up due to rounding.

7.2. Solid Waste Disposal (CRF Category 5.A.1)

7.2.1. Source Category Description

The Solid Waste Disposal category measures CH_4 emissions from municipal solid waste (MSW) landfills. In Canada, most waste disposal occurs in managed municipal landfills. In previous inventories, the Solid Waste Disposal category included both industrial wood waste disposal and municipal solid waste disposal. Industrial wood waste is now reported as a separate category (section 7.3). MSW landfills accept waste from residential sources, industrial, commercial, institutional sources and construction and demolition waste.

Very 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 organics bans on landfilled waste, or per capita waste generation goals.

Emissions from waste disposal are generated by the anaerobic decomposition of buried organic waste in the landfill. While CO_2 is also produced, it is of biogenic origin and is therefore not reportable under this sector. Emissions of N_2O are considered negligible.

Municipal solid waste disposal is the dominant contributor of emissions from the Waste sector. This category represents 75% of the waste sector emissions in 1990, 69% in 2005 and 70% of waste sector emissions in 2018 (Table 7–1).

Factors influencing emissions from MSW landfills over time include population growth and waste management practices. As population increases, more waste is generated. However, waste diversion practices as well as landfill gas capture by landfill facilities have been increasing over time, and offset the amount of methane ultimately released from landfills.

7.2.2. Methodological Issues

Waste disposal emissions in Canada are estimated using the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) first-order decay (FOD) methodology. The same method, but different parameters are used for (municipal) 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).

Landfilling of MSW waste is a common practice across Canada, and as a result, there are numerous landfills of varying sizes across the country. However, 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. Data for all provinces and territories are available as far back as 1941, and so the FOD model is run for all years 1941–present.

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, and it is assumed that precipitation is the major factor affecting moisture content within the landfill. While there are a number of other factors affecting CH_4 generation in landfills, such as pH, nutrient availability and temperature, they are not represented in the model. It is assumed that these factors have a minor influence on generation rates in comparison with waste composition and moisture.

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 (LFG) capture technology as well as the proportion of CH_4 oxidized in landfill covers is accounted for. Landfill gas capture on managed landfill sites is an increasingly popular activity in Canada. LFG 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 LFG 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 in the range of -35% to +40%. This uncertainty range closely resembles the uncertainty range of -40% to +35% estimated in a study on CH_4 emissions from MSW landfills (ICF Consulting 2004), which was largely influenced by the uncertainty in the CH_4 generation rate constant k, which was based on an estimate from one expert elicitation.

The estimates are calculated in a consistent manner over time.

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

Emission estimations from MSW landfills were recalculated over the 1990–2017 time-series to account for the following:

- Landfill gas capture data were recompiled for the entire time series of 1990–2018. A number of errors were corrected to historical years, and the latest survey data were incorporated for more recent years.
- Extrapolation of landfill gas flared, for each facility, was limited to the period in which either landfill gas capture or flaring were reported to be occurring or the earliest recorded value of landfill gas flaring for that facility. This limited how far back in time flaring is extrapolated for many facilities.
- Extrapolation of landfill gas utilization for energy, for each facility, was limited to the period in which landfill gas utilization is reported to be occurring or the earliest recorded value of landfill gas utilization for that facility. Similar to the recalculations for flaring, this limited how far back in time flaring is extrapolated for many facilities.
- New and updated activity data for 2016, 2017 and 2018 yielded updated landfill gas recovery (flaring and utilization) for those years.
- New waste characterization data, which informs the degradable organic carbon (DOC) of the MSW waste landfilled. DOC values change over time as waste disposal habits and waste diversion strategies change. The new DOC values are applied

from 2015 to 2018. The DOC values previously applied to the 2008–2017 period are now applied to 2002–2014, which reflects the time-period of waste characterization data used for that data-point.

- Industrial wood waste landfills were separated into a distinct category. No recalculations or changes occurred to the emissions values for industrial wood waste, other than its reallocation.

Recalculations, including removal of industrial wood waste to a new category, resulted in a decrease in the solid waste disposal category of 2.5 Mt (14%) in 1990, 4.5 Mt (25%) in 2005 and a 4.2 Mt in 2017, relative to previous submissions. Most of this decrease is due to the reallocation of industrial wood waste (section 7.3).

For comparison to the previous inventory submission, the combined solid waste disposal and industrial wood waste landfilling emissions (previously both under solid waste disposal) are 8% higher in 1990 (1.3 Mt) compared to previous, 1% lower in 2005 (0.2 Mt) and 4% lower (0.7 Mt) in 2017. These changes are solely driven by updates and recalculations in the municipal solid waste disposal category. No recalculations or method changes took place for industrial wood waste other than moving it to a separate category (see section 7.3).

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 Disposal (CRF Category 5.A)

7.3.1. Source Category Description

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 sludges. 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 20% (3,8 Mt) of the emissions from landfilling in 1990, 24% (4.2 Mt) in 2005, and 22% (3.4 Mt) in 2018.

7.3.2. Methodological Issues

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. More recently, the vast majority of wood waste is attributed to Quebec and British Columbia.

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 if 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

Previously, emissions from wood waste landfills were grouped with municipal solid waste landfills. The emissions values for wood waste landfills have not changed relative to previous submissions.

7.3.4. Uncertainties and Time-Series Consistency

The level of uncertainty associated with CH_4 emissions from MSW and wood waste landfills combined was estimated to be in the range of -35% to +40%. This uncertainty range closely resembles the uncertainty range of -40% to +35% estimated in a study on CH_4 emissions from MSW landfills (ICF Consulting 2004), which was largely influenced by the uncertainty in the CH_4 generation rate constant k, which was based on an estimate from one expert elicitation.

Although the uncertainty range for wood waste landfills was significantly higher (i.e. -60% to +190%) than that for MSW landfills, its contribution to the uncertainty in the key category was much lower, owing to its relatively low contribution of emissions (i.e. approximately 10%). The uncertainty estimate for wood waste landfills was largely influenced by the CH_4 generation rate, carbon content of the waste landfilled, and biodegradable fraction of the waste.

7.3.5. Planned Improvements

The amount of wood waste landfilled at industrial wood waste landfill sites each year is under review. Several anecdotal reports have indicated that the practice of wood waste landfilling is lower than expected for the reasons described in 7.3.2. These reports and other information will be synthesized in a comprehensive review in order to make a future update.

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). While current emissions from anaerobic digestion of food, garden and park waste in Canada are considered insignificant, the number of anaerobic digesters under construction and in operation is growing, especially in farming operations and municipalities.

In 2018, the Biological Treatment of Solid Waste category contributed 445 kt of CO_2 eq or 2.5% of total emissions to the Waste sector and 0.06% to Canada's total. Emissions were 390 kt (700%) above the 1990 levels of 55 kt.

7.4.2. Methodological Issues

The estimation of CH_4 and N_2O emissions from the biological treatment of solid waste in Canada is carried out by using a Tier 1 method since country-specific emission factors have not been developed and only minimal composting activity data are available. Default equations and emission factors from the IPCC 2006 Guidelines (IPCC 2006) are applied to the quantities of provincial/territorial organic waste diverted (see Annex A3.6.2 for more information). These data are available from Statistics Canada's *Waste Management Industry Survey: Business and Government Sectors* (CANSIM 153-0043) (Statistics Canada, no date [b]) on a biennial basis, for the years 1998 to 2014. The amount of organic waste diverted is assumed to be entirely directed to composting activities in Canada since more detailed information on biological treatment methods is not available at this time.

Some gaps exist in the Statistics Canada data, including a lack of data prior to the year 1998, a lack of data for alternating years between 1998 and 2016 due to the biennial survey schedule, and suppressed data points for certain provinces/territories in the study's time series. Several methods are used to bridge these gaps, including extrapolating a data point from the last known two data points, averaging the known data points for the year before with the year after and, in the case of one province and two territories, using data supplied directly by regional waste representatives on the quantities of waste composted in their jurisdictions. One additional gap potentially exists with the Statistics Canada data in that some large private-sector industrial composting facilities that use composting feedstock other than MSW may have been excluded from the survey.

Presently, greenhouse gas emissions from anaerobic digestion of solid waste at biogas facilities are not estimated for Canada. There are five large anaerobic digesters known to be operating in Canada that process source-separated organics from municipal and commercial waste streams. The likely level of emissions from these identified facilities is 7 kt CO_2 eq or 0.001% of the total national emissions. This is less than 0.05% of total emissions and less than the 500 kt threshold as specified in paragraph 37(b) of the UNFCCC Annex I Inventory Reporting guidelines. As this emission value can be considered representative for all years, this source can be considered insignificant.

More information on the current method used to estimate emissions from the Biological Treatment of Solid Waste category can be found in Annex A3.6.2.

7.4.3. Uncertainties and Time-Series Consistency

The combined uncertainties for emissions of CH_4 and N_2O from composting were each calculated as 165% after correction factors were applied for lognormal distribution and high uncertainty as per the 2006 IPCC Guidelines (IPCC 2006), Volume 1,

Chapter 3, Equation 3.3. Emission factor uncertainty is defined as the range of default values set out in the 2006 IPCC Guidelines (IPCC 2006), Volume 5, Chapter 4, Table 4.1.

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 extrapolate, average or otherwise derive activity data to bridge gaps in the time series;
- inputted emission factors; and
- unit conversions and emission calculations.

The final activity data and emission trends were plotted to identify any outliers. The recalculated emission estimates were also compared with the previous inventory's estimates to ensure that the changes in emission levels made sense.

7.4.5. Recalculations

No significant recalculations were made for this subcategory.

7.4.6. Planned Improvements

Opportunities for acquiring more refined data on the amounts of waste being composted and/or anaerobically digested in the provinces and territories will continue to be investigated. Increased collaboration with provincial and other regional authorities may result in a more complete data set and higher quality data that could be used to improve or verify the current emission estimates. In addition, emission estimates from anaerobic digestion of waste will be periodically reviewed to ensure that the levels remain less than 0.05% of total emissions and less than the 500 kt threshold as specified in paragraph 37(b) of the UNFCCC Annex I Inventory Reporting guidelines.

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 municipal solid waste (MSW), hazardous wastes, sewage sludge and 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. Also, incineration can be used for energy recovery from waste. GHG emissions from Open Burning are assumed negligible, representing less than the reporting threshold of 500 kt CO_2 eq and 0.05% of national GHG total emissions.

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.

The Incineration and Open Burning of Waste category contributed 393 kt CO_2 eq (11.5%) of total emissions to the Waste sector or 0.06% of Canada's total emissions in 2018. Emissions from the Incineration and Open Burning of Waste category are -16.5% below the 1990 level of 471 kt CO_2 eq.

7.5.1.1. MSW Incineration

Incineration of municipal solid waste 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 waste.

Emissions from MSW 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 plastics and rubber. Both CH_4 and N_2O emissions are estimated from all incinerated waste.

7.5.1.2. Hazardous Waste Incineration

There are four hazardous waste incinerators in Canada, all located in Ontario and Alberta. CO_2, N_2O and CH_4 emissions are derived from the quantities of hazardous waste incinerated that were provided directly by the facilities in a series of surveys conducted by Environment and Climate Change Canada (ECCC 2018). In accordance with the 2006 IPCC Guidelines, CO_2 emissions from biomass waste combustion are not included in the inventory totals. Both CH_4 and N_2O emissions are estimated from all incinerated waste.

7.5.1.3. Sewage Sludge Incineration

There are two different types of sewage sludge incinerators, multiple hearth and fluidized bed. In Canada it is assumed that all sewage sludge incinerators are of the fluidized bed type. In both types of incinerators, the sewage sludge is partially dewatered prior to incineration. The dewatering is typically done in a centrifuge or using a filter press. GHGs emitted from the incineration of

sewage sludge include CO_2, CH_4, and N_2O, as in the case of MSW incinerators. However, since the carbon present in the wastewater sewage sludge is of biological origin, the CO_2 emissions are not accounted for in the inventory totals from this source. Both CH_4 and N_2O emissions are estimated from all incinerated waste.

7.5.1.4. Clinical Waste Incineration

TwoT major centralized clinical waste incinerators in Canada—located in Ontario and Alberta—accounted for nearly 80% of the greenhouse gas emissions from this source in 2018. The remaining 20% of greenhouse gas emissions are from a number of small hospital-based incinerators and incinerators operated by the Government of Canada. CO_2, N_2O and CH_4 are the greenhouse gases emitted from this source. The amounts of clinical waste incinerated are generated from activity data provided directly by facilities from surveys conducted by Environment and Climate Change Canada (ECCC 2018), as well as additional reports on the topic of interest (Chandler 2006; RWDI AIR Inc. 2014). In accordance with the 2006 IPCC Guidelines, CO_2 emissions from biomass waste combustion are not included in the inventory totals. Both CH_4 and N_2O emissions are estimated from all incinerated waste.

