Environment and Climate Change Canada
Environnement et Changement climatique Canada

NATIONAL INVENTORY REPORT
1990-2015:
GREENHOUSE GAS SOURCES AND SINKS IN CANADA

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

PART 1

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FOREWORD

Canada ratified the United Nations Framework Convention on Climate Change (UNFCCC 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 2017 National GHG Inventory complies with the requirements of the Revised UNFCCC reporting guidelines for national GHG inventories (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 national and regional 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 2016. Ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce uncertainties associated with them.

April 2017

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Executive Summary

Alice Au, Warren Baker, Dominique Blain, Ana Blondel, Corey Flemming, Shari Hayne, Chang Liang, Doug MacDonald, Jackie Mercer, Scott McKibbon, Frank Neitzert, Lindsay Pratt, Duane Smith, Steve Smyth, Brett Taylor.

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Overall coordination of Canada's National Inventory Report was led by Lindsay Pratt, with support from Mona Jennings, Jackie Mercer, and Angie Giammario. Compilation, layout, and development of the National Inventory Report for publication were led by Mona Jennings, with assistance from Alain Piquette. 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 web pages related to this publication. The compilation and coordination of the Common Reporting Format tables (companion to this document in Canada's UNFCCC submission) was managed Ana Blondel with support from Warren Baker.

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Readers' Comments

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LIST OF COMMON ACRONYMS, ABBREVIATIONS AND UNITS

Acronymns and 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
N/A	not available
MSW	municipal solid waste
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
Al_2O_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
Na_3AlF_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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EXECUTIVE SUMMARY

ES.1 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 greenhouse gas (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 (COP) 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 Inventory is prepared and submitted annually to the UNFCCC by April 15 of each year, in accordance with 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 at COP 19 in Warsaw in 2013. The annual inventory submission consists of the National Inventory Report (NIR) and the Common Reporting Format (CRF) tables.

The inventory GHG estimates include 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 defined by the Intergovernmental Panel on Climate Change (IPCC): Energy, Industrial Processes and Product Use, Agriculture, Waste, and Land Use, Land-Use Change and Forestry (LULUCF). The GHG emission and removal estimates contained in Canada's GHG inventory are developed using methodologies consistent with the 2006 IPCC inventory guidelines. 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. In December 2015 at COP 21, Canada, alongside the countries of the world, reached an ambitious and balanced agreement to fight climate change. Since 2005 was adopted as a base year for both Canada's 2020 and 2030 targets, many of the metrics within this report are presented in that context, in addition to the 1990 base year 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

Established on December 9, 2016, the Pan-Canadian Framework on Clean Growth and Climate Change is a comprehensive plan to reduce emissions across all sectors of Canada's economy, as well as to stimulate clean economic growth, and build resilience to the impacts of climate change. The actions outlined in the Pan-Canadian Framework will enable Canada to meet or exceed its target to reduce emissions to 30% below 2005 levels by 2030.

The Framework was developed in collaboration with Canada's provinces and territories. It builds on the early leadership of provinces and territories and the diverse array of policies and measures already in place across Canada to reduce greenhouse gas emissions in all sectors of the economy. Many of the policies and measures in the Framework are intended to be scalable to enable increasing ambition over time, and will be subject to rigorous and ongoing evaluation in order to ensure that Canada is well-positioned to meet its current and future climate change commitments. Canada's GHG inventory plays a key role in keeping Canadians informed of progress made in reducing GHG emissions. Section ES.6 presents a pathway for Canada to meet its international emissions reduction target, based on the measures included in the Pan-Canadian Framework.

Pricing carbon pollution is central to Canada's plan. The Government of Canada has outlined a benchmark for pricing carbon pollution that will build on existing provincial systems and ensure a minimum price of $10 CAD per tonne is in place across Canada by 2018, rising to $50 CAD per tonne by 2022. Carbon pricing will help influence investment and purchase decisions towards less carbon-intensive options.

In addition to carbon pricing, the complementary mitigation measures included in the Framework will enable Canada to achieve emissions reductions across all sectors, both in the near-term and as part of a longer-term strategy. Expanding the use of clean electricity and low-carbon fuels are foundational actions that will reduce emissions across the economy. Canada will also take action to reduce energy use by improving energy efficiency, encouraging fuel switching and supporting innovative alternatives. In the built environment sector, this will include developing "net-zero energy ready" building codes.

Actions in the transportation sector include increasingly stringent emission standards for light- and heavy-duty vehicles, as well as taking action to improve efficiency and support fuel switching in the rail, aviation, marine, and off-road sectors. Zero-emissions vehicles will be supported through development of a national strategy and through investments in supportive infrastructure such as charging stations. To reduce emissions from industrial sectors, Canada is developing regulations to achieve a reduction of methane emissions from the oil and gas sector, including offshore activities, by 40-45 percent by 2025, and Canada has also committed to finalizing regulations to phase down the use of hydrofluorocarbons in line

with the Kigali Amendment to the Montreal Protocol.

The Pan-Canadian Framework also recognizes the importance of building climate resilience and sets out measures to help Canadians understand, plan for, and take action to adapt to the unavoidable impacts of climate change. A number of measures are being developed in this area with a focus on infrastructure, information and capacity building, and health. This includes a particular focus on supporting Canada's Indigenous Peoples and northern and remote communities, which are particularly vulnerable to the effects of climate change.

The Framework also includes support for clean technology and innovation, including for early-stage technology development, establishing international partnerships, and encouraging "mission-oriented" research to help generate innovative new opportunities to reduce emissions.

Section ES.2 of this Executive Summary summarizes the latest information on Canada's net anthropogenic GHG emissions over the period 2005–2015 and links this information to relevant indicators of the Canadian economy. Section ES.3 outlines the major trends in emissions from each of the IPCC sectors.

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.4 presents Canada's emissions by the following economic sectors: Oil and Gas, Electricity, Transportation, Heavy Industry, Buildings, Agriculture, Waste, and Others. This breakdown is also used in *Canada's Second Biennial Report on Climate Change* (ECCC 2016). 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.5 details GHG emissions for Canada's 13 sub-national jurisdictions. Finally, as Canada's annual inventory submission to the UNFCCC embodies almost two decades of learning and improvements, Section ES.7 provides some detail on the components of this submission and outlines key elements of its preparation.

ES.2 Overview, National GHG Emissions

In 2015, the most recent annual dataset in this report, Canada's GHG emissions were 722 megatonnes of carbon dioxide equivalent (Mt CO_2 eq),[2] a net decrease of 16 Mt in total emissions or 2.2% from 2005 emissions (Figure S–1).[3] Annual emissions fluctuated between 2005 and 2008, dropped in 2009, and gradually increased thereafter.

In 2015, the Energy Sector (consisting of Stationary Combustion Sources, Transport, and Fugitive Sources) emitted 587 Mt of greenhouse gases, or 81% of Canada's total GHG emissions (Table S–3). The remaining emissions were largely generated by the Agriculture (8%) and Industrial Processes and Product Use (7%) sectors, with minor contributions from the Waste Sector (3%). The LULUCF Sector was a sink in 2015, with net removals of 34 Mt, a 3-Mt reduction from the net removals of 37 Mt in 2005.

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

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

Figure S–1 Canadian GHG Emissions Trend (2005–2015) (excluding LULUCF)

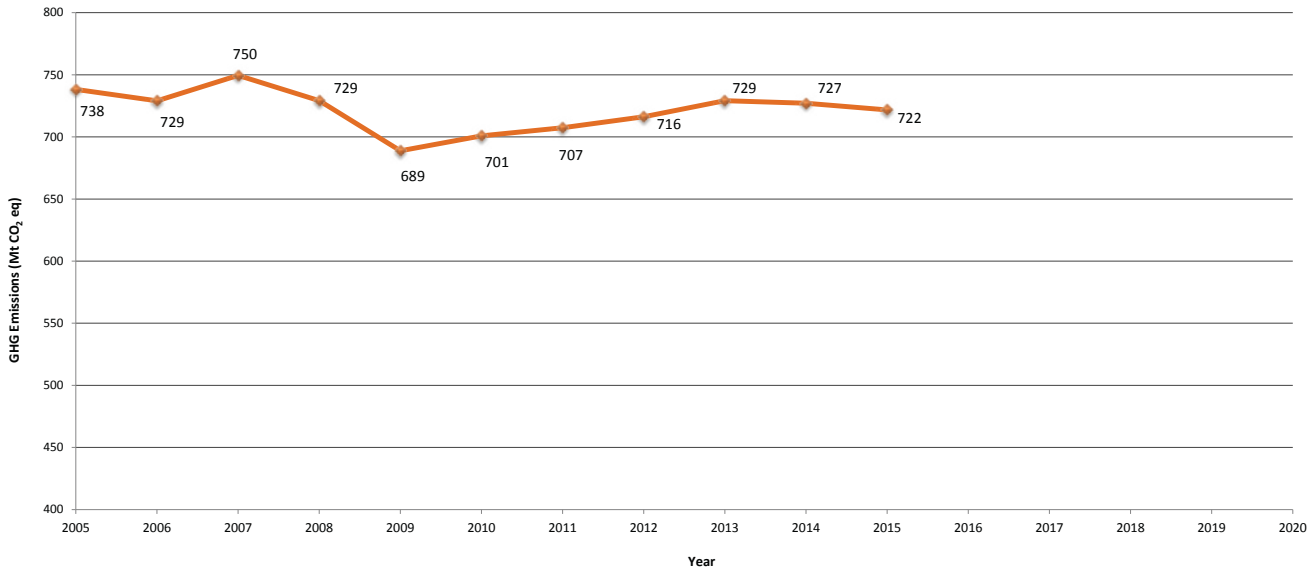


Figure S–2 Canada's Emissions Breakdown by IPCC Sector (2015)*

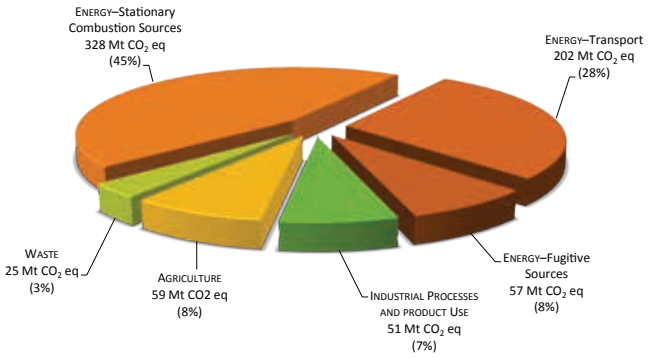
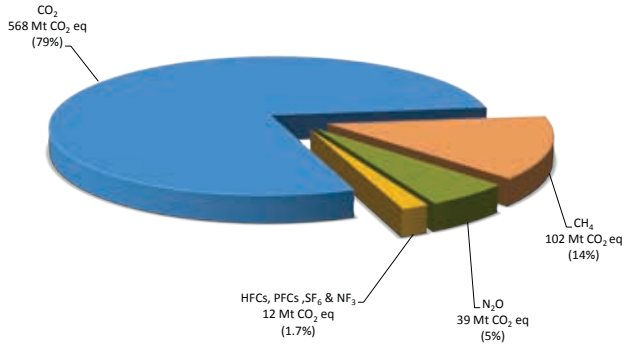


Figure S–3 Canada's Emissions Breakdown by GHG (2015)*



Total: 722 Mt CO_2 eq

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

Canada's emissions profile is similar to that of most industrialized countries. Carbon dioxide (CO_2) is the largest contributor to Canada's GHG emissions, accounting for 568 Mt or 79% of total emissions in 2015 (Figure S–3). The majority of the CO_2 emissions in Canada result from the combustion of fossil fuels. CH_4 emissions in 2015 amounted to 102 Mt or 14% of Canada's total. These emissions consist largely of fugitive emissions from oil and natural gas systems, agriculture and landfills. N_2O emissions arise from activities such as agricultural soil management and transport, and accounted for 39 Mt or 5.4% of Canada's emissions in 2015. Emissions of synthetic gases (HFCs, PFCs, SF_6 and NF_3) constituted slightly less than 2%.

Over the last decades Canada's economy has grown more rapidly than its GHG emissions. As a result, the emission intensity for the entire economy

Figure S–4 Indexed Trend in GHG Emissions and GHG Emissions Intensity (1990–2015)

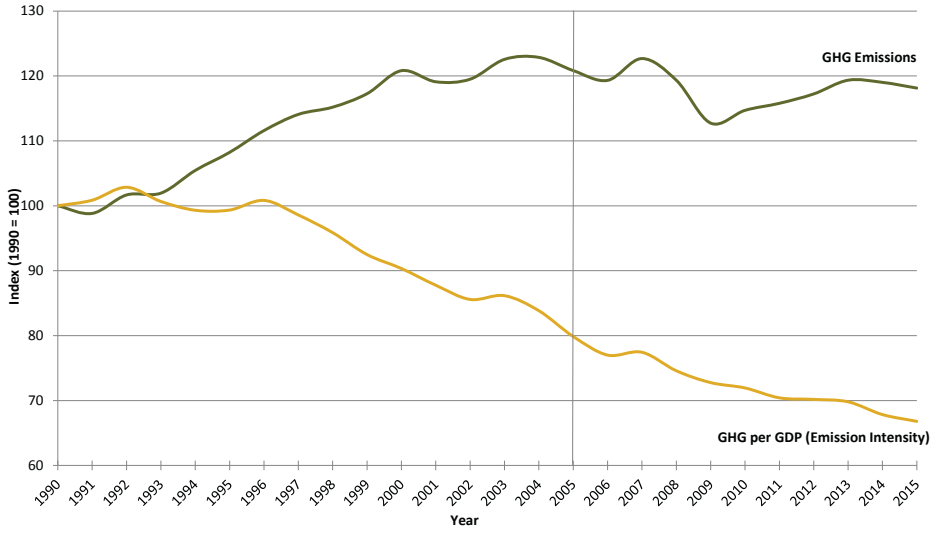
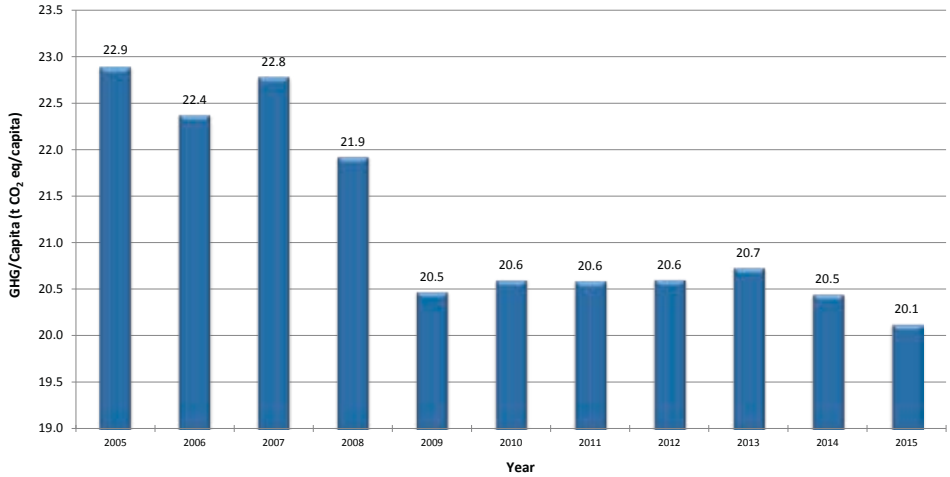


Table S–1 Trends in Emissions and Economic Indicators, Selected Years

Year	2005	2010	2011	2012	2013	2014	2015
Total GHG (Mt)	**738**	**701**	**707**	**716**	**729**	**727**	**722**
Change since 2005 (%)	NA	-5.1%	-4.2%	-3.0%	-1.2%	-1.5%	-2.2%
GDP (Billion 2007$)	**1 503**	**1 584**	**1 633**	**1 659**	**1 698**	**1 742**	**1 757**
Change since 2005 (%)	NA	5.4%	8.7%	10.4%	13.0%	16.0%	16.9%
GHG Intensity (Mt/$B GDP)	**0.49**	**0.44**	**0.43**	**0.43**	**0.43**	**0.42**	**0.41**
Change since 2005 (%)	NA	-9.9%	-11.8%	-12.1%	-12.6%	-15.1%	-16.4%

GDP data source: Statistics Canada (no date(a)) Table 380-0106 - Gross domestic product at 2007 prices, expenditure-based, annual (dollars). CANSIM (database).