7.5.2. Methodological Issues

The emission estimation methodology depends on waste type and gas emitted. A more detailed discussion of the methodologies is presented in Annex 3.6.

7.5.2.1. MSW Incineration

Given the relatively small number of MSW incinerators in Canada, emissions from incineration can be estimated at the facility level. Most facilities 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 the vast majority 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.

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.

7.5.2.2. Hazardous Waste Incineration

CO_2 emissions were estimated from the quantities of hazardous waste combusted over the 1990–2018 time series. The emission estimation method used the IPCC default values for carbon content of waste and fossil carbon as a percentage of total carbon of 50% and 90%, respectively, for hazardous waste (IPCC 2000).

N_2O and CH_4 emissions were estimated from emission factors derived from site-specific data provided by a facility, which were deemed more representative than IPCC default values. Site-specific data consisted of the quantities of hazardous waste processed at the facility and the cumulative measured N_2O and CH_4 emissions for 2009 (Environment Canada 2011).

7.5.2.3. Sewage Sludge Incineration

CO_2 generated from the incineration of sewage sludge is not reported in the inventory emission totals since the sludge consists solely of biogenic matter.

Emissions generated by the incineration of sewage sludge are dependent on the amount of dried solids incinerated. It is assumed that sewage sludge incineration is conducted with fluidized bed incinerators. Therefore, the emission factor is 1.6 t CH_4/kt of total dried solids for fluidized bed sewage incinerators equipped with venture scrubbers. The national emissions were then determined as the summation of emissions for all provinces.

Emissions of N_2O from sewage sludge incineration were estimated using the IPCC default emission factor for fluidized beds, 0.99 kg N_2O/t of dried sewage sludge incinerated (IPCC 2006). To estimate emissions, the emission factor was multiplied by the amount of waste incinerated by each province. The national emissions were then determined as the summation of emissions for all provinces.

7.5.2.4. Clinical Waste Incineration

CO_2 emissions were estimated from the quantities of clinical waste combusted over the 1990–2018 time series. The emission estimation method uses the IPCC default carbon content and fossil carbon percent of total carbon of 60% and 40%, respectively, for clinical waste (IPCC 2006).

Emissions of CH_4 and N_2O from clinical waste incineration were estimated using a Tier 1 method (IPCC 2006). 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.

The available activity data indicated either continuous or batch-type incineration (with no semi-continuously operated incinerators identified). As in the case of MSW incineration, expert judgement was used in assuming that the default stoker-type emission factors were the most representative of the clinical waste incinerators in Canada, due in part to the absence of identified fluidized bed clinical waste incinerators in Canada.

7.5.3. Uncertainties and Time-Series Consistency

The overall level of uncertainty associated with the waste incineration source category was estimated to be in the range of -12% to +65% (ICF Consulting 2004). For 2001 inventory estimates, the overall trend uncertainty associated with the total GHG emissions (comprising CO_2, CH_4 and N_2O) from incineration of waste (comprising MSW and sewage sludge) was estimated to be in the range of about +10% to +11%. The inventory trend uncertainty was estimated at +10%.

The extrapolation of trend uncertainty in 2001 to the 2016 inventory should be made with caution, as the trend uncertainty is more sensitive than level uncertainty to the changes in the inventory estimate values for the more recent years.

Uncertainties about emissions from hazardous waste incineration, clinical waste incineration or N_2O emissions from sewage sludge incineration have been calculated separately using the error propagation approach. The overall level of uncertainty associated with clinical waste incineration is 30% for CO_2 emissions and 107% for CH_4 and N_2O emissions. The overall level uncertainty associated with hazardous waste incineration is 94% for CO_2 emissions and 107% for CH_4 and N_2O emissions. The overall level uncertainty associated with N_2O emissions from sewage sludge incineration is 107%. High uncertainty values were subject to lognormal distribution correction factors in accordance with IPCC 2006 Volume 1, Chapter 3, Equation 3.3.

7.5.4. QA/QC and Verification

The quality control process consisted of a 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

An MSWincinerator previously considered a non-Energy facility was correctly allocated to the Energy sector, reducing emission estimates across the time series reported under MSW incineration. A conversion error for CH_4 was corrected causing a reduction in emissions reported under sewage sludge incineration. The activity data was corrected for clinical, hazardous and sewage sludge incineration resulting in changes in emissions under these subcategories across the time series. The overall result of these updates is a 9% decrease in CO_2 eq emissions in 2017 for the Incineration and Open Burning of Waste category.

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 both domestic and industrial sources is treated in centralized municipal wastewater treatment plants. In rural areas, most wastewater is treated by private and occasionally communal septic systems. 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 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 practised in some coastal regions. Wetland treatment systems, sequence batch reactors, anaerobic lagoons and some other treatment types are also in use in Canada.

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 greater 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. Emissions from anaerobic sludge digestion (fugitive and from the flaring and use of digester gas) are currently not estimated because of a lack of data.

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 contributed 1200 kt CO_2 eq, 6.3% of total emissions to the Waste sector and 0.17% of Canada's total in 2017. Wastewater treatment and discharge emissions in 2017 were 330 kt CO_2 eq (39%) above the 1990 level of 850 kt.

Emissions from wastewater treatment have an increasing trend over time that roughly follows the trend of 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 trend of increasing 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 grams per person per day in 1991 to 69.85 grams 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 IPCC 2006 Guidelines, 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 no date (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 Canada conducts facility-level surveys on a biennial basis to obtain methane 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.

The N_2O emissions are estimated based on nitrogen in the wastewater according to 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 2007, 2008, 2010; 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 -40% to +55% (ICF Consulting 2004). Based on 2001 data, the trend uncertainty associated with total GHG emissions (comprising CH_4 and N_2O) from wastewater treatment systems was estimated to be in the range of about +12% to +13%. The extrapolation of trend uncertainty in 2001 to the 2016 inventory should be made with caution, as trend uncertainty is more sensitive than level uncertainty to the changes in the inventory estimate values for the more recent years.

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 (in Excel). 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

Recalculations for this category involved updates to activity data. This included more information about treatment technology employed at various facilities in the 1990s, more information on smaller facilities, particularly in Alberta, Saskatchewan and Manitoba, better data from the territories and updated data on volumes treated fro 2013 to 2018 and private septic system use from for 2018. These updates resulted in a 7% increase in emissions (0.06 Mt) in 1990, a 1% increase (0.01 Mt) in 2005 and a 5% decrease (0.06 Mt) in 2017 relative to previous inventory submissions.

7.6.6. Planned Improvements

7.6.6.1. Capturing sludge removal

Sludge removal volumes and the associated reduction in CH_4 emissions (organics diverted to sludge rather than emitted as CH_4) are not known. A planned improvement is to determine the volumes of sludge produced and removed from wastewater treatment systems in Canada.

7.6.6.2. Anaerobic sludge digestion as part of wastewater treatment, and CH_4 capture

Emissions from anaerobic reactors and anaerobic digestion of sewage sludge cannot be estimated because of insufficient data. It is assumed that all anaerobic reactors and sludge digesters have CH_4 recovery systems; the effectiveness and efficiency of the CH_4 recovery for anaerobic reactors and sludge digesters systems is unknown, but assumed to be close to 100%. A planned improvement is to determine the number of systems with anaerobic sludge digesters and the volume or mass of sludge digested, and to develop updated estimates of the efficiency of CH_4 capture and recovery.

CHAPTER 8

RECALCULATIONS AND IMPROVEMENTS

Canada's greenhouse gas (GHG) inventory undergoes a continuous process of updates, revisions and improvements to maintain and enhance the completeness, consistency and accuracy of the reported information. Section 8.1 of this chapter provides an overview of the recalculations performed in this year's GHG inventory, including analyses by sector to facilitate an integrated view of changes in, and impacts on, emission levels and trends. A summary of the major inventory improvements that were 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 within the individual chapters for each sector (Chapters 3–7).

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.

As such, recalculations are expected to occur annually for any number of reasons, including the following:

i. Correction of errors detected by quality control procedures;

ii. Incorporation of updates to activity data, including changes in data sources;

iii. Reallocation of activities to different categories (this only affects subtotals);

iv. Refinements of methodologies and emission factors;

v. Inclusion of categories previously not estimated (which improves inventory completeness); and

vi. 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. Overall, recalculations of previously reported 1990–2017 estimates have resulted in relatively minimal changes to national totals (i.e. < 3 Mt in any year) (Figure 8–1).

The trend between 1990 and 2017 is now reported as an 18.3% increase in total GHG emissions since 1990 compared with an 18.9% increase reported in last year's NIR. There is a net downward recalculation of 0.6 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 information for all Intergovernmental Panel on Climate Change (IPCC) sectors (Energy; 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 (1990–2017) (see Table 8–3 for more information).

These revisions are largely due to improved estimation methodologies and updated energy data. For 2017, the revisions that have the most significant changes are in Stationary Combustion (-5.5 Mt), Transport (5.9 Mt) and Agriculture (-1.5 Mt). (See Table 8–2 for more information).

Figure 8–1 **Comparison of Emission Trends (2019 NIR vs 2020 NIR)**

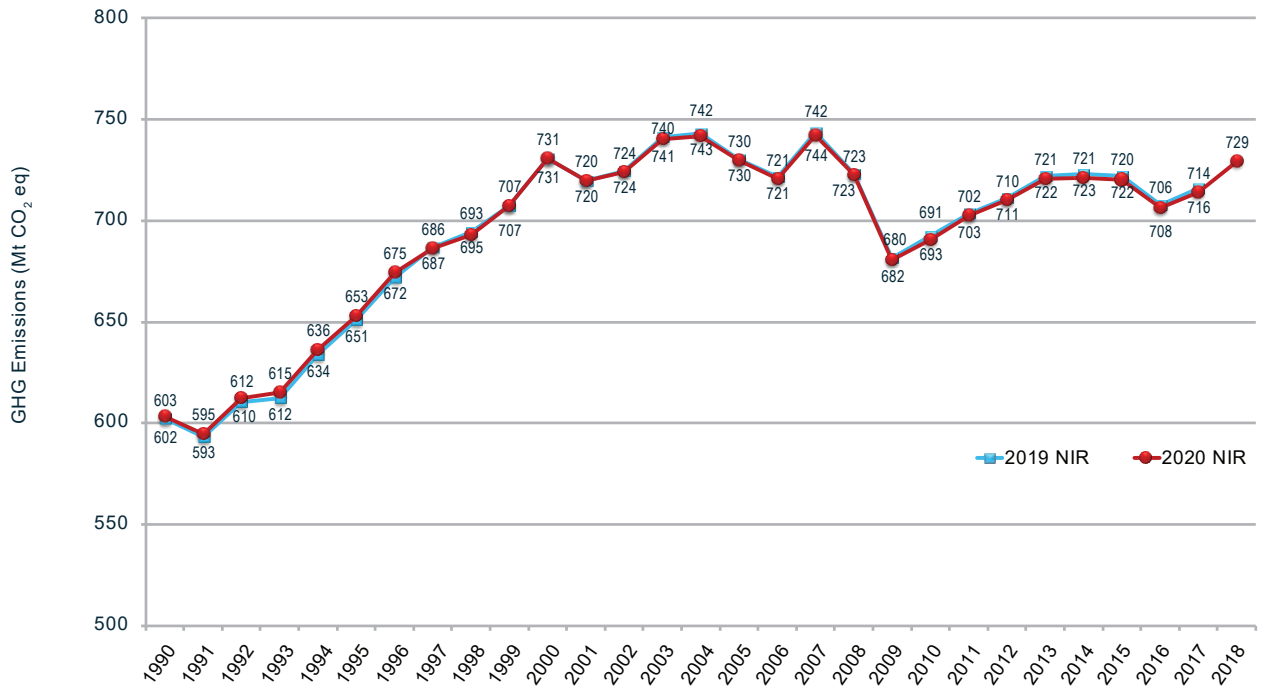


Table 8–1 **Summary of Recalculations in the 2020 National Inventory (excluding Land Use, Land-Use Change and Forestry)**

National Total	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2013	2014	2015	2016	2017	(1990–2017)	(2005–2017)
Previous Submission (2019 NIR)	602 187	730 591	730 361	722 077	723 101	722 001	707 736	715 760	18.9%	-2.0%
Current Submission (2020 NIR)	603 222	730 682	729 746	720 877	721 354	720 378	706 194	713 837	18.3%	-2.2%
Change in total emissions:	1 035	91	-615	-1 200	-1 747	-1 623	-1 542	-1 923	-	-
	0.17%	0.01%	-0.08%	-0.17%	-0.24%	-0.22%	-0.22%	-0.27%	-	-

Table 8–2 **Changes in Canada's GHG emissions from 716 Mt (for 2017, Previous Submission) to 729 Mt (for 2018, Current Submission)**

Sector	2017 to 2018 change (Mt CO_2 eq)	2017 change due to recalculations (Mt CO_2 eq)
Energy (Stationary Combustion)	2.5	-5.5
Energy (Transportation)	9.9	5.9
Energy (Fugitive)	0.1	-0.2
Industrial Processes and Product Use	2.3	0.2
Agriculture	1.0	-1.5
Waste	-0.3	-0.8
Total Change:	**15.5**	**-1.9**

Energy (Stationary Combustion)

With respect to Stationary Combustion emissions, most of the recalculations for 2017 occurred in Oil and Gas Extraction (-4.2 Mt), Petroleum Refining Industries (-2.1 Mt) and Mining (0.8 Mt). The recalculations for Oil and Gas Extraction are due to downward revisions in both producer-consumed natural gas and purchased natural gas. Additionally, revisions to the volumes of flared gas in Saskatchewan and Newfoundland and Labrador, which are subtracted from stationary combustion emission estimates in order to avoid double counting, resulted in a downward recalculation. For Petroleum Refining Industries, the change is a result of restated energy data; in this case, a decrease in refinery fuel gas. Finally, for Mining, increased volumes of heavy fuel oil combusted in Quebec and natural gas in Saskatchewan resulted in an upward revision in calculated emissions.

Minor recalculations to all inventory years also occurred as a result of updated emission factors for the following fuels: lignite, subbituminous and Canadian bituminous coal (CO_2); diesel (CH_4, N_2O); and solid wood waste and spent pulping liquor (CO_2, CH_4 and N_2O). These had a total impact of about 400 kt CO_2 eq on 2017 emissions.

Energy (Transportation)

Notable recalculations for the Transport sector include emissions changes of approximately -2.0 Mt (-1.0%) in 2004 and 5.9 Mt (2.9%) in 2017. The 2004 recalculations are primarily due to the implementation of a consumption-based marine model. This implementation also results in recalculations for the entire time series but to a lesser degree. The 2017 recalculations are mostly updates to preliminary data used in the previous inventory; for Transport, this was mainly a revision to both motor gasoline and diesel fuel volumes.

Energy (Fugitives)

In the Fugitives subsector, Oil and Gas emission recalculations resulted in updated historical estimates for the entire time series. Updated volumes of gas flared in Alberta, Manitoba and Saskatchewan, along with new sources of flaring data for British Columbia and Newfoundland and Labrador, resulted in revisions to emission estimates from 1990 to 2017 (ranging from -0.3 Mt to +0.8 Mt). Updated volumes of non-associated gas production in Alberta from 2014 to 2017 resulted in revisions to fugitive equipment leaks and unreported venting emissions (ranging from +0.1 Mt to +0.3 Mt). The total number of operating wells in Alberta in 2017 was revised downward, causing a decrease in surface casing vent emission estimates (-0.3 Mt). Revisions to abandoned well counts caused small revisions to emission estimates for the entire time series (ranging from +0.002 Mt to +0.012 Mt) while other minor activity data changes resulted in additional minor revisions in 2016 and 2017.

Table 8–3 **Summary of Recalculations by Sector**

	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2013	2014	2015	2016	2017	(1990–2017)	(2005–2017)
ENERGY (Stationary Combustion)										
Previous Submission (2019 NIR)	284 301	352 118	341 790	326 762	331 404	329 916	319 557	326 612	14.9%	-4.4%
Current Submission (2020 NIR)	284 465	352 434	342 017	325 737	329 388	328 382	317 654	321 123	12.9%	-6.1%
Change in Emissions	**164**	**316**	**228**	**-1 025**	**-2 016**	**-1 534**	**-1 904**	**-5 489**	-	-
	-0.1%	**-0.1%**	**-0.1%**	**0.3%**	**0.6%**	**0.5%**	**0.6%**	**1.7%**	-	-
ENERGY (Transportation)										
Previous Submission (2019 NIR)	146 250	178 719	192 109	201 808	200 007	201 957	200 822	201 147	37.5%	4.7%
Current Submission (2020 NIR)	145 239	178 168	190 518	200 892	199 301	201 170	201 149	207 038	42.5%	8.7%
Change in Emissions	**-1 011**	**-551**	**-1 591**	**-916**	**-706**	**-787**	**326**	**5 891**	-	-
	-0.7%	**-0.3%**	**-0.8%**	**-0.5%**	**-0.4%**	**-0.4%**	**0.2%**	**2.9%**	-	-
ENERGY (Fugitive)										
Previous Submission (2019 NIR)	48 840	69 395	60 968	60 793	62 711	60 245	54 923	55 533	13.7%	-8.9%
Current Submission (2020 NIR)	48 955	69 426	60 908	60 674	62 801	60 302	54 876	55 343	13.0%	-9.1%
Change in Emissions	**115**	**30**	**-60**	**-119**	**91**	**57**	**-47**	**-190**	-	-
	0.2%	**0.0%**	**-0.1%**	**-0.2%**	**0.1%**	**0.1%**	**-0.1%**	**-0.3%**	-	-
IPPU										
Previous Submission (2019 NIR)	56 636	53 216	55 571	55 251	52 688	52 931	54 513	53 790	-5.0%	-3.2%
Current Submission (2020 NIR)	56 912	54 005	56 553	56 815	54 736	54 338	55 226	54 015	-5.1%	-4.5%
Change in Emissions	**276**	**789**	**981**	**1 565**	**2 048**	**1 407**	**713**	**226**	-	-
	0.5%	**1.5%**	**1.8%**	**2.8%**	**3.9%**	**2.7%**	**1.3%**	**0.4%**	-	-
AGRICULTURE										
Previous Submission (2019 NIR)	46 876	56 939	59 755	59 215	57 581	58 157	59 212	59 907	27.8%	0.3%
Current Submission (2020 NIR)	46 939	57 021	59 852	59 292	57 646	58 232	59 333	58 382	24.4%	-2.5%
Change in Emissions	**63**	**83**	**97**	**77**	**65**	**75**	**122**	**-1 525**	-	-
	0.1%	**0.1%**	**0.2%**	**0.1%**	**0.1%**	**0.1%**	**0.2%**	**-2.5%**	-	-
WASTE										
Previous Submission (2019 NIR)	19 284	20 203	20 167	18 249	18 709	18 794	18 709	18 771	-2.7%	-6.9%
Current Submission (2020 NIR)	20 711	19 628	19 898	17 467	17 481	17 953	17 957	17 934	-13.4%	-9.9%
Change in Emissions	**1 427**	**-575**	**-269**	**-782**	**-1 228**	**-841**	**-752**	**-837**	-	-
	7.4%	**-2.8%**	**-1.3%**	**-4.3%**	**-6.6%**	**-4.5%**	**-4.0%**	**-4.5%**	-	-
LULUCF										
Previous Submission (2019 NIR)	-68 241	-41 906	-21 267	-32 545	-31 829	-25 138	-25 411	-23 723	-65.2%	11.5%
Current Submission (2020 NIR)	-59 627	-31 791	-12 706	-25 248	-24 721	-18 154	-18 528	-16 414	-72.5%	29.2%
Change in Emissions	**8 615**	**10 115**	**8 561**	**7 297**	**7 108**	**6 984**	**6 883**	**7 309**	-	-
	-12.6%	**-24.1%**	**-40.3%**	**-22.4%**	**-22.3%**	**-27.8%**	**-27.1%**	**-30.8%**	-	-

Industrial Processes and Product Use

There were recalculations for the IPPU sector for all years of the time series (1990–2017), ranging from 0.22 Mt to +2.0 Mt. A large driver of recalculated emission values for the sector is the Product Uses as Substitutes for ODS category, specifically consumption of HFCs. Corrected activity data affected the HFC emission estimates for the years 2005 to 2017. The impact of these corrections ranged from + 0.87 Mt in 2014 to -1.0 Mt in 2017. The addition of two new categories (Other Uses of Urea and Ethylene Oxide Production) also contributed to the sector's overall recalculations (+0.26 to +1.2 Mt, respectively).

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 2015 to 2017 (+0.36 Mt in 2015; +0.44 Mt in 2016 and +0.80 Mt in 2017). For the Iron and Steel Production category, there was also a recalculation in 2017 (of -0.4 Mt) due to a revision of limestone and dolomite use data provided by Statistics Canada.

Other minor recalculations include revised 1991–2017 emission estimates (-0.08 to +0.04 Mt) for the N_2O Use in Medical Applications and in Propellants category due to an update in the estimation methodology (IPCC, 2006) and revised 2010–2017 emission estimates (-0.14 to +0.0036 Mt) for the Magnesium Casting category due to updated activity data obtained from facilities.

Agriculture

Recalculations in the Agriculture sector were due to a new methodology for estimating emissions from biosolid application to agricultural soils and updates to inorganic fertilizer activity data.

For the biosolid estimates, an activity data time series at the provincial scale was developed and used in conjunction with existing country-specific emission factors to estimate emissions for this category, both for direct and indirect N_2O. A detailed description of the implementation can be found in the "Biosolid Nitrogen" subsection of Annex 3.4.5.1. Recalculations also occurred in emissions from inorganic nitrogen fertilizers for the years 2013 to 2017 due to both error correction and alignment with revised survey data. As a result of these recalculations, agricultural emissions were revised upward by 63 kt in 1990 and 97 kt in 2005, and downward by 1.5 Mt in 2017.

Waste

Recalculations in the Waste sector ranged from an increase of 1.9 Mt (10.1%) in 1993 to a decrease of 2.0 Mt (-10.0%) in 1998. The largest driver of recalculated emissions values was municipal solid waste (MSW) landfilling. This sector had corrections to calculation errors in landfill gas methane recovery (from flaring and utilization), which includes more strictly applied limits on extrapolation to the reported time periods in which flaring and utilization were reported to occur at each facility. Updates to the MSW landfill sector were due to the addition of new degradable organic carbon fractions for 2015 to 2018 based on recent waste characterization studies. The recalculations of MSW landfill resulted in both increases and decreases throughout the time series, ranging from an upward revision of 1.9 Mt in 1993 to a downward revision of 1.9 Mt in 1998. Other recalculations in the Waste sector stem from updates to the incineration models and from updated wastewater treatment activity data. For wastewater treatment and discharge, recalculations reflect updated activity data of treatment technology (mostly for the 1990s), inclusion of previously missed facilities and updated treatment volumes – mostly after 2014. These resulted in an upward revision of 0.06 Mt in 1990 and a downward revision of 0.06 Mt in 2017. For incineration, corrections were made to the models, and emissions were reclassified from two energy-from-waste facilities to the Energy sector, but the major driver for revisions within this category was an update to all activity data for the time series based on inputs from the ECCC biennial incineration survey. These resulted in downward revisions ranging from 0.0045 Mt to 0.043 Mt.

Land-Use, Land-Use Change and Forestry

Recalculations also occurred in the estimates of emissions and removals from the LULUCF sector, notably in the Forest Land and Settlements categories. The most important recalculations were due to i.) a correction in the volume-to-biomass coefficients used in modelling forests of the province of British Columbia, ii.) new estimates for the drainage of forested wetlands and iii.) improvements in the estimates of the sink in urban trees. Other less significant recalculations occurred in the Cropland, Wetlands and Harvested Wood Products categories and in land categories associated with forest conversion, mainly as a result of updates in activity data related to harvest, peat extraction and forest conversion activities and as an indirect impact of changes to the forest ecosystem model. The combined impact of these recalculations in the LULUCF sector decreased the estimates of net removals by 8.6 Mt (-13%) for 1990, 8.6 Mt (-40%) for 2005 and 7.3 Mt (-31%) for 2017.

Refer to Table 8–4 for more details on implemented improvements.

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 Methodological Guidance (2006 IPCC Guidelines) or internal continuous improvement activities.

Table 8–4 provides additional information about the improvements implemented this year.

8.2.1. ERT Recommendations

With the exception of 2018, Canada's inventory submission is reviewed annually by an expert review team 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 (ARR) 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: https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/inventory-review-reports/inventory-review-reports-2017.

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

Methodological changes this year that addressed ERT recommendations include the following:

- Updates to the types and numbers of wastewater treatment technologies, and emission factors for the treatment technologies;
- Inclusion of two new emission categories: Ethylene Oxide Production and Other Uses of Urea in the IPPU sector;
- Updated emission factors for PFCs from refrigeration and air conditioning;
- New methodology for estimating emissions from biosolids applied to agricultural soils; and
- GHG estimates from drainage on forest wetlands.

8.2.2. 2006 IPCC Guidelines

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 included:

- Updated N_2O Emissions from Product Use to reflect the approach outline in the 2006 IPCC Guidelines.