Figure S–5 Canadian per Capita GHG Emissions (2005–2015)



Population data source: Statistics Canada. No date(b). Table 051-0001: Estimates of Population, by Age Group and Sex for July 1, Canada, Provinces and Territories, Annual (persons unless otherwise noted) CANSIM (database).

(GHG per GDP) has declined by 16.4% since 2005 (Figure S–4 and Table S–1). A divergence of emissions and emissions intensity began in the early 1990s (Figure S–4) and can be attributed to fuel switching, increases in efficiency, the modernization of industrial processes, and structural changes in the economy. These long-term trends have led to continued reduction in emissions intensity. Section ES.3 provides more information on trends in GHG emissions.

Canada represented approximately 1.6% of total global GHG emissions in 2013 (CAIT 2017), although it is one of the highest per capita emitters. Canada's per capita emissions have dropeed substantially since 2005, when this indicator was 22.9 t. By 2009, it had dropped to 20.5 t and has remained at historic lows ever since, with 2015 seeing the smallest per capita emissions yet at 20.1 t (Figure S–5).

ES.3 Emissions and Trends by IPCC Sectors

Trends in Emissions

Over the period 2005–2015, total emissions decreased by 16 Mt or 2.2% (Figure S–6). The Energy Sector dominated the long-term trend, with emission decreases of 11 Mt (3%) in Stationary Combustion Sources and 4 Mt (7%) in Fugitive Sources (Table S–2). In addition, the IPPU and Waste Sectors each saw decreases of 3 Mt (6% and 10% respectively), while emissions from Agriculture decreased by 2 Mt (3%). Over the same period, emissions from Transport increased by 7 Mt (4%) partially offsetting the decreases from the other sectors (Figure S–7)

Increases in emissions since 2009 can be attributed to increases in energy consumption and

Figure S–6 Trends in Canadian GHG Emissions by IPCC Sector (2005–2015)

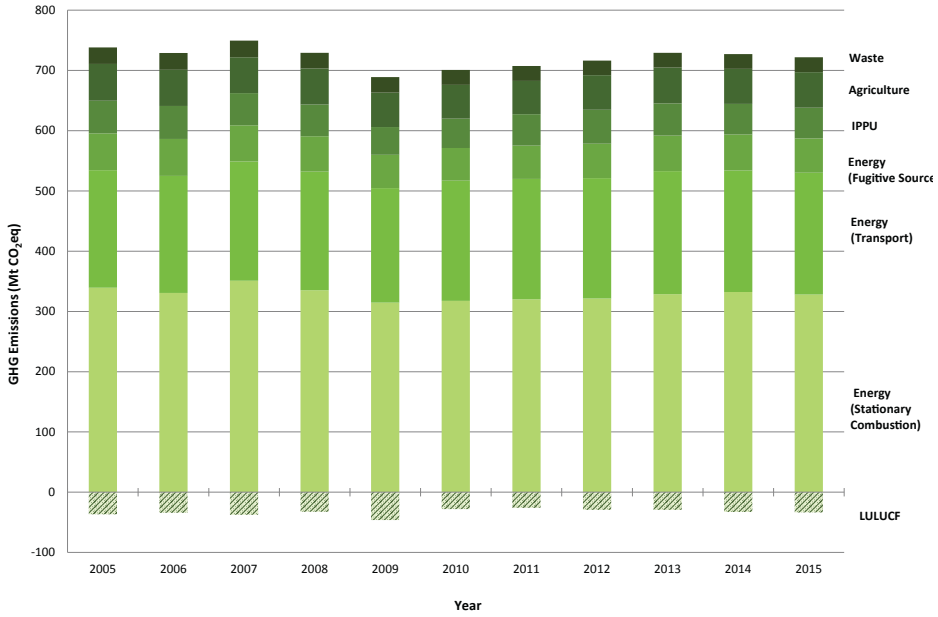
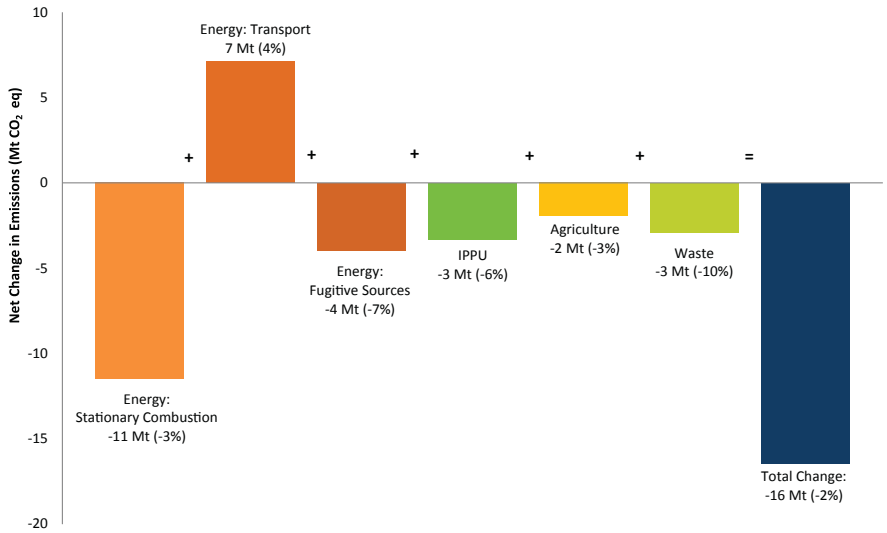


Table S–2 Canada's GHG Emissions by IPCC Sector, Selected Years

Greenhouse Gas Categories	2005	2009	2010	2011	2012	2013	2014	2015
				Mt CO_2 equivalent				
TOTAL[1,2]	**738**	**689**	**701**	**707**	**716**	**729**	**727**	**722**
ENERGY	**595**	**560**	**571**	**575**	**578**	**592**	**594**	**587**
a. Stationary Combustion Sources	339	315	318	320	322	329	332	328
Public Electricity and Heat Production	122	99	101	94	91	88	85	84
Petroleum Refining Industries	20	19	19	19	20	19	18	17
Mining and Upstream Oil and Gas Production	68	78	81	82	91	99	102	105
Manufacturing Industries	48	40	41	44	44	45	45	43
Construction	1	1	2	1	1	1	1	1
Commercial and Institutional	32	30	28	30	28	30	32	31
Residential	46	45	43	46	42	44	46	43
Agriculture and Forestry	2	3	3	4	4	4	4	4
b. Transport	195	190	199	200	200	204	202	202
Domestic Aviation	8	6	6	6	7	8	7	7
Road Transportation	134	136	142	143	144	147	144	144
Railways	7	5	7	8	8	7	8	7
Domestic Navigation	6	6	7	6	6	5	5	4
Other Transportation	41	36	38	38	36	37	38	39
c. Fugitive Sources	61	55	54	55	57	59	60	57
Coal Mining	1	1	1	1	1	2	1	1
Oil and Natural Gas	59	54	53	54	56	57	58	56
d. CO_2 Transport and Storage	0	0	0	0	0	0	0	0
INDUSTRIAL PROCESSES AND PRODUCT USE	**54**	**46**	**48**	**52**	**56**	**54**	**51**	**51**
a. Mineral Products	10	7	8	8	8	8	8	8
b. Chemical Industry	9	6	5	6	6	6	6	7
c. Metal Production	20	16	16	17	17	15	15	14
d. Production and Consumption of Halocarbons, SF_6 and NF_3	5	7	8	9	9	9	10	11
e. Non-Energy Products from Fuels and Solvent Use	9	10	11	12	15	15	12	11
f. Other Product Manufacture and Use	1	0	0	0	0	0	0	0
AGRICULTURE	**61**	**57**	**56**	**55**	**57**	**60**	**58**	**59**
a. Enteric Fermentation	31	27	26	25	25	25	25	25
b. Manure Management	10	9	8	8	8	8	8	9
c. Agricultural Soils	18	20	20	20	21	23	22	23
d. Field Burning of Agricultural Residues	0	0	0	0	0	0	0	0
e. Liming, Urea Application and Other Carbon-containing Fertilizers	1	2	2	2	2	3	2	3
WASTE	**28**	**26**	**25**	**25**	**24**	**24**	**25**	**25**
a. Solid Waste Disposal	25	23	22	22	22	22	22	22
b. Biological Treatment of Solid Waste	1	1	1	1	1	1	1	1
c. Wastewater Treatment and Discharge	1	1	1	1	1	1	1	1
d. Incineration and Open Burning of Waste	1	1	1	1	1	1	1	1
LAND USE, LAND-USE CHANGE AND FORESTRY	**-37**	**-46**	**-28**	**-26**	**-30**	**-29**	**-33**	**-34**
a. Forest Land	-183	-166	-159	-160	-164	-163	-166	-164
b. Cropland	-10	-12	-12	-12	-12	-11	-11	-11
c. Grassland	1	0	0	1	2	1	1	1
d. Wetlands	3	3	3	3	3	3	3	3
e. Settlements	4	4	4	4	4	4	4	4
f. Harvested Wood Products	149	125	136	138	137	138	137	135

Notes:
1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry Sector
2. These summary data are presented in more detail in Annex 9

Figure S–7 Short-term Emission Trends by IPCC Sector (2005–2014)



fugitive emissions in oil and gas operations (29 Mt),[4] increases in the number of heavy-duty diesel vehicles in operation (8 Mt), increased consumption of halocarbons (4 Mt), and continuous increases in the application of inorganic nitrogen fertilizers (3 Mt). During the same period, there was a 15-Mt decrease in emissions from electricity generation, which partly offset emission growth.

The measures established through the Pan-Canadian Framework on Clean Growth and Climate Change will set emissions on a downward trajectory in all sectors. Carbon pricing will play a central and cross-cutting role, while complementary mitigation actions across all sectors will support additional emissions reductions. This will include a broad suite of measures to: further decarbonize Canada's electricity sector; reduce emissions from fuels used in transportation, buildings and industry; improve the efficiency of transportation systems, buildings and industrial operations; and, protecting and enhancing Canada's carbon sinks. In addition, support for clean technology and innovation will support new emission reduction opportunities across all sectors.

Chapter 2 provides more information on trends in GHG emissions from both 1990 and 2005 and their drivers[5]. Further breakdowns of emissions by subsector and gas, and a complete time series can be found in Annex 9.

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

Energy—2015 GHG Emissions (587 Mt)

In 2015, GHG emissions from the IPCC Energy Sector (587 Mt) were 1.4% lower than in 2005 (595 Mt). Within the Energy Sector, the 37-Mt increase in emissions from Mining and Upstream Oil and Gas Production was offset by a 38-Mt decrease in emissions from Public Electricity and Heat Production.

Decreasing energy generation from coal and oil, accompanied by an increase in hydro, nuclear and wind generation, was the largest driver of the 31% decrease in emissions associated with

4 Energy consumption and fugitive emissions from oil and gas operations is the sum of emissions from: Petroleum Refining Industries, Mining and Upstream Oil and Gas Production, Pipeline Transport (under *Other Transportation*) and Fugitive Sources (see Table S–2).

5 The complete NIR can be accessed here: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php.

Electricity Production between 2005 and 2015. The permanent closure of all coal generating stations in the province of Ontario by 2014 was the determinant factor.[6] Emission fluctuations over the period reflect variations in the mix of electricity generation sources.[7]

GHG emissions from Manufacturing Industries decreased by 5.0 Mt between 2005 and 2015, consistent with both a 16% decrease in energy use and an observed decline in output[8] in these industries.

Oil production has been driven primarily by a rapid rise in the extraction of bitumen and synthetic crude oil from Canada's oil sands operations, where total output has increased by 140% since 2005. This has contributed to the 37 Mt increase in emissions between 2005 to 2015 from Mining and Upstream Oil and Gas Production. However, from 2010 to 2015 the emission intensity of oil sands operations themselves have dropped by approximately 16% as a result of technological and efficiency improvements, less venting emissions and reductions in the percentage of crude bitumen being upgraded to synthetic crude oil.

The majority of transport emissions in Canada are related to Road Transportation, which includes personal transportation (light-duty vehicles and trucks) and heavy duty trucks. The growth in road transport emissions is largely due to more driving. Despite a reduction in kilometres driven per vehicle, the total vehicle fleet has increased by 19% since 2005, most notably for trucks (both light-and heavy-duty), leading to more kilometres driven overall.

Industrial Processes and Product Use — 2015 GHG Emissions (51 Mt)

The Industrial Processes and Product Use Sector covers non-energy GHG emissions that result from manufacturing processes and use of products, such as limestone calcination in cement production and the use of HFCs and PFCs as replacement refrigerants for ozone-depleting substances (ODSs). Emissions from the IPPU Sector contributed 51 Mt (7%) to Canada's 2015 emissions.

Emissions of most industries decreased in 2008 and 2009 and have remained at similar levels since then. A notable exception includes the 5.9 Mt (116%) increase in emissions from the use of HFCs since 2005.

The aluminium industry has decreased its process emissions, largely due to technological improvements introduced to mitigate PFC emissions. The overall decrease in GHG emissions from chemical industries is primarily a result of the closure in 2009 of the sole Canadian adipic acid plant located in Ontario.

Agriculture — 2015 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% of total GHG emissions for Canada in 2015, down 2 Mt from their peak in 2005.

In 2015, Agriculture accounted for 28% of national CH_4 emissions and 71% of national N_2O emissions.

The main drivers of the emission trend in the Agriculture Sector are the fluctuations in livestock populations and application of inorganic nitrogen fertilizers in the Prairie Provinces. Since 2005, fertilizer use has increased, while livestock populations peaked in 2005 and decreased sharply to 2011. In 2015, emissions from livestock digestion (enteric fermentation) accounted for 42% of total agricul-

6 Ontario Power Generation News, April 15, 2014; http://www.opg.com/news-and-media/news-releases/Pages/news-releases.aspx?year=2014, accessed January 2016).

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, Energy Consumption by the Manufacturing Sector, 2015, Statistics Canada Daily, October 31, 2016; http://www.statcan.gc.ca/daily-quotidien/161031/dq161031d-eng.pdf (accessed January 24, 2017).

tural emissions, and the application of inorganic nitrogen fertilizers accounted for 22% of total agricultural emissions.

Waste — 2015 GHG Emissions (25 Mt)

The Waste Sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from Waste contributed 25 Mt (3.4%) to Canada's total emissions in 2015 and 28 Mt (3.7%) in 2005.

The primary source of emissions in the Waste Sector is Solid Waste Disposal, which includes municipal solid waste (MSW) landfills (19 Mt in 2015) and wood waste landfills (4 Mt in 2015). In 2015, Solid Waste Disposal accounted for 90% of Waste emissions, while Biological Treatment of Solid Waste (composting), Wastewater Treatment and Discharge, and Incineration and Open Burning of Waste contributed 3.8%, 4.3% Mt and 2.2%, respectively.

Methane emissions from publicly and privately owned municipal solid waste landfills (MSW) make up 86% of emissions from Solid Waste Disposal. The remainder originate from on-site industrial landfills of wood residues; such landfills are declining in number as markets for wood residues grow.

Methane emissions from MSW landfills decreased 11% between 2005 and 2015. Of the 30 Mt CO_2 eq of CH_4 generated by MSW landfills in 2015, only 19 Mt (or 62% of generated emissions) were actually emitted to the atmosphere. The other 11 Mt were captured and combusted at 81 landfill gas collection sites. The quantity of captured CH_4 increased from 27% in 2005 to 38% in 2015. Of the total amount of CH_4 collected in 2015, 51% (5.6 Mt) was utilized for various energy purposes and the remainder was flared.

Land Use, Land-use Change and Forestry — 2015 (Net GHG Removals of 34 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 2015, this net flux amounted to removals of 34 Mt, which, if included, would decrease the total Canadian GHG emissions by 4.6%. New this year, the LULUCF estimates now exclude the impact of significant natural disturbances in managed forests (wildfires and insects), revealing more meaningful trends associated with anthropogenic activities. Additional information on the changes made this year can be found in Chapter 6.

The trend in net removals is mainly driven by a decrease in net CO_2 removals from Forest Land combined with HWP, partially attenuated by an increase in net CO_2 removals in Cropland and reduced emissions from the conversion of forests to other land use.