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 emission factors for Canadian bituminous, lignite and sub-bituminous coal on a provincial basis;
- Updated diesel emission factors for stationary combustion;

- Updated emission factors for industrial biomass: solid wood waste and spent pulping liquor;
- Integration of a marine consumption-based model;
- Revised volumes of gas flared subtracted from stationary combustion to avoid double counting;
- Updated activity data for volumes of gas flared;
- Refinements to allocation of IPCC sector to Economic sector emission estimates for the Oil and Gas sector;
- Updated SF_6 use data in magnesium casting obtained from voluntary surveys;
- Corrected HFC activity data;
- Update of degradable organic carbon content of municipal solid waste;
- Updated Sequestration rates to urban trees based on direct Canadian sampling; and
- Improvements to Forest Land GHG estimates—revised volume-to-biomass parameters.

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, emission factors 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 2020 NIR**

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Energy (Transportation)	Marine Navigation (1.A.3.d) Fishing (1.A.4.c.iii) Other Mobile (Military Navigation) (1.A.5.b)	Development of a consumption-based marine model.	A fuel consumption-based marine model was integrated into the development of the marine estimates. ECCC used the Marine Emissions Inventory Tool (MEIT) to assist with the provincial allocation of marine emissions. This allows the emissions to be distinguished by vessel class/activity as well as port of origin. MEIT was also used to determine the amonut of fuel used in Canadian waters that was not purchased from a domestic fuel supplier.	Continuous improvement	A3.1.4.2.3
Energy (Combustion)	Public Electricity and Heat Production (CRF 1.A.1.a) Manufacturing Industries and Construction (CRF 1.A.2) Commercial/Institutional (CRF 1.A.4.a) Agriculture/Forestry/ Fisheries (CRF 1.A.4.c)	Updated emission factors for industrial biomass combustion	Updates to emission factors for CH_4 and N_2O from wood / wood waste combustion and spent pulping liquor, using references that are more representative of Canadian conditions. In addition, 0% moisture content (m.c.) was used rather than 50% m.c., which impacts the higher heating value (HHV) used to convert the estimates to energy units. In the case of spent pulping liquor, an updated relationship between HHV and m.c. was used, based on Canadian research. The moisture content changes for both wood and spent pulping liquor were made based on discussions with the industry, which indicated that they report the wood / wood waste and spent pulping liquor consumed to Statistics Canada at 0% m.c., rather than 50% m.c.	Continuous inventory improvement	Annex 6.6.1
	Public Electricity and Heat Production (CRF 1.A.1.a) Petroleum Refining (CRF 1.A.1.b) Manufacture of solid fuels and other energy industries (CRF 1.A.1.c) Manufacturing Industries and Construction (CRF 1.A.2) Commercial/Institutional (CRF 1.A.4.a) Agriculture Forestry/Fisheries (CRF 1.A.4.c)	Updated emissions factors for stationary diesel combustion	New CH_4 and N_2O emission factors for stationary diesel combustion that are more representative of diesel generators in Canada.	Continuous inventory improvement	Annex 6.1.2

Table 8–4 **Improvements to Canada's 2020 NIR** (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
	Public Electricity and Heat Production (CRF 1.A.1.a Manufacture of solid fuels (CRF 1.A.1.c.i Manufacturing Industries and Construction (CRF 1.A.2) Commercial/Institutional (CRF 1.A.4.a) Residential (CRF 1.A.4.b) Agriculture/Forestry/ Fisheries (CRF 1.A.4.c)	Updated emission factors for stationary coal combustion	Updates to CO_2 emission factors for coal combustion with aggregated data from electricity generation facilities and from coal mines. The previous method uses data from either electricity generation facilities or coal mines; however, in certain instances, the coal mine is onsite at the electricity generation facility and using an aggregated data set provides a much larger data set, and provides more coverage throughout the timeseries.	Continuous inventory improvement	Annex 6.1.3
	Commercial/institutional (CRF 1.A.4.a)	Reallocation of energy from medical waste emissions from the Waste Sector to the Energy category where it is consumed	GHG emissions estimates from Medical Waste Incineration (CRF 5.C.1) were reallocated to the Energy sector when the facility was an energy-from-waste operation.	Continuous inventory improvement	Annex 3.6.3
	Oil and Gas Extraction (CRF 1.A.1.c.ii)	Revised volumes of gas flared subtracted from stationary combustion in order to avoid double counting	In order to avoid double counting, volumes of flared gas and associated emissions must be subtracted from Oil and Gas Extraction (CRF 1.A.1.c.ii) since flared volumes are included in Statistics Canada's producer consumption fuel data and flaring emissions are reported in Fugitive Emissions from Fuels—Venting and Flaring—Flaring (CRF 1.B.2.c). The flared gas volumes subtracted for the years 2010 to 2017 in Saskatchewan and 2016 to 2017 in Newfoundland and Labrador were revised based on improved understanding of the data and updated activity data, respectively.	Continuous inventory improvement	Annex 3.2.2.7
Energy (Fugitive Emissions)	Fugitive Emissions from Fuels—Venting and Flaring—Flaring (CRF 1.B.2.c)	Updated activity data for volumes of gas flared	More detailed flaring data was provided by the British Columbia Oil and Gas Commission and the Canada-Newfoundland and Labrador Offshore Petroleum Board. Updated flaring activity data for Saskatchewan, Alberta and Manitoba were also obtained. The new data resulted in revisions to emission estimates for the 1990 to 2017 time period.	Continuous inventory improvement	Annex 3.2.2
Oil and Gas (Economic Sector)	Natural Gas Production and Processing Conventional Light Oil Production Oil Sands (Mining, In-situ, Upgrading)	Refinements to allocation of IPCC sector to Economic sector emission estimates for Oil and Gas sector	Previously, quantities of natural gas used by industrial cogeneration units in the Oil Sands (Mining, In-situ, Upgrading) category were incorrectly allocated to the Natural Gas Production and Processing and Conventional Light Oil Production categories. Refinements to the allocation model corrected this issue.	Continuous inventory improvement	Annex 10
IPPU	Other Uses of Urea (CRF 2.B.1)	Inclusion of estimates of CO_2 emissions from other uses of urea	An assessment was done to determine the significance of CO_2 emissions from other uses of urea. Because the emission source was determined to be "significant" as per the definition provided in the "Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex 1 to the Convention," emission estimates for this category were added to the inventory.	ERT recommendation	Chapter 4
	Ethylene Oxide Production (CRF 2.B.8.d)	Inclusion of CO_2 and CH_4 emission estimates related to the production of ethylene oxide	Production of ethylene oxide is a source of CO_2 and CH_4 emissions that has been added to the inventory.	ERT recommendation	Chapter 4
	Product Uses as Substitutes for ODS—HFCs (CRF 2.F)	Corrections to HFC activity data	Corrected HFC activity data for the years 2008 to 2015 were provided by the Ozone Layer Protection and Export Controls Section of ECCC. These data were used to update HFC emission estimates in the inventory.	Continuous inventory improvement	Chapter 4
	Magnesium Casting (CRF 2.C.4)	Collection of 2014 to 2018 SF_6 use data from magnesium casting facilities	Magnesium casting facilities have been surveyed for their 2014–2018 SF_6 use. The majority of the facilities have responded to the survey. SF_6 use data obtained were used in the inventory.	Continuous inventory improvement	Chapter 4
	Product Uses as Substitutes for ODS—PFCs (CRF 2.F)	Use of 2006 IPCC Guidelines default emission factors	2006 IPCC Guidelines default emission factors have been used to estimate PFC emissions from refrigeration and air conditioning.	ERT recommendation	Chapter 4
Agriculture	Agricultural Soils, Direct N_2O Emissions (CRF 3.D.1) Agricultural Soils, Indirect N_2O Emissions (CRF 3.D.2)	New methodology for estimating emissions from biosolids applied to agricultural soils.	New methodology for estimating nitrogen impacts of the land-application of sewage sludge (a.k.a. biosolids). A provincial activity data time series was developed and combined with existing country-specific emission factors to estimate emissions for this category.	ERT recommendation	A3.4.5.1 A3.4.5.2

Table 8–4 **Improvements to Canada's 2020 NIR** (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
LULUCF	Forest Land remaining Forest Land (CRF 1.A.1)	Improvements to Forest Land GHG estimates	Correction BC volume-to-biomass parameters, and changes in CBM executables (to address differences in model results when running on Windows 10 versus Windows 7, and to enhance diagnostics).	Continuous improvement	6.3.1.5
	Forest Land remaining Forest Land (CRF 1.A.1)	GHG estimates from drainage on forest wetlands	Development of Tier 1 estimates of emissions and removals associated with forest wetland drainage in Canada.	Address ERT recommendation	6.3.1.5
	Settlement remaining Settlement (CRF 4.E.1)	Updated sequestration rates to Canadian values	Sequestration rates were researched and developed for 18 different Canadian reconciliation units that represent Canada's different type of urban trees.	Continuous improvement	A3.5.7.1
Waste	Solid Waste Disposal (5.A)	MSW model updates	Updates include time series modifications to waste volumes and landfill gas collection data based on a review and recompilation of activity data, implementation of new LFG collection data for 2016–2018 and new DOC values from 2015–2018 based on new studies.	Continuous improvement	7.2.5

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 underway
	General	Natural gas fuel composition study. Update carbon and energy content for inventory use.	Canada is a producer, exporter and importer of natural gas, with varying composition across consuming regions. The objective of this project is to determine, develop and collect representative natural gas composition at key delivery points for each consuming province and territory to improve the accuracy of GHG emission estimates.	Continuous improvement	Data collection underway
	Residential (1.A.4.b)	Updated residential biomass combustion activity data.	Work is underway to incorporate new activity data for residential wood combustion, to update the model to use wood density–based ecozones and to develop a consistent method for extrapolating wood use between survey years.	Continuous improvement	Data analysis underway
	Oil and Natural Gas—Fugitive (1.B.2)	More adaptive method of estimating fugitive emissions from Oil and Natural Gas systems.	Work is underway to develop a method to estimate fugitive emissions from the oil and gas industry that more easily facilitates the adoption of new scientific data and properly captures the impact of technological improvements and/or regulations on emissions. The current method is dependent on comprehensive studies that occur approximately every 5 years with emission intensities remaining static between studies. Currently, emissions are estimated for intervening years based on changes to activity data such as production volumes, number of wells drilled, volumes of fuel flared and vented, etc.	Continuous improvement	Alternative methods being considered
	Oil and Natural Gas—Fugitive (1.B.2)	Incorporation of emissions data from accidental venting from well surface casing vents.	The Alberta Energy Regulator (AER) has supplied new data on accidental venting from well surface casing vents, which currently accounts for approximately 13% of all oil and gas fugitive emissions. The current estimation method has high uncertainty while the new data is based on measurements and should increase accuracy and lower uncertainty.	Continuous improvement	Data analysis underway
	Road Transportation (CRF 1.A.3.b)	Review of CH_4 and N_2O emission factors in MOVES.	Comparison of EFs employed in the NIR and MOVES. Since the vehicle characteristics between Canada and the U.S. are made virtually identical through regulation, a review of MOVES emission factors will be done to determine their suitability for future emissions estimates.	Continuous improvement	Literature search underway
	Off-Road Transportation (General)	Inclusion of oil consumption in two-stroke engines.	Include oil consumption of two-stroke gasoline engines and report the emissions in the Energy sector.	ERT recommendation	Literature search underway
	Off-Road Transportation (General)	Off-road sector-specific improvements.	Review of key off-road sectors for potential improvement (e.g., agriculture, recreational boating).	Continuous improvement	Literature search 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 from Total Mining and Oil and Gas Extraction to the various oil and gas industry segments (i.e. Light crude oil production, Natural gas production and processing, Oil sands mining, extraction 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, 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 sub-categories. Additional analysis is being done to refine the allocation of fugitive emissions between conventional heavy oil and primary oil sands production.	Continuous improvement	Data analysis underway
IPPU	Cement Production (CRF 2.A.1)	Update the CFckd correction factor and EFtoc emission factor used in Equation 4-1. Update clinker production capacities.	CFckd correction factor, EFtoc emission factor and clinker production capacities were last updated for 2013. Due to unavailability of data for years 2014-2017, these factors and capacities have been assumed to stay constant at 2013 levels.	Continuous Improvement	No significant progress made
	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.	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 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 originates from the use of reductants other than metallurgical coke; more importantly, 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 sub-category. It is planned to allocate the aforementioned emission to the Iron and Steel Production Category.	ERT recommendation	No significant progress made
	Non-Energy Products from Fuels and Solvent Use (CRF 2.D)	Update emission factors for various non-energy petroleum products and natural gas.	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 emissions factors are still valid and update if necessary.	ERT recommendation	No significant progress made
	Semiconductor Manufacturing (CRF 2.E.1)	Obtain up-to-date SF_6 and NF_3 use data.	Voluntary collection of up-to-date SF_6 and NF_3 use data, covering the reporting years 2014 to 2018, was started in September 2019. Data gathered will be analyzed for potential integration into future NIRs, and the implementation year in the NIR will depend on the findings of the data analyses.	Continuous improvement	Initiated data collection / study
	Product Uses as Substitutes for ODS (PFCs, CRF 2.F)	Obtain up-to-date PFC use data.	Voluntary collection of up-to-date PFC data, covering the reporting years 2014 to 2018, was started in September 2019. Data gathered will be analyzed for potential integration into future NIRs, and the implementation year in the NIR will depend on the findings of the data analyses.	Continuous improvement	Initiated data collection / study
	Product Uses as Substitutes for ODS (HFCs, CRF 2.F)	Develop means to annually update in-item HFC use.	A data gap exists with the in-item data that is 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.	Collect hydrogen production activity data and estimate CO_2 emissions from this source using methods presented in the 2019 Refinements to the 2006 IPCC Guidelines.	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
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.	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	New parameters are under development
	Agricultural Soils (CRF 3.D)	Revision of methodologies for estimating soil nitrous oxide emissions.	A compilation of soil N_2O flux data since 1990 collected mainly through published literature is on-going to identify key factors, including soil properties, climatic conditions, N sources and management practices in explaining N_2O emissions from agricultural soils in Canada, and to re-evaluate the empirical relationship between N_2O emission factors and the growing season precipitation and evapotranspiration.	Continuous improvement	Data analysis underway
	Agricultural Soils (CRF 3.D)	Integrate estimates of N_2O emissions from land application of compost	Canada currently does not report N_2O emissions from the application of compost to agricultural soils, due to a lack of activity data. A contract is underway to collect information on land application of compost in Canada, after which the data will undergo analysis, approval, alignment and integration with the existing organic N fertilizer methodology.	ERT recommendation	Initiated data collection / study
	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 (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 sub-categories 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
	Forest Land Conversion FLCL, FLWL, FLSL (CRF 4.B.2, 4.D.2, 4.E.2)	Land-use change improvements—Update and improve forest conversion activity data, parameters and processes.	Ongoing activities, associated with the addition of a new mapping time period (2013–2018), and medium-to long-term plan to review 1970–2004 time series of deforestation areas that will lead to improved estimates for earlier time periods. In the medium -term, improvements to: i) 1970 to 201X deforestation activity data used by CBM-CFS_3 and others; ii) Northern RU Deforestation Mapping, improved alignment with non-forested northern land-use change; and iii) Update deforestation pre-type proportion assumptions.	Continuous improvement	Data analysis underway