Net removals from Forest Land decreased from 180 Mt in 2005 to 165 in 2015, fluctuating in recent years between removals of 160 to 170 Mt as forests recover from peak harvest rates and insect disturbance in the mid-2000s. Over this same period emissions from Harvested Wood Products (HWP) originating from Canada fluctuated between 150 Mt in to 2005, to a low of 125 Mt in 2009 (the year of the lowest harvest rates), and have since increased to 135 Mt in 2015. A significant proportion of HWP emissions result from the decay of long-lived wood products reaching the end of their economic life decades after the wood was harvested. Harvested Wood Product emissions like

Forest Land emissions and removals are influenced by recent forest management trends, but also by the long-term impact of forest management that occurred in past decades.

Since 2005, net removals from Cropland have increased slightly from 10.3 to 10.9 Mt. However removals actually peaked in 2009 at 11.7 Mt and have since declined as a result of an increase in the conversion of perennial to annual crops on the prairies, the declining effect of conversion to conservation tillage and slower rates of agricultural expansion onto forest land.

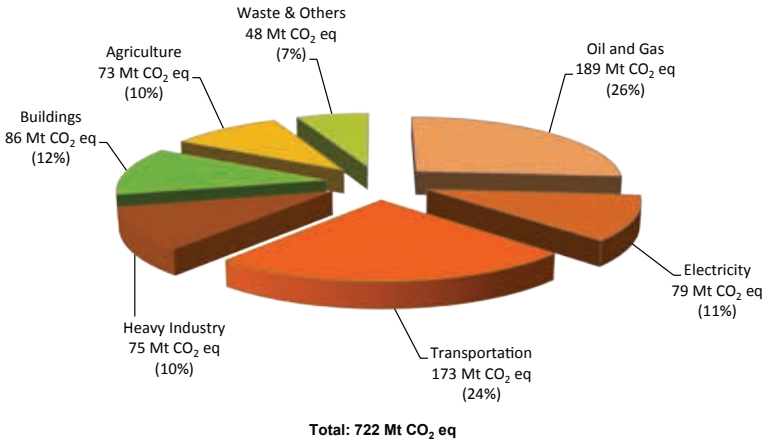
The conversion of forests[9] to other land uses is a prevalent, yet declining, practice in Canada and is mainly due to forest conversion to settlements for resource extraction and cropland expansion. Emissions due to forest conversion fell from 16 Mt in 2005 to 14 Mt in 2015.

ES.4 Canadian Economic Sectors

For the purposes of analyzing economic trends and policies, it is useful to allocate emissions to the

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.

Figure S–8 Canada's Emissions Breakdown by Economic Sector (2015)



Note: Totals may not add up due to rounding.

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

	2005	2009	2010	2011	2012	2013	2014	2015
				Mt CO_2 equivalent				
NATIONAL GHG TOTAL	738	689	701	707	716	729	727	722
Oil and Gas	158	158	160	161	174	185	190	189
Electricity	117	95	96	89	85	82	80	79
Transportation	163	163	171	171	173	176	173	173
Heavy Industry[1]	86	71	73	80	79	77	77	75
Buildings	85	84	81	87	85	85	88	86
Agriculture	74	70	70	70	71	74	72	73
Waste & Others[2]	54	49	50	50	49	49	48	48

Notes: Totals may not add up due to rounding.
Estimates presented here are under continual improvement. Historical emissions may be changed in future publications as new data become available and methods and models are refined and improved.

1. Heavy Industry represent emissions arising from non-coal, -oil and -gas mining activities, smelting and refining, and the production and processing of industrial goods such as paper or cement.
2. "Others" includes Coal Production, Light Manufacturing, Construction & Forest Resources.

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 re-categorizes emissions under different headings and does not change the overall magnitude of Canadian emissions estimates.

GHG emissions trends in Canada's economic sectors from 2005 to 2015 are consistent with those described for IPCC sectors, with the Oil and Gas and Transportation economic sectors showing emission increases of 20% and 6% respectively over the last decade (Figure S–8 and Table S–3) These increases have been more than offset by emission decreases in Electricity (33%), Heavy Industry (13%) and Waste & Others (13%).

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 cross-walk between IPCC and economic sector categories, can be found in Part 3 of this report.

ES.5 Provincial and Territorial GHG Emissions

Emissions vary significantly by province as a result of 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 diverged. Emissions in Alberta increased from 233 Mt in 2005 to 274 Mt in 2015 (18%), primarily as a result of the expansion of oil and gas operations (Figure S–9 and Table S–4). In contrast, Ontario's emissions have steadily decreased since 2005 (by 38 Mt or 19%), owing primarily to the closure of coal-fired electricity generation plants.

Electricity production in Quebec and British Columbia relies on abundant hydroelectric

Figure S–9 Emissions by Province in 2005, 2010 and 2015

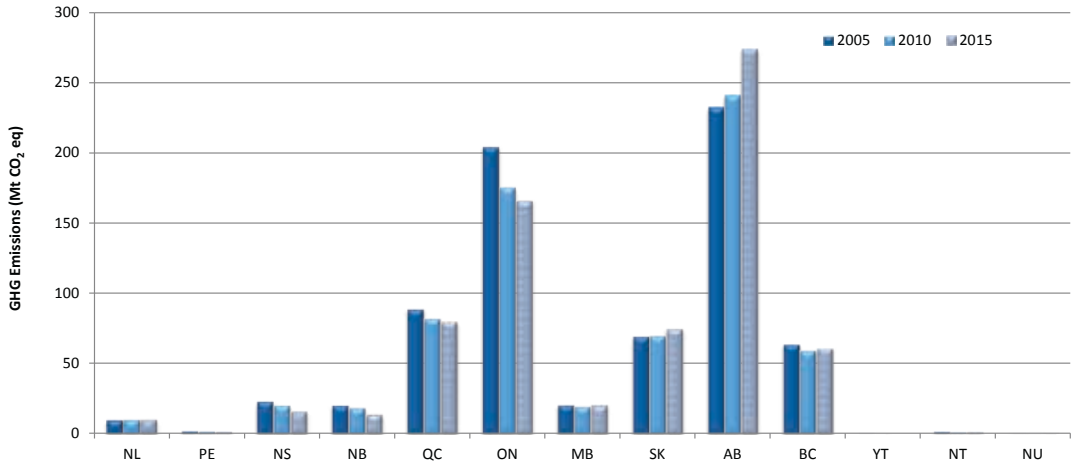


Table S–4 GHG Emissions by Provinces / Territories, Selected Years

	GHG Emissions (Mt CO_2 eq)							Change (%)
Year	2005	2010	2011	2012	2013	2014	2015	2005-2015
Total (Canada)	738	701	707	716	729	727	722	-2.2%
NL	10.1	10.3	10.3	9.9	9.6	10.6	10.3	2.1%
PE	2.1	2.0	2.2	2.1	1.8	1.8	1.8	-14%
NS	23	20	21	19	18	16	16	-30%
NB	20	19	19	17	15	14	14	-31%
QC	89	82	84	81	82	80	80	-10%
ON	204	175	175	171	171	168	166	-19%
MB	21	20	19	21	21	21	21	0.7%
SK	70	70	69	72	74	75	75	7.8%
AB	233	241	246	260	272	276	274	18%
BC	64	59	60	61	62	61	61	-4.7%
YT	0.4	0.4	0.4	0.4	0.4	0.3	0.3	-43%
NT	1.6	1.3	1.4	1.5	1.4	1.3	1.4	-12%
NU	0.5	0.5	0.5	0.6	0.6	0.7	0.6	38%

Notes:
1. Totals may not add up due to rounding.

resources, resulting in more stable emission patterns across the time series. Quebec experienced a 9.8% (8.7 Mt) decrease from its 2005 emissions level, while British Columbia had a decline of 4.7% (3.0 Mt).

Emissions in Saskatchewan increased by 7.8% (5.5 Mt) between 2005 and 2015 as a result of activities in the oil and gas industry, potash and uranium mining and transportation. Emissions in Manitoba and Newfoundland and Labrador have also increased since 2005, but to a lesser extent (0.7% and 2% respectively). Provinces which have seen more significant decreases in emissions include New Brunswick (31% reduction, or 6.2 Mt), Nova Scotia (30% reduction, or 7.0 Mt), and Prince Edward (14% reduction, or 0.3 Mt).

ES.6 Pathway to Canada's 2030 target

To achieve its target, Canada must reduce its total economy-wide emissions to 523 Mt in 2030. The Government of Canada uses a recognized energy and macroeconomic modeling framework to produce emissions projections to 2030, which are published on an annual basis. The most recent emissions projections, published in December 2016 (https://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=1F24D9EE-1), indicate that with federal, provincial and territorial policies and measures that have legislated or funding certainty and were in place as of November 1st, 2016, (just prior to the Pan-Canadian Framework) total Canadian GHG emissions would be 742 megatonnes of carbon dioxide equivalent (Mt CO_2eq) in 2030.

Figure S–10 Pathway to Canada's 2030 target

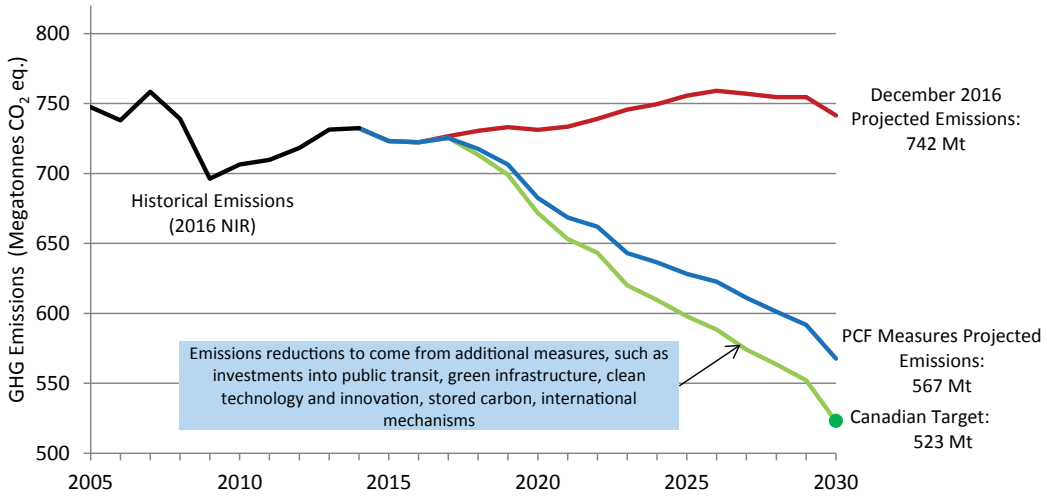
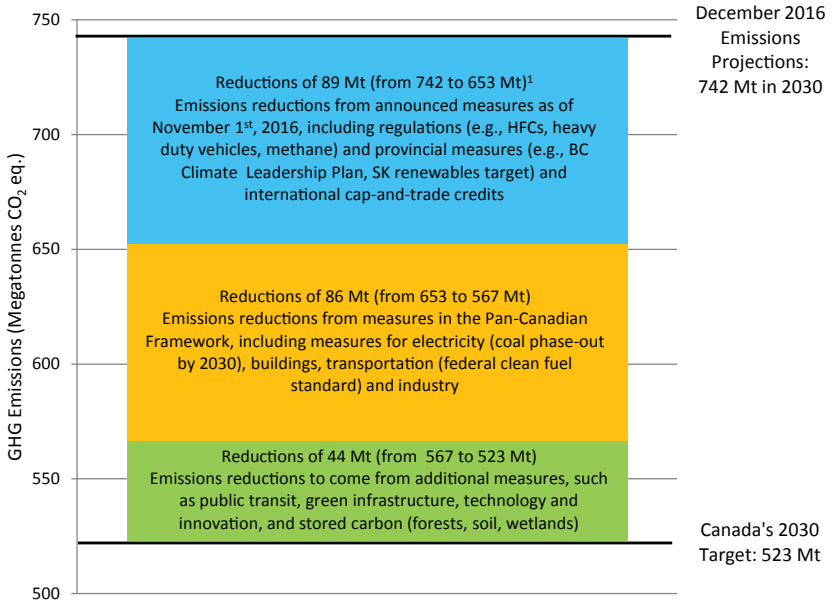


Figure S–11 Emissions Reductions from the Pan-Canadian Framework



Note: Reductions from carbon pricing are built into the different elements depending on whether they are implemented, announced, or included in the Pan-Canadian Framework. The path forward on pricing will be determined by the review to be completed by early 2022.

1. Estimates assume purchase of carbon allowances (credits) from California by regulated entities under Quebec and Ontario's cap-and-trade system that are or will be linked through the Western Climate Initiative.

ES.7 National Inventory Arrangements

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

The institutional arrangements for the preparation of the inventory include: formal agreements supporting 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, 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: http://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b.

Chapter 1

INTRODUCTION

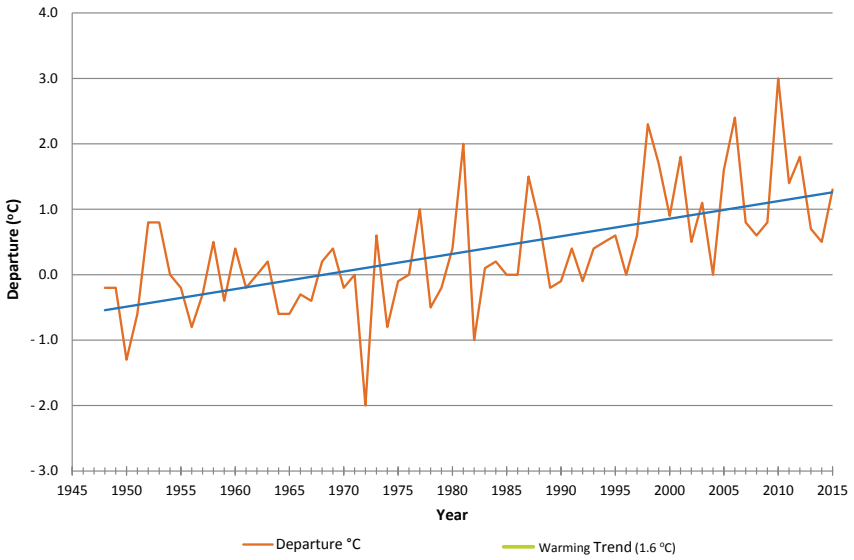
1.1. Greenhouse Gas Inventories and Climate Change

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 144%, CH_4 by 256% and nitrous oxide (N_2O) by 121% (WMO 2016). 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).

Figure 1–1 Annual Canadian Temperature Departures and Long-term Trend, 1948–2015



Data source: Environment Canada (2016)

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 2015 was 1.3°C above normal (see Figure 1–1). Annual temperatures in Canada have been at or above normal since 1993, with a warming trend of 1.6°C over the last 68 years (Environment and Climate Change Canada 2016).

In December 2015 at COP 21, parties to the UNFCCC established the Paris Agreement, an ambitious and balanced agreement to fight climate change under which Canada committed to an emissions reduction target of 30% below 2005 levels by 2030. More recently, Canada established a Pan-Canadian Framework on Clean Growth and Climate Change in December 2016. This Framework is a comprehensive plan to reduce emissions across all sectors of Canada's economy, as well as to stimulate clean economic growth, and build resilience to the impacts of climate change. The actions outlined in the Pan-Canadian Framework will enable Canada to meet or exceed its target to reduce emissions to 30% below 2005 levels by 2030. Canada's greenhouse gas inventory will continued to play a key role in keeping both Canadians and the international community informed of progress made in reducing GHG emissions and meeting these commitments.

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 Conference of the Parties (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 1990–2015. The NIR, along with the Common Reporting Format (CRF) tables, comprise Canada's 2016 submission to the UNFCCC. The NIR and CRF tables have been prepared in accordance with the revised *Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual greenhouse gas inventories* (UNFCCC Reporting Guidelines) adopted by the Conference of the Parties at its nineteenth session in 2013.

1.1.2. Greenhouse Gases

This report documents estimates of Canada's

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.