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
	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.	ERT recommendation	Alternative methods being considered
	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 post- 1990 insect disturbances activity data; iii) Refinements to forest management activity data time series; and in the **medium-term** include: iv) Improvements to the spatial distribution of harvest; v) Refinements to wildfire emissions estimates, incorporating variable fire intensity; vi) Refinements to regional estimates of slashburning activity; vii) Updates to volume-to-biomass coefficients for the province of Ontario; viii) Further updates to insect disturbance activity data in certain provinces; and ix) Improvements to nationwide estimates of controlled biomass burning.	Continuous improvement	Data analysis underway
	Forest Land (CRF 4.A)	Bioenergy data improvements.	Improve activity data and model approach to estimate emissions from residential firewood harvest and use in Canada and correction to key industrial firewood parameters and emission factors.	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 / ForCS simulation platform.	Continuous improvement	Data analysis underway
	Forest Land (CRF 4.A)	Validation analysis.	Independent EO-based validation dataset of forest carbon stocks for National Greenhouse Gas inventory in hardwood forests of Eastern Canada.	Continuous improvement	Data analysis underway
	Cropland (CRF 4.B)	Develop methods for estimating changes in soil organic carbon stocks from the addition/removal of crop residues and manure application.	Refine estimates of C & N inputs from crop residues, taking into account crop residue baling based on the Farm Environmental Management Survey (FEMS) by Statistics Canada, and provide estimates of changes in soil organic carbon stocks from the addition/removal of crop residues and manure application.	Continuous improvement	Data analysis underway
	Cropland (CRF 4.B.1)	Improve the estimates of carbon emissions from woody biomass in croplands through additional data points.	A third time-point dataset from 2010 is being added and the estimation procedures are being reviewed to improve the carbon emission estimates at the reporting zone level.	Continuous improvement	Verification and finalization of improvement
	Cropland converted to Settlements (CRF 4.E.2.2)	Address completeness of LULUCF sub-categories with estimates reported as "NE".	Improve the completeness of reporting of pools in mandatory categories currently reported as NE.	UNFCCC ERT recommendation	Initiated data collection / study
	Settlements, Land Converted to Settlements (CRF 4.E.2)	Collection of activity data on Wetland Conversion to Settlements.	Estimates of areas of Wetland Conversion to Industrial Settlements are being conducted in the oil sands region and work will be initiated this year to estimate emissions.	ERT recommendation	Initiated data collection / study
	Settlements remaining Settlements (CRF 4.E.1.1)	Development of a new time series data point for 2020 for urban trees.	Update sampling point is planned for 2020 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	Initiated data collection / study
	Forest Land (CRF 4.A) / Harvested Wood Products (CRF 4.G)	Improve activity data and model approach to estimate emissions from residential firewood harvest.	Work is ongoing to: refine residential firewood consumption rates and develop spatially defined harvest rates for use in CBM modelling, refine disturbance matrices used in the harvest of firewood and carry out data collection and study of production and use of firewood for residential heating in Canada.	Continuous improvement	Verification and finalization of improvement
	Land converted to Forest Land (CRF 4.A.2)	Afforestation activity data.	Integrate recent afforestation activity data update for the province of Ontario.	Continuous improvement	Initiated data collection / study

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
	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. Development of country-specific half-lives, and the expansion of the temporal coverage currently limited by available data.	Continuous improvement	New parameters are under development
	Harvested Wood Products (CRF 4.G)	Improve parameters and emission factors for industrial firewood.	Correction of key industrial firewood parameters and emissions factors being carried out in the Energy sector will impact CO_2 emissions from industrial firewood reported in the LULUCF sector.	Continuous improvement	New parameters are under development
	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 reflect 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)	Estimate long-term emissions from solid waste disposal sites.	Research is ongoing to include the incorporation of the effects of wood and paper waste in solid waste disposal sites, the development of country-specific half-lives, the expansion of temporal coverage—which is currently limited by available data—and the development of a better regional representation of commodity production and foreign resolution (addition of more export regions).	2006 IPCC guidelines / Continuous improvement	No significant progress made
	Wetlands (CRF 4.D	Land-use change improvements.	Carbon loss from wetland soils during Wetland to Settlement conversion in the oil sands region.	Continuous improvement	No significant progress made
	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.	ERT recommendation	Data analysis underway
Waste	Solid Waste Disposal (CRF - 5.A.1)	Updated methane generation rate (k).	Improvements are planned for better spatial and temporal resolution for the methane generation rates (k). Work is also under way to apply k by waste type.	Continuous improvement	Data analysis underway
	Solid Waste Disposal (CRF - 5.A.1)	Model first order decay by waste type.	Currently, the decomposition in landfills is modelled as bulk waste. Waste-characteristics such as degradable organic carbon (DOC) and the fraction of degradable organic carbon that decomposes (DOCf) and the methane generation rate (k) are calculated as single values for bulk waste. Some are weighted averages (DOC) and others are Tier 1 values (DOCf, K). Work is underway to estimated waste disposal by waste type (waste material), and to model decomposition in landfills by waste type.	Continuous improvement	Data analysis underway
	Solid Waste Disposal (CRF - 5.A.1)	Include landfilled sludge.	Currently, there is insufficient data on landfilling of sludge to estimate emissions from the decomposition of landfilled sludge. Efforts are underway to estimate the amount of sludge generated from wastewater treatment, and to estimate the proportion of sludge that is landfilled in Canada.	Continuous improvement	Initiated data collection / study
	Solid Waste Disposal (CRF - 5.A.2)	Update to current volumes of wood waste landfilled and more precision to model parameter specific to industrial wood waste.	Due to changes in industry practices, landfilling of wood waste has been expected to decline for many years. The project will update the last known data point (2004) and make precisions to the model to be more specific to industrial wood waste landfilling.	Continuous Improvement	Initiated data collection / study
	Biological Treatment of Solid Waste (CRF - 5.B)	Further study on composting and anaerobic digestion of solid waste in Canada.	Opportunities for acquiring more refined data on the amounts of waste being composted and 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 dataset and higher quality data which could be used to improve or verify the current emission estimates.	Continuous improvement	Initiated data collection / study
	Wastewater Treatment and Discharge (CRF - 5.D)	Refinements based on sludge removal and review of nitrogen parameters.	An investigation to determine if the wastewater model can be improved by incorporating sludge removal and/or developing improved nitrogen influent and effluent parameters.	Continuous improvement	Data analysis underway

Table 8–5 **Summary of Canada's Inventory Improvement Plan** (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
	Wastewater Treatment and Discharge (CRF - 5.D)	Refinements to include industrial wastewater correction factor "I", for industrial inputs to municipal wastewater treatment.	An investigation to determine if industrial wastewater correction factor "I" for industrial inputs to municipal wastewater treatment should be applied (is applicable in the Canadian context) is underway.	UNFCCC ERT recommendation	Initiated data collection / study
	Wastewater Treatment and Discharge (CRF - 5.D)	Update to industrial on-site wastewater treatment.	Revise and update estimates of emissions from industrial wastewater treatment.	Continuous improvement	Initiated data collection / study
	Wastewater Treatment and Discharge (CRF - 5.D)	Update to N_2O from wastewater treatment to distinguish emissions from centralized modern treatment versus from receiving water bodies.	Update methods to estimate and distinguish N_2O emissions from centralized modern wastewater treatment.	Continuous improvement	Initiated data collection / study

REFERENCES

Chapter 1, Introduction

Canada. 1999. *Canadian Environmental Protection Act, 1999*. Ottawa: Queen's Printer. Available online at http://laws-lois.justice.gc.ca/PDF/C-15.31.pdf.

Environment Canada. 2015. Unpublished document. General QC (Tier I QC Checklist), Quality Manual of the Pollutant Inventories and Reporting Division (PIRD).

[ECCC] Environment and Climate Change Canada. 2019. *Climate Trends and Variations Bulletin*: Annual 2019. Environment and Climate Change Canada. Available online https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/climate-trends-variability/trends-variations/annual-2019-bulletin.html.

Environment and Climate Change Canada. 2019. *Facility Greenhouse Gas Reporting Program - Overview of 2017 Reported Emissions.* Environment and Climate Change Canada. Available online at https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/facility-reporting/data.html.

Hengeveld H, Whitewood B, Ferguson A. 2005. *An Introduction to Climate Change – A Canadian Perspective.* Ottawa (ON): Environment Canada.

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme.

[IPCC] Intergovernmental Panel on Climate Change. 2012. *Climate Change 2007: The Physical Science Basis, Working Group 1 contribution to the IPCC Fourth Assessment Report - Errata.* Available online at http://www.ipcc.ch/report/ar4/wg1/.

[IPCC] Intergovernmental Panel on Climate Change. 2013. *Climate Change 2013: The Physical Science Basis, Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker T, Qin D, Plattner GK, Tignor M, Allen S, Boschung J, Nauels A, Xia Y, Bex V, MidgleyP, editors. Cambridge (UK): Cambridge University Press. Available online at http://www.ipcc.ch/report/ar5/wg1/.

[IPCC] Intergovernmental Panel on Climate Change. 2014. *Climate Change 2014: Synthesis Report.* Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Treasury Board of Canada. 2012. *Policy on Information Management*. Treasury Board of Canada Secretariat. [modified 2012 April 1]. Available online at http://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=12742.

[UNFCCC] United Nations Framework Convention on Climate Change. 2010. *Compilation of technical information on the new greenhouse gases and groups of gases included in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Webpage]. [revised 2010 July 27; cited 2015 January 15].

[UNFCCC] United Nations Framework Convention on Climate Change. 2014. *Report of the Conference of the Parties on its nineteenth session, held in Warsaw from 11 to 23 November 2013*. Addendum. Part two: Action taken by the Conference of the Parties at its nineteenth session, 24/CP.19 Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention. Available online at: http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf.

[WMO] World Meteorological Organization. 2019. *WMO Greenhouse Gas Bulletin: The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2018*. 25 November 2019. No. 15. Available online at https://library.wmo.int/doc_num.php?explnum_id=10100.