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 (SF6)

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

GHGs are not all equal: 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 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,

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[1]
Carbon Dioxide	CO_2	1
Methane[2]	CH_4	25
Nitrous Oxide	N_2O	298
Sulphur Hexafluoride	SF_6	22 800
Nitrogen Trifluoride	NF_3	17 200
Hydrofluorocarbons (HFCs)		
HFC-23	CHF_3	14 800
HFC-32	CH_2F_2	675
HFC-41	CH_3F	92
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1 640
HFC-125	CHF_2CF_3	3 500
HFC-134	CHF_2CHF_2	1 100
HFC-134a	CH_2FCF_3	1 430
HFC-143	CH_2FCHF_2	353
HFC-143a	CH_3CF_3	4 470
HFC-152	CH_2FCH_2F	53
HFC-152a	CH_3CHF_2	124
HFC-161	CH_3CH_2F	12
HFC-227ea	CF_3CHFCF_3	3 220
HFC-236cb	$CH_2FCF_2CF_3$	1 340
HFC-236ea	CHF_2CHFCF_3	1 370
HFC-236fa	$CF_3CH_2CF_3$	9 810
HFC-245ca	$CH_2FCF_2CHF_2$	693
HFC-245fa	$CHF_2CH_2CF_3$	1 030
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794
Perfluorocarbons (PFCs)		
Perfluoromethane	CF_4	7 390
Perfluoroethane	C_2F_6	12 200
Perfluoropropane	C_3F_8	8 830
Perfluorobutane	C_4F_{10}	8 860
Perfluorocyclobutane	c-C_4F_8	10 300
Perfluoropentane	C_5F_{12}	9 160
Perfluorohexane	C_6F_{14}	9 300
Perfluorodecalin	$C_{10}F_{18}$	7 500
Perfluorocyclopropane	c-C_3F_6	17 340

Note:
1. Data source: IPCC's *Fourth Assessment Report - Errata* (IPCC 2012).
2. The GWP for methane includes indirect effects from enhancements of ozone and stratospheric water vapour.

they need to be adjusted on a regular basis to capture the increase of gases already existing in the atmosphere and changing atmospheric conditions. Consistent with Decision 24/CP19, the 100-year GWP values provided by the IPCC in its *Fourth Assessment Report* (Table 1–1) are used in this report. For example, the 100-year GWP for 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.r.

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

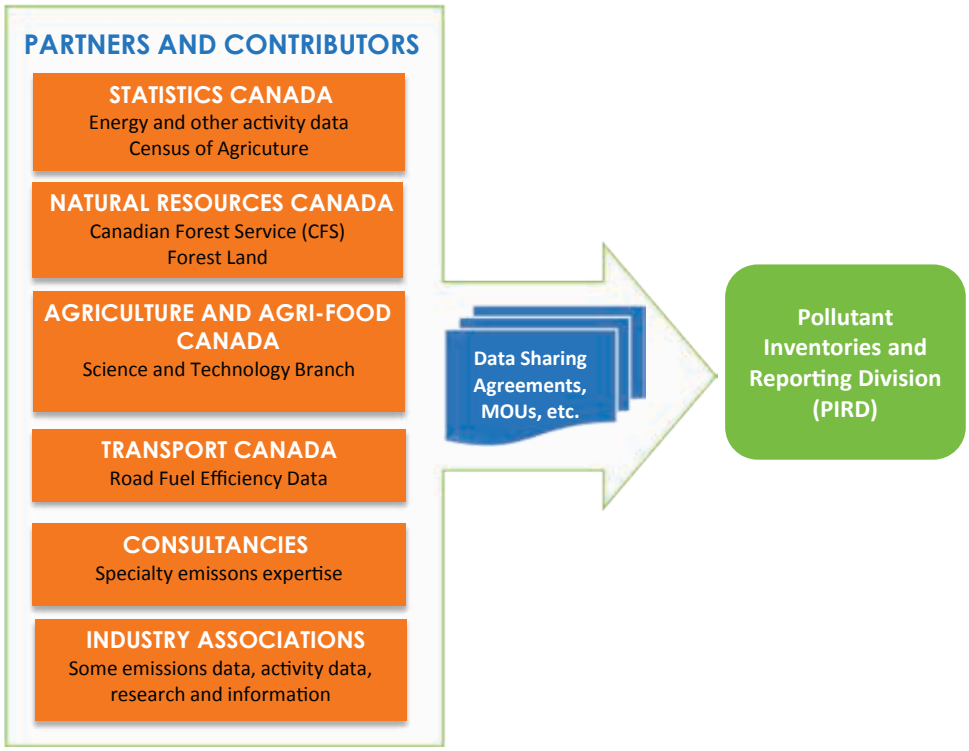
A detailed description of the functions of the Pollutant Inventories and Reporting Division is provided in Section 1.2.2 "Process for Inventory Preparation".

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 has established and manages all aspects of the arrangements supporting the GHG inventory.

Sources and sinks of GHGs originate from a tremendous range of economic sectors and activities. Recognizing the need to draw on the best available technical and scientific expertise and information, Environment and Climate Change Canada has defined roles and responsibilities for the preparation of the inventory, both internally and externally. As such, Environment and Climate

Figure 1–2 Partners and Contributors to National Inventory Arrangements



Change Canada is involved in many agreements with data providers and expert contributors in a variety of ways, ranging from informal to formal arrangements. These agreements include: partnerships with other government departments, namely Statistics Canada, Natural Resources Canada (NRCan), Agriculture and Agri-Food Canada (AAFC), and Transport Canada; arrangements with industry associations, consultants and universities; and collaborative agreements with provincial and territorial governments on a bilateral basis.

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 Environment and Climate Change Canada 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 Environment and Climate Change Canada 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, Environment and Climate Change Canada, Natural Resources Canada (NRCan) and the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC) 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.

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

Since 2005, Environment and Climate Change Canada 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 and has established formal and explicit governance mechanisms to that effect 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.

Environment and Climate Change Canada 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.

Environment and Climate Change Canada annually collects GHG emissions data from facilities that directly emit large amounts of GHGs under its GHG Emissions 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 Aluminum 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 Environment and Climate Change Canada. 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. Environment and Climate Change Canada has also been collaborating with magnesium casting companies and companies that import or distribute HFCs, with regard to their annual data on GHG emissions and/or supporting activity data.

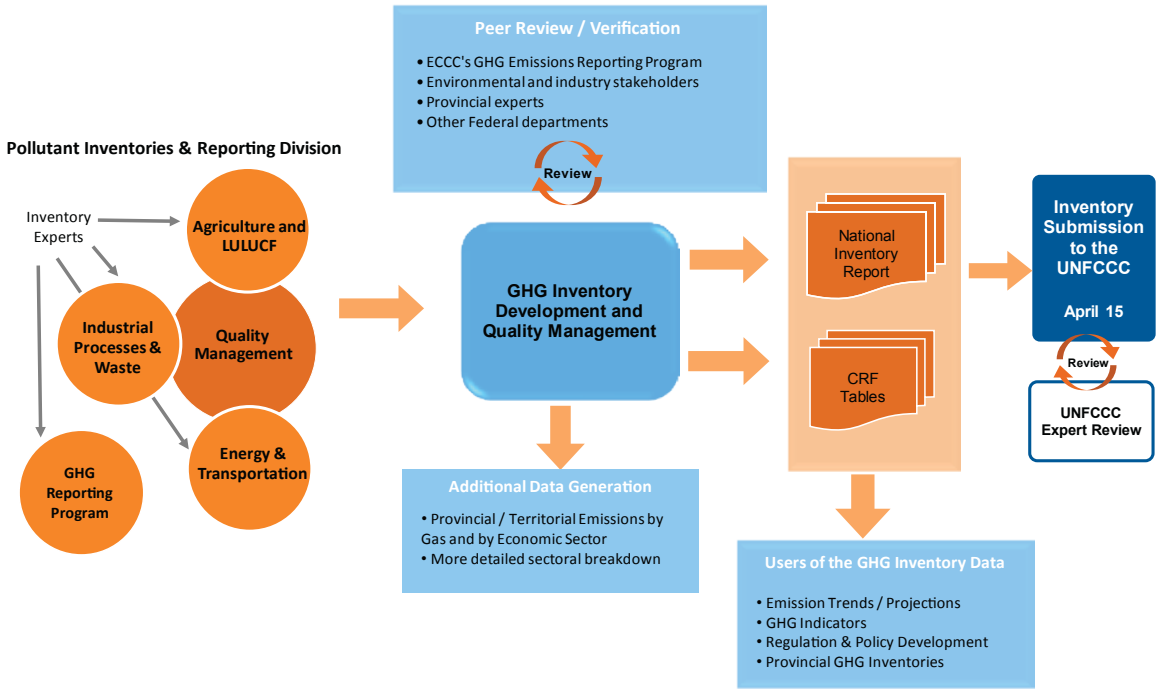
When required, and resources permitting, contracts are established with consulting firms and universities to conduct in-depth studies—for example, on developing or updating country-specific emission factors.