Chapter 2, Greenhouse Gas Emission Trends, 1990–2018

[AAC] Aluminium Association of Canada. 2018. Data on production and GHG emissions obtained from the Aluminium Association of Canada under the Memorandum of Understanding signed between AAC and EC.

[AER] Alberta Energy Regulator. 2014. *Directive 060: Upstream Petroleum Industry Flaring, Incinerating, and Venting.* Available online at: https://www.aer.ca/documents/directives/Directive060.pdf.

[AER] Alberta Energy Regulator. 2019. *Alberta's Energy Reserves and Supply/Demand Outlook*: ST98-2019. Available online at: https://www.aer.ca/providing-information/data-and-reports/statistical-reports/st98.

[BCOGC] British Columbia Oil and Gas Commission. 2015. *Flaring and Venting Reduction Guideline – v 4.4.* April 2015. Available online at: http://www.bcogc.ca/node/5916/download.

[CAIT] Climate Analysis Indicators Tool. 2017. CAIT 2.0. Washington (DC): World Resources Institute. Available online at: https://www.wri.org/our-work/project/caitclimate-data-explorer.

[CAPP] Canadian Association of Petroleum Producers. 2007. Best Management Practice: Management of Fugitive Emissions at Upstream Oil and Gas Facilities. January 2007. Available online at: https://www.capp.ca/wp-content/uploads/2019/11/Best_Management_Practice_for_Fugitive_Emissions_Management-116116.pdf.

[CAPP] Canadian Association of Petroleum Producers. 2019. *Statistical Handbook for Canada's Upstream Petroleum Industry.* [accessed 2019 Sep 11]. Available online at: https://www.capp.ca/resources/statistics/.

[CSPA] Canadian Steel Producers Association. 2013–2018. Data on iron and steel production acquired through a purchase contract between ECCC and CSPA.

[Husky] Husky Energy Inc. 2019. *Husky Energy Annual Report 2018*. [accessed 2019 Jun 5]. Available online at: https://huskyenergy.com/downloads/abouthusky/publications/annualreports/HSE_Annual2018.pdf.

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds). IGES, Japan.

Liang BC, MacDonald JD, Desjardins RL, McConkey BG, Beauchemin, KA, Flemming C, Cerkowniak D, and Blondel A. 2020. Beef cattle production impacts soil organic carbon storage. Science of the Total Environment, in revision.

[NRCan] Natural Resources Canada. 2013. *Energy Efficiency Trends in Canada, 1990 to 2010*. Ottawa (ON): Office of Energy Efficiency, Natural Resources Canada. M141-1/2010.

[NRCan] Natural Resources Canada. 2018. *The State of Canada's Forests: Annual Report 2018*. Natural Resources Canada, Canadian Forest Service, Ottawa. 80 p. Available online at: https://cfs.nrcan.gc.ca/publications?id=39336.

[StatCan] Statistics Canada. 1991–2019. *Report on Energy Supply and Demand in Canada* (Annual). Catalogue No. 57 003 X. Available online at: http://www5.statcan.gc.ca/olc-cel/olc.action?objId=57-003-X&objType=2&lang=en&limit=0.

[StatCan] Statistics Canada. 2004–2012. *Steel, Tubular Products and Steel Wire*. Monthly. Catalogue No. 41 019-X (discontinued).

[StatCan] Statistics Canada. No date (a). *Table 361-00369-01 (formerly CANSIM 380-0106): Gross domestic product, expenditure-based, at 2012 constant prices, annual (x 1,000,000)*. Data. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610036901 [accessed 2019 Dec 05].

[StatCan] Statistics Canada. No date (b). *Table 17-10-0005-01 (formerly CANSIM 051-0001): Population Estimates on July 1st, by age and sex*. Data. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000501 [accessed 2019 Dec 05].

[StatCan] Statistics Canada. No date (c). *Table 25-10-0014-01 (formerly CANSIM 126-0001): Historical Supply and disposition of crude oil and equivalent, monthly (cubic metres)*. Data. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510001401 [accessed 2016 Aug 15].

[StatCan] Statistics Canada. No date (d). *Table 25-10-0063-01 (formerly CANSIM 126-0003): Supply and disposition of crude oil and equivalent, monthly (cubic metres)*. Data. Available online at: https://www150.statcan.gc.ca/n1/en/type/data?text=25100063 [accessed 2019 Jul 4].

[StatCan] Statistics Canada. No date (e). *Table 32-10-0130-01: Number of cattle, by class and farm type, annual (head)*. Data. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210013001 [accessed 2019 Oct 22].

[StatCan] Statistics Canada. No date (f). *Table 23-10-0219-01: Trucking commodity industry activities, annual*. Data. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310021901.

Chapter 3, Energy

[AER] Alberta Energy Regulator. 2018. *Alberta Mineable Oil Sands Plant Statistics*, Monthly Supplement December 2017: ST39-2017. [revised 2018 Mar 23; accessed 2018 Aug 21]. Available online at: https://www.aer.ca/documents/sts/ST39-2017.pdf.

BioMer. 2005. *Biodiesel Demonstration and Assessment for Tour Boats in the Old Port of Montreal and Lachine Canal National Historic Site*. Final Report.

[CAPP] Canadian Association of Petroleum Producers. 1999. *CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry*, Vols. 1 and 2. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd. Canada. Publication No. 1999-0010.

[CAPP] Canadian Association of Petroleum Producers. 2005. *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emissions by the Upstream Oil and Gas Industry*, Vols. 1–5. Calgary (AB): Clearstone Engineering Ltd.

[CAPP] Canadian Association of Petroleum Producers. 2006. *An Inventory of GHGs, CACs, and H_2S Emissions by the Canadian Bitumen Industry: 1990 to 2003*. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd.

[CGA] Canadian Gas Association. 1997. *1995 Air Inventory of the Canadian Natural Gas Industry*. Calgary (AB): Radian International LLC.

Cheminfo Services Inc. and Clearstone Engineering Ltd. 2014. *Compilation of a National Inventory of Greenhouse Gas and Fugitive VOC Emissions by the Canadian Coal Mining Industry*. Final report submitted to the Energy Group, PIRD, Environment Canada.

[CIEEDAC] Canadian Industrial Energy End-Use Data Analysis Centre. 2015. *Energy Use and CO_2 Emissions in Canadian Oil Refineries 1990, 1994 – 2013*. Burnaby (BC): Simon Fraser University.

Clearstone Engineering Ltd. 2014. *Technical Report on Canada's Upstream Oil and Gas Industry*. Vols. 1–4. Prepared for Environment Canada. Calgary (AB): Clearstone Engineering Ltd.

Clearstone Engineering Ltd. 2017. *An Inventory of GHG, CAC and Other Priority Emissions by the Canadian Oil Sands Industry: 2003 to 2015*. Vols 1–3. Prepared for Environment and Climate Change Canada. Calgary (AB): Clearstone Engineering Ltd.

[CP_{PI}] Canadian Petroleum Products Institute. 2004. *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production*. Prepared for the Canadian Petroleum Products Institute. Calgary (AB): Levelton Consultants Ltd. in association with Purvin & Gertz Inc.

Environment and Climate Change Canada. 2017. *Updated Coal Emission, Energy Conversion and Oxidation Factors*. Unpublished Environment Canada internal report. Ottawa (ON): Pollutant Inventories and Reporting Division.

Environment and Climate Change Canada. 2017. *Updated CO_2 Emission Factors for Gasoline and Diesel Fuel*. Unpublished report. Prepared by S. Tobin, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada. Gatineau (QC).

[ECCC] Environment Climate Change Canada. 2018a. *Off-road Equipment Analysis – Oil Sands Mining Equipment.* Unpublished report. Prepared by B. Greenlaw, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada. Gatineau (QC).

[ECCC] Environment Climate Change Canada. 2018b. *Off-road Equipment Analysis – Snowmobiles*. Unpublished report. Prepared by B. Greenlaw, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada. Gatineau (QC).

[GRI] Gas Research Institute. 2000. *Vented Emissions from Maintenance at Natural Gas Distribution Stations in Canada.* Austin (TX): Radian International LLC.

Husky Energy Inc. 2018. *Husky Energy Annual Report 2017*. [accessed 2018 Aug 13]. Available online at: http://www.huskyenergy.ca/downloads/abouthusky/publications/annualreports/HSE_Annual2017.pdf.

ICF Consulting. 2004. *Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001*. Final report submitted to the Greenhouse Gas Division, Environment Canada by ICF Consulting.

[IPCC] Intergovernmental Panel on Climate Change. 2000. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: http://www.ipcc-nggip.iges.or.jp/public/gp/english/.

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Prepared by the National Greenhouse Gas Inventories Programme. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, editors. Kanagawa (JP): Institute for Global Environmental Studies. Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/.

King B. 1994. *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options.* Report prepared by Neill and Gunter Ltd. for Environment Canada.

McCann TJ. 2000. *1998 Fossil Fuel and Derivative Factors.* Report prepared by T.J. McCann and Associates for Environment Canada.

Mourits F. 2008. Overview of the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project: Presentation to Interdepartmental CCS Coordinating Committee. Natural Resources Canada.

ORTECH Consulting Inc. 2013. *Canadian Natural Gas Companies 2005 and 2011 Greenhouse Gas and Criteria Air Contaminant Inventory Report* and Validation by Audit. Prepared for CEPEI. Guelph (ON).

[PTRC] Petroleum Technology Research Centre. 2004. *IEA GHG Weyburn CO_2 Monitoring & Storage Project Summary Report 2000–2004*. Regina (SK).

SaskPower. 2017. BD3 Status Update: January 2018. Available online at: https://wcms.saskpower.com/about-us/Our-Company/Blog/2018/03/bd3-status-update-january-2018.

SGA Energy Ltd. 2000. *Emission Factors and Uncertainties for CH_4 & N_2O from Fuel Combustion.* Unpublished report prepared by SGA Energy Ltd for the Greenhouse Gas Division, Environment Canada.

[Statistics Canada 1990–] Statistics Canada. *Report on Energy Supply and Demand in Canada*. Catalogue No. 57-003-X. Available online at: https://www150.statcan.gc.ca/n1/en/catalogue/57-003-X.

Statistics Canada. 2002–2009. *Electric Power Generation, Transmission and Distribution.* Annual. Catalogue No. 57-202-X (discontinued).

Townsend-Small A, Ferrara TW, Lyon DR, Fries AE, Lamb BK. 2016. *Emissions of coalbed and natural gas methane from abandoned oil and gas wells in the United States.* Geophysical Research Letters 43:2283–2290. doi: http://dx.doi.org/10.1002/2015GL067623.

[UNFCCC] United Nations Framework Convention on Climate Change. 2012. FCCC/ARR/2011/CAN. *Report of the individual review of the annual submission of Canada submitted in 2011,* April 2012. Available online at: http://unfccc.int/resource/docs/2012/arr/can.pdf.

[UNFCCC] United Nations Framework Convention on Climate Change. 2014. FCCC/CP/2013/10/Add.3. *Report of the Conference of the Parties on its nineteenth session*, held in Warsaw from 11 to 23 November 2013. Decisions adopted by the Conference of the Parties. Decision 24/CP.19. Revision of the UNFCCC Reporting on annual inventories for Parties included in Annex I to the Convention.

Chapter 4, Industrial Processes and Product Use

Alcan. 2010. Alcan's response to EC's questions related to the UNFCCC In-Country Review of the Canadian GHG Inventory.

AMEC. 2006. *Identifying and Updating Industrial Process Activity Data in the Minerals Sector for the Canadian Greenhouse Gas Inventory.* Unpublished report. Mississauga (ON): AMEC Earth & Environmental, a division of AMEC Americas Ltd.

Bliss JD, Hayes TS, Orris GJ. 2008. *Limestone—A Crucial and Versatile Industrial Mineral Commodity*. U.S. Geological Survey Fact Sheet 2008–3089, version 1.1, revised August 2012.

British Columbia Geological Survey. 2016. Provincial Overview of Exploration and Mining in British Columbia, 2015. British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Information Circular 2016-1 [accessed 2016 Jun 9]. Available online at: https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/publications/informationcirculars.

[CAC] Cement Association of Canada. 2014. Unpublished data on Canadian clinker production.

Cheminfo Services. 2002. *Review of Canadian SF_6 Emissions Inventory.* Unpublished report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2005a. *Improving and Updating Industrial Process-Related Activity Data and Methodologies in Canada's Greenhouse Gas Inventory, Sulphur Hexafluoride (SF_6) from Electrical Equipment.* Unpublished report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2005b. *Improving and Updating Industrial Process-Related Activity Data and Methodologies Used in Canada's Greenhouse Gas Inventory, Sulphur Hexafluoride Emissions from the Magnesium Casting Sector*. Unpublished report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2005c. *Improving and Updating Industrial Process-Related Activity Data and Methodologies Used in Canada's Greenhouse Gas Inventory, Hydrofluorocarbons (HFCs)*. Unpublished report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2006. *Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory*. Final Report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2010. *Study of Potential Additions and Updates to the Industrial Process Sources of GHGs in the Canadian GHG Inventory, and Development of Canadian-Specific Methodologies and Emission Estimates for such Sources*. Final Report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2014. *Chemical Management Plan 2 (CMP_2) Scoping Project for Substance Information on Nitrogen Trifluoride (NF_3)*. Confidential Final Report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2015. *Petrochemical Production Study: Carbon Flows and GHG Emissions*. Final Report. Markham (ON): Cheminfo Services Inc.

[CIEEDAC] Canadian Industrial Energy End-Use Data and Analysis Centre. 2006. *A Review of Energy Consumption in Canadian Oil Refineries 1990, 1994 to 2004*. Burnaby (BC): Simon Fraser University.

[CIEEDAC] Canadian Industrial Energy End-Use Data and Analysis Centre. 2010. *A Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry, 1990 to 2008.* Burnaby (BC): Simon Fraser University.

[CSPA] Canadian Steel Producers Association. 2009. Unpublished, confidential data. Industry-average pig iron content.

[CSPA]. Canadian Steel Producers Association. 2013-2018. Unpublished data on pig iron charged to steel furnaces in Canada.

Derry Michener Booth and Wahl and Ontario Geological Survey. 1989. *Limestone Industries of Ontario, Vol. III — Limestone Industries and Resources of Central and Southwestern Ontario.* Report prepared for the Ontario Ministry of Natural Resources, Land Management Branch, 175 p.

[EHS] Environmental Health Strategies Inc. 2013. *Report on Emission Factors for HFCs in Canada.* Unpublished Report. Toronto (ON). Prepared for Environment Canada.

Environment Canada. 1999–2007. National Pollutant Release Inventory (NPRI). *Public data on SF_6 emissions from magnesium production*. Available online at: http://www.ec.gc.ca/inrp-npri/.

Environment Canada. 1986. *Domestic Substances List.* Available online at: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/substances-list/domestic.html.

Environment Canada. 2015. Unpublished document. *General Quality Control Checklist Guidance* (PIRD).

Environment Canada. 2015. *Review of Country-specific HFCs Emission Estimations in the Refrigeration and Air Conditioning Sectors.* Unpublished report. Ottawa (ON).

Environment Canada and Canadian Electricity Association. 2008. *SF_6 Emission Estimation and Reporting Protocol for Electric Utilities.*

[GTIS] Global Trade Information Services Inc. *Canadian Soda Ash Import and Export Data*. [1995–2006 trade data accessed on 2007 October 1; 2007–2009 data accessed on 2010 June 21.] Available online at: http://www.gtis.com.

[HRAI] Heating, Refrigeration and Air Conditioning Institute of Canada. 2008. *HCFC Phase-Out Awareness*.

[IAI] International Aluminium Institute. 2006. *The Aluminium Sector Greenhouse Gas Protocol* (Addendum to the WRI/WBCSD Greenhouse Gas Protocol). Available online at: http://www.world-aluminium.org/publications/.

ICF Consulting. 2004. *Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001*. Final report submitted to the Greenhouse Gas Division. Environment Canada, by ICF Consulting.

[IPCC] Intergovernmental Panel on Climate Change. 2000. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: http://www.ipcc-nggip.iges.or.jp/public/gp/english/.

[IPCC] Intergovernmental Panel on Climate Change. 2002. Background Papers – *IPCC Expert Meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (section on HFC-23 Emissions from HCFC-22 Production). Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: http://www.ipcc-nggip.iges.or.jp/public/gp/gpg-bgp.htm.

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 3, Industrial Processes and Product Use*. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol3.htm.

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. Available online at: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Japan Ministry of the Environment. 2009. *National Greenhouse Gas Inventory Report of Japan*. Greenhouse Gas Inventory Office of the Japan Ministry of the Environment.

Jaques AP. 1992. *Canada's Greenhouse Gas Emissions: Estimates for 1990.* Environmental Protection, Conservation and Protection, Environment Canada. Report EPS 5/AP/4.

McCann TJ. 2000. *1998 Fossil Fuel and Derivative Factors*. Unpublished report. Prepared by TJ McCann and Associates for Environment Canada.

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

[NRCan] Natural Resources Canada. 1990–2008. *Canadian Minerals Yearbook. Minerals and Metals Sector* (Annual). Natural Resources Canada (discontinued).

Statistics Canada. No date (a). *Table 303-0060: Production, Shipments and Stocks of Cement, Monthly* (table). CANSIM (database) [accessed 2016 June 7]. Available online at: http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=3030060&pattern=Production%2C+Shipments+and+Stocks+of+Cement&tabMode=dataTable&srchLan=-1&p1=1&p2=-1.

Statistics Canada. No date (b). *Table 161-00043: Destination of Shipments of Cement, Monthly* (table). Data. [accessed 2016 June 7]. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1610004301.

Statistics Canada. No date (c). *Table 161-00041: Production of Industrial Chemicals and Synthetic Resins, Annual* (table). Data. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1610004101.

Statistics Canada. No date (d). *Table 171-00005: Estimates of population, by age group and sex for July 1,* Canada, provinces and territories, Annual (table). Data. Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000501.

Statistics Canada. 1985–1998. *Non-Metallic Mineral Products Industries*. Catalogue No. 44-250-XPB (discontinued).

Statistics Canada. 1990–2003. *Primary Iron and Steel.* Monthly. Catalogue No. 41-001-XIB (discontinued).

Statistics Canada. 1990–2004. *Cement*. Monthly. Catalogue No 44-001-XIB (discontinued).

Statistics Canada. 1990–2007. *Industrial Chemicals and Synthetic Resins*. Monthly. Catalogue No. 46-002-XIE (discontinued).

Statistics Canada. 1990–2018. *Report on Energy Supply and Demand in Canada*. Annual. Catalogue No. 57 003 XIB.

Statistics Canada. 2004–2012. *Steel, Tubular Products and Steel Wire*. Monthly. Catalogue No. 41 019-X (discontinued).

Statistics Canada. 2010–2018. *Canadian International Merchandise Trade Database.* Catalogue No. 65C 0003 [accessed 2019 Nov 28]. Available online at: http://www5.statcan.gc.ca/cimt-cicm/home-accueil?lang=eng.

Chapter 5, Agriculture

Boadi DA, Ominski KH, Fulawka DL, Wittenberg KM. 2004. *Improving Estimates of Methane Emissions Associated with Enteric Fermentation of Cattle in Canada by Adopting an IPCC* (Intergovernmental Panel on Climate Change) Tier-2 Methodology. Final report submitted to the Greenhouse Gas Division, Environment Canada. Winnipeg (MB): Department of Animal Science, University of Manitoba.

Campbell CA, Zentner RP, Janzen HH, Bowren KE. 1990. *Crop Rotation Studies on the Canadian Prairie*. Ottawa (ON): Canadian Government Publishing Centre.

Campbell CA, Janzen HH, Paustian K, Gregorich EG, Sherrod L, Liang BC, Zentner RP. 2005. Carbon storage in soils of the North American Great Plains: effect of cropping frequency. *Agronomy Journal 97*:349–363.

Chai L, Kröbel R, MacDonald D, Bittman S, Beauchemin KA, Janzen HH, McGinn SM, VanderZaag A. 2016. An ecoregion-specific ammonia emissions inventory of Ontario dairy farming: Mitigation potential of diet and manure management practices. *Atmospheric Environment 126*:1–14.

Coote DR, Liang BC, Huffman EC. 2008. *Crop residue burning in Canada*. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Desjardins RL, Pattey E, Smith WN, Worth D, Grant B, Srinivasan R, MacPherson JI, Mauder M. 2010. Multiscale estimates of N_2O emissions from agricultural lands. *Agricultural and Forest Meteorology 150*:817–824.

Desjardins RL, Worth DE, Srinivasan R, Pattey E, VanderZaag AC, Mauder M, Metzger S, Worthy D, Sweeney C. 2018. The challenge of reconciling bottom-up agricultural methane emissions inventories with top-down measurements. *Agricultural and Forest Meteorology 248*:48–59.

Gregorich EG, Rochette P, VandenBygaart AJ, Angers DA. 2005. Greenhouse gas contributions of agricultural soils and potential mitigation practices in eastern Canada. *Soil & Tillage Research 83*:53–72.

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4: Agriculture, Forestry and Other Land Use*. Intergovernmental Panel on Climate Change. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

Jambert C, Delmas R, Serça D, Thouron L, Labroue L, Delprat L. 1997. N_2O and CH_4 emissions from fertilized agricultural soils in southwest France. *Nutrient Cycling in Agroecosystems 48*:105–114.

Janzen HH, Beauchemin KA, Bruinsma Y, Campbell CA, Desjardins RL, Ellert BH, Smith EG. 2003. The fate of nitrogen in agroecosystems: an illustration using Canadian estimates. *Nutrient Cycling in Agroecosystems 67*:85–102.

Karimi-Zindashty Y, Macdonald JD, Desjardins RL, Worth D, Hutchinson JJ, Vergé XPC. 2012. Sources of uncertainty in the IPCC Tier 2 Canadian livestock model. *The Journal of Agricultural Science 150*:556–559.

Karimi-Zindashty Y, Macdonald JD, Desjardins RL, Worth D, Liang BC. 2014. *Determining the uncertainty in agricultural nitrous oxide emissions for Canada*. Internal report. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Liang BC, Padbury G, Patterson G. 2004a. *Cultivated organic soils in Canada*. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Liang BC, McConkey BG, Campbell CA, Curtin D, Lafond GP, Brandt SA, Lafond AP. 2004b. Total and labile soil organic nitrogen as influenced by crop rotations and tillage in Canadian prairie soils. *Biology and Fertility of Soils 39*:249–257.

MacDonald JD, Liang BC. 2011. *Analysis of Canadian Quantification Methodologies of Greenhouse Gas emissions from Livestock: IPCC Tier 2 Quality Control Documentation 2011 submission*. Internal report. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Malhi SS, Lemke R. 2007. Tillage, crop residue and N fertilizer effects on crop yield, nutrient uptake, soil quality and nitrous oxide gas emissions in a second 4-yr rotation cycle. *Soil Tillage Research 96*:269–283.

Marinier M, Clark K, Wagner-Riddle C. 2004. *Improving Estimates of Methane Emissions Associated with Animal Waste Management Systems in Canada by Adopting an IPCC Tier 2 Methodology*. Final report submitted to the Greenhouse Gas Division, Environment Canada, by the Department of Land Resource Science. Guelph (ON): University of Guelph.

Marinier M, Clark K, Wagner-Riddle C. 2005. *Determining manure management practices for major domestic animals in Canada*. Final report submitted to the Greenhouse Gas Division, Environment Canada, by the Department of Land Resource Science. Guelph (ON): University of Guelph.

McAllister TA, Basarab J. 2004. *A review of the report "Improving Estimates of Methane Emissions Associated with Enteric Fermentation of Cattle in Canada by Adopting an IPCC (Intergovernmental Panel on Climate Change) Tier-2 Methodology".* Report submitted to the Greenhouse Gas Division, Environment Canada, by Agriculture and Agri-Food Canada, Lethbridge (AB), and Alberta Agriculture, Lacombe (AB).

McConkey BG, Campbell CA, Zentner RP, Dyck FB, Selles F. 1996. Long-term tillage effects on spring wheat production on three soil textures in the Brown soil zone. *Canadian Journal of Plant Science 76*:747–756.

McConkey BG, Liang BC, Campbell CA, Curtin D, Moulin A, Brandt SA, Lafond GP. 2003. Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. *Soil & Tillage Research 74*:81–90.

Mosier A, Kroeze C, Nevison C, Oenema O, Seitzinger S, van Cleemput O. 1998. Closing the global N_2O budget: nitrous oxide emissions through the agricultural nitrogen cycle. *Nutrient Cycling in Agroecosystems 52*:225–248.

Patni N, Desjardins R. 2004. *Comments on "Determining Manure Management Practices for Major Domestic Animals in Canada"* by Marinier et al. (2004). Report submitted to the Greenhouse Gas Division, Environment Canada, by Agriculture and Agri-Food Canada, Ottawa (ON).

Rochette P, Angers DA, Chantigny MH, Bertrand N. 2008a. Nitrous oxide emissions respond differently in a loam and a heavy clay soil. *Soil Science Society of America Journal 72*:1363–1369.

Rochette P, Worth DE, Lemke RL, McConkey BG, Pennock DJ, Wagner-Riddle C, Desjardins RL. 2008b. Estimation of N_2O emissions from agricultural soils in Canada. I. Development of a country-specific methodology. *Canadian Journal of Soil Science 88*:641–654.

Rochette P, Chantigny MH, Ziadi N, Angers, DA, Bélanger G, Charbonneau E, Pellerin D, Liang BC, Bertrand N. 2014. Soil nitrous oxide emissions after deposition of dairy cow excreta in eastern Canada. *Journal of Environmental Quality 43*:829–841.

Sheppard SC, Bittman S, Tait J. 2009a. Monthly NH_3 emissions from poultry in 12 Ecoregions of Canada. *Canadian Journal of Animal Science 89*:21–35.

Sheppard SC, Bittman S, Beaulieu M, Sheppard MI. 2009b. Ecoregion and farm-size differences in feed and manure nitrogen management: 1. Survey methods and results for poultry. *Canadian Journal of Animal Science 89*:1–19.

Sheppard SC, Bittman S, Swift ML, Tait J. 2010. Farm practices survey and modelling to estimate monthly NH_3 emissions from swine production in 12 Ecoregions of Canada. *Canadian Journal of Animal Science 90*:145–158.

Sheppard SC, Bittman S. 2011. Farm survey used to guide estimates of nitrogen intake and ammonia emissions for beef cattle, including early season grazing and piosphere effects. *Animal Feed Science and Technology 166-167*:688–698.

Sheppard SC, Bittman S, Swift ML, Beaulieu M, Sheppard MI. 2011a. Ecoregion and farm size differences in dairy feed and manure nitrogen management: A survey. *Canadian Journal of Animal Science 91*:459–473.

Sheppard SC, Bittman S, Swift ML, Tait J. 2011b. Modelling monthly NH_3 emissions from dairy in 12 Ecoregions of Canada. *Canadian Journal of Animal Science 91*:649–661.

Sheppard SC, Bittman S. 2012. Farm practices as they affect NH_3 emissions from beef cattle. *Canadian Journal of Animal Science 92*(4):525–543.

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

Bailey AW, Liang BC. 2013. *Burning of Managed Grasslands in Alberta, Saskatchewan and British Columbia*. Western Rangeland Consultants Inc., Edmonton (AB); Environment Canada, Pollutant Inventories and Reporting Division, Gatineau, (QC).

Bruce JP, Frome M, Haites E, Janzen H, Lal R, Paustian K. 1999. Carbon sequestration in soils. *Journal of Soil Water Conservation 54*:382–389.

Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D. 1996. Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. *Canadian Journal of Soil Science 76*:395–401.

Dyk A, Tinis S, Leckie D. 2011. *Deforestation Area Estimation for Canada: Quality Control Overview*. Internal Report DRS-N-031. Canadian Forest Service, Natural Resources Canada.

Dyk A, Leckie D, Tinis S, Ortlepp S. 2015. *Canada's National Deforestation Monitoring System: System Description*. Victoria (BC): Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre. Information report BC-X-439. 30 p. Available online at: http://cfs.nrcan.gc.ca/publications?id=36042.

Dymond C. 2008. *Overview QAQC Procedures for NIR 2009*. Internal Report. Victoria (BC): Natural Resources Canada, Canadian Forest Service.

Environment and Climate Change Canada. 2016. *Water sources: wetlands*. Available online at: https://www.ec.gc.ca/eau-water/default.asp?lang=En&n=27147C37-1.

Huffman T, Leckie D, McGovern M, Olesen M, Green M, Hill DA, Rounce T, Churchill J, Liu J. 2015a. *Integration of multiple spatial datasets in the development of a temporal series of high-accuracy, high-resolution land use maps*. Proceedings of the 35th EARSeL Symposium; Stockholm, Sweden, June 15–19, 2015.

Huffman T, Liu J, McGovern M, McConkey B, Martin T. 2015b. Carbon stock and change from woody biomass on Canada's cropland between 1990 and 2000. *Agriculture, Ecosystems & Environment 205*:102–111.

Hutchinson JJ, Rochette P, Verge X, Desjardins R, Worth D. 2007. *Uncertainties in Methane and Nitrous Oxide Emissions Estimates from Canadian Agroecosystems Using Crystal Ball*. Preliminary report submitted to the Greenhouse Gas Division, Environment Canada, by the Research Branch, Agriculture and Agri-Food Canada.

[IPCC] Intergovernmental Panel on Climate Change. 2003. *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf.

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 4: Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

[IPCC] Intergovernmental Panel on Climate Change. 2010. *Revisiting the Use of Managed Land as a Proxy for Estimating National Anthropogenic Emissions and Removals.* Eggleston HS, Srivastava N, Tanabe K, Baasansuren J, editors. IGES, Japan, IPCC meeting São José dos Campos, Brazil. Available online at: http://www.ipcc-nggip.iges.or.jp/public/mtdocs/pdfiles/0905_MLP_Report.pdf.

[IPCC] Intergovernmental Panel on Climate Change. 2014. *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. Hiraishi T, Krug T, Tanabe K, Srivastava N, Baasansuren J, Fukuda M, Troxler TG, editors. IPCC, Switzerland. Available online at: http://www.ipcc-nggip.iges.or.jp/public/wetlands/.

Janzen HH, Campbell CA, Gregorich EG, Ellert BH. 1997. *Soil carbon dynamics in Canadian agroecosystems*. In: Lal R, Kimble JM, Follett RF, Stewart BA, editors. Soil Processes and Carbon Cycles. Boca Raton (FL): CRC Press. p. 57–80.

Janzen HH, Campbell CA, Izaurralde RC, Ellert BH, Juma N, McGill WB, Zentner RP. 1998. Management effects on soil C storage on the Canadian prairies. *Soil & Tillage Research 47*:181–195.

Keys D. 1992. *Canadian Peat Moss and the Environment*. Issues Paper No. 1992-3. North American Wetlands Conservation Council (Canada).

Kull SJ, Rampley GJ, Morken S, Metsaranta J, Neilson ET, Kurz WA. 2019. *Operational-Scale Carbon Budget Model of the Canadian Forest Sector* (CBM-CFS3) Version 1.2: User's Guide. Edmonton (AB): Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre.

Kurz WA, Dymond CC, White TM, Stinson G, Shaw CH, Rampley GJ, Smyth C, Simpson BN, Neilson ET, Trofymow JA, Metsaranta J, Apps MJ. 2009. CBM-CFS3: A model of carbon-dynamics in forestry and land-use change implementing IPCC standards. *Ecological Modelling 220*:480–504.

Kurz WA, Hayne S, Fellows M, MacDonald JD, Metsaranta JM, Hafer M, Blain D. 2018. Quantifying the impacts of human activities on reported greenhouse gas emissions and removals in Canada's managed forest: conceptual framework and implementation. *Canadian Journal of Forest Research 48*(10):1227–1240. Available online at: http://www.nrcresearchpress.com/doi/full/10.1139/cjfr-2018-0176.

Leckie D. 2011. *Deforestation Area Estimation Uncertainty for Canada's National Inventory Report Greenhouse Gas Sources and Sinks 2011*. Internal Report DRS-N-0XX, Canadian Forest Service, Natural Resources Canada.

Liang BC, Padbury G, Patterson G. 2004. *Cultivated Organic Soils in Canada*. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Liang BC, Campbell CA, McConkey BG, Padbury B, Collas P. 2005. An empirical model for estimating carbon sequestration on the Canadian prairies. *Canadian Journal of Soil Science 85*:549–556.

Marshall IB, Shut P. 1999. *A National Ecological Framework for Canada. Ecosystems Science Directorate, Environment Canada, and Research Branch, Agriculture and Agri-Food Canada.* Available online at: http://sis.agr.gc.ca/cansis/nsdb/ecostrat/1999report/index.html.

McConkey B, Liang BC, Campbell CA, Curtin D, Moulin A, Brandt SA, Lafond GP. 2003. Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. *Soil & Tillage Research 74*:81–90.

McConkey BG, VandenBygaart AJ, Hutchinson J, Huffman T, Martin T. 2007. *Uncertainty Analysis for Carbon Change—Cropland Remaining Cropland.* Report submitted to Environment Canada by the Research Branch, Agriculture and Agri-Food Canada.

Metsaranta JM, Shaw CH, Kurz WA, Boisvenue C, Morken S. 2017. Uncertainty of inventory-based estimates of the carbon dynamics of Canada's managed forest (1990–2014). *Canadian Journal of Forest Research. 47*:1082–1094.

National Wetlands Working Group. 1997. *The Canadian Wetland Classification System*. 2nd Edition. Warner BG, Rubec CDA, editors. Waterloo (ON): Wetlands Research Centre, University of Waterloo. Available online at: http://www.wetlandpolicy.ca/canadian-wetland-classification-system/.

Nowak DL, Greenfield EJ, Hoehn RE, Lapoint E. 2013. *Carbon storage and sequestration by trees in urban and community areas of the United States*. Environmental Pollution 178:229–236.

[NRCan] Natural Resources Canada. 2005a. *Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) Initiative: Afforestation Policy Analysis*. Canadian Forest Service.

[NRCan] Natural Resources Canada. 2005b. *Forest 2020 Plantation Demonstration Assessment (PDA): Afforestation Policy Analysis.* Canadian Forest Service.

[NRCan] Natural Resources Canada. 2011. *Peatlands of Canada. Geological Survey of Canada*. Available online at: https://doi.org/10.4095/288786.

[NRCan] Natural Resources Canada. 2018a. *Annual Statistic of Mineral Production*. Natural Resources Canada. Available online at: http://sead.nrcan.gc.ca/prod-prod/ann-ann-eng.aspx.

[NRCan] Natural Resources Canada. 2018b. *Canada's Statistical Data – Forest Inventory.* Natural Resources Canada. Available online at: https://cfs.nrcan.gc.ca/statsprofile.

[NRCan] Natural Resources Canada. 2018c. *State of the Forest Report 2018*. Available online at: https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/state-canadas-forests-report/16496.

Shaw CH, Hilger AB, Metsaranta J, Kurz WA, Eichel F, Stinson G, Smyth C, Filiatrault M. 2014. *Evaluation of simulated estimates of forest ecosystem carbon stocks using ground plot data from Canada's National Forest Inventory.* Ecological Modelling 272:323–347.

Soil Classification Working Group. 1998. *The Canadian System of Soil Classification. Research Branch, Agriculture and Agri-Food Canada*. Publication 1646, Third Edition 1998, NRC Research Press.

VandenBygaart AJ, Gregorich EG, Angers DA. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. *Canadian Journal of Soil Science 83*:363–380.

VandenBygaart AJ, McConkey BG, Angers DA, Smith W, De Gooijer H, Bentham M, Martin T. 2008. Soil carbon change factors for the Canadian agriculture national greenhouse gas inventory. *Canadian Journal of Soil Science 88*:671–680.

White T, Dymond C. 2008. *NIR 2007 QAQC Report*. Internal report. Ottawa (ON): Environment Canada.

Chapter 7, Waste

AECOM Canada. 2011. Improved Methodology for the Estimation of Greenhouse Gases from Canadian Municipal Wastewater Treatment Facilities.

AECOM Canada. 2012. *Evaluation of Canada's Estimation Methodology of Nitrous Oxide Emissions from Human Sewage*. Final report.

Chandler. 2006. *Review of Dioxins and Furans from Incineration: In support of a Canada-wide Standard Review*. Prepared by A,J. Chandler & Associates.

Environment and Climate Change Canada. 2018. Waste Incineration in Canada 1990-2008 – A summary of findings from surveys conducted in 2006-2018. Unpublished Environment and Climate Change Canada internal report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

ICF Consulting. 2004. *Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001*. Final report submitted to the Greenhouse Gas Division. Environment Canada, by ICF Consulting.

[IPCC] Intergovernmental Panel on Climate Change. 2000. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: http://www.ipcc-nggip.iges.or.jp/public/gp/english/.

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

[Levelton] Levelton & Associates Ltd. 1991. *Inventory of Methane Emissions from Landfills in Canada*. Report prepared for Environment Canada. H. El Rayes. 173p.

Statistics Canada. *2009 Food Statistics*. Catalogue No. 21-020-X. Available online at: https://www150.statcan.gc.ca/n1/pub/21-020-x/2009001/t046-eng.htm [accessed July 2019].

Statistics Canada. No Date (a). Households and the Environment Survey. [accessed July 2019].

Statistics Canada. No date (b). *Table 153-0043 Materials diverted, by type, Canada, provinces and territories, every 2 years (tonnes)* (table). CANSIM (database). Last updated 2017 March 24. http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=1530043 [accessed July 2019].

Chapter 8, Recalculations and Improvements

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Prepared by the National Greenhouse Gas Inventories Programme, Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds.). IGES, Japan.