1.2.2. Process for Inventory Preparation

Canada's inventory is developed, compiled and reported annually by Environment and Climate Change Canada'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 Inventory Coordinator within 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

Figure 1–3 Inventory Preparation Process



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 October and the data collection process is completed by the end of November. 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 forms of models. In December and January, 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 signed off by managers before the report and national totals are prepared. 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 fully edited. 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. Initial checks of the April submission are performed by the UNFCCC in May and June. 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, several briefings of senior officials take place 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

In general, and for the purpose of developing Canada's GHG inventory, confidential information is defined as information that could directly or indirectly identify an individual person, business or organization. During the d evelopment of the inventory, procedures are in place to ensure confidentiality of source data, when required. To safeguard confidential information, some emissions are aggregated to a level such that confidentiality is no longer an issue. Examples include:

- In the Industrial Processes and Product Use Sector, emissions are aggregated across categories at a provincial level to protect confidential data (emissions from ammonia, nitric acid and petrochemical production are aggregated with the Non-energy Products from Fuels and Solvent Use Sector at the provincial level).
- In certain cases, emissions from Croplands are aggregated with neighbouring reporting zones I to protect confidential data.

These procedures are documented and confidential source data is protected and archived accordingly.

Specific to data received from Statistics Canada that are used to estimate GHG emissions in the Energy and Industrial Processes and Product Use sectors, Statistics Canada reviews and approves the confidentiality protocol 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 Environment and Climate Change Canada.

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 is documented in a *Quality Manual*, which 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 also 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.

1.3.2.1. 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

Although Canada produces a high quality inventory on an annual basis, there is always room for improvement. 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.

The following verification activities are performed annually:

- Comparison of Canada's GHG inventory with other independently compiled inventories (e.g. provincial inventories or those compiled by research organisations), other national inventories, independent literature sources or direct source testing results; and
- Bottom-up comparisons of sectoral estimates against facility-level data collected under the GHGRP (where appropriate).

1.3.4.1. The GHG Emissions Reporting Program

In March 2004, the Government of Canada established the Greenhouse Gas Emissions Reporting Program (GHGRP) and, under section 46(1) of the *Canadian Environmental Protection Act, 1999* (CEPA), it collects GHG emissions information annually from facilities. As per the legal notice published annually in the Canada Gazette, facilities that produce emissions of 50 kt CO_2 eq or more during any given year are required to submit a GHG emission report by June 1 of the following year. Voluntary submissions from facilities with GHG emissions below the reporting threshold are accepted.

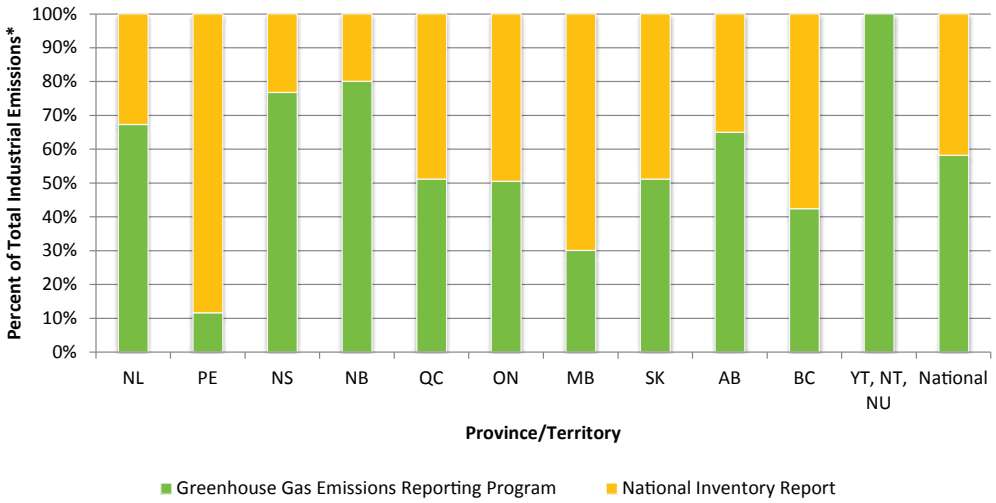
The types of facilities reporting GHG emissions to Canada's GHGRP are mainly large industrial operations such as:

- Power generation plants that use fossil fuels to produce electricity, heat or steam;
- Integrated steel mills;
- Oil and gas extraction operations;
- Facilities involved in the mining, smelting and refining of metals;
- Pulp, paper and sawmills;
- Petroleum refineries; and
- Chemical producers.

Specific estimation methods are not prescribed, and reporters can choose the quantification methodologies most appropriate for their particular industry or application. However, 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.

It is important to note that the GHGRP applies to the largest GHG-emitting facilities (mostly industrial) and does not cover other sources of GHG emissions (e.g. road transportation, agricultural sources), whereas the NIR is a complete accounting of all GHG sources and sinks in Canada.

Figure 1–4 2015 Facility-Reported Emissions as a Percentage of Industrial GHG Emissions by Province/Territory



* Canada's industrial GHG emissions include the following GHG categories from the National Inventory Report 1990–2015: Greenhouse Gas Sources and Sinks in Canada: Stationary Combustion Sources (except Residential), Other Transportation, Fugitive Sources, Industrial Processes and Product Use, and Waste

Environment and Climate Change Canada's GHGRP website[5] provides public access to the reported GHG emission information (GHG totals by gas by facility). The total facility-reported GHG emissions for 2015 represent just over one third (37%) of Canada's total GHG emissions in 2015 (722 Mt) and over half (58%) of Canada's industrial GHG emissions. The degree of coverage from the facility-reported data of industrial GHG emissions at the provincial level varies significantly from province to province, depending on the size and number of industrial facilities in each province that have emissions above the 50kt reporting threshold (Figure 1–4).

Facility-level GHG emission data are used, where appropriate, to confirm reasonableness of emission estimates in the NIR developed from national and provincial statistics. Information gathered from these large industrial facilities is shared with provincial and territorial jurisdictions. The GHGRP also provides Canadians with consistent information about the GHG emissions reported by facilities. 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 Environment and Climate Change Canada's GHGRP, including short- and long-term changes observed in facility emissions, refer to the publication *Facility Greenhouse Gas Emissions Reporting Program – Overview of Reported 2015 Emissions* (Environment and Climate Change Canada 2017).

5 The Greenhouse Gas Emissions Reporting Program website can be found at www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=040E378D-1.

1.4. Annual Inventory Review

Since 2003, 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.[6] Review reports are posted on-line by the UNFCCC Secretariat once finalized.[7] At the time of preparing this NIR, the results of Canada's last review were still forthcoming.

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: SOx, 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.[8]

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

6 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.

7 Annual Inventory Review Reports are available online at http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/9916.php.

8 Information on Canada's ozone and aerosol precursors, including carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO_x) can be found in Canada's Air Pollutant Emission Inventory which is available online at http://www.ec.gc.ca/pollution/default.asp?lang=En&n=E96450C4-1.

considerable spatial and interannual variability, and they also span several years or decades. The most practical approach to estimating emissions and removals requires a combination of repeated measurements and modelling. The need, unique to these systems, to separate anthropogenic impacts from large natural fluxes creates an additional challenge.

The methodologies (Annex 3) and 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) for the choice of estimation methods. The decision trees formalize the choice of estimation method most suited to national circumstances, considering at the same time 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 one that 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 1990–2015 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 most contribute to the national total (excluding LULUCF) are the fuel combustion categories Stationary Combustion – Gaseous, Liquid and Solid Fuels, Road Transportation, and Adipic acid Production. The categories that

have the strongest influence on the trend (including LULUCF) are the fuel combustion categories Stationary Combustion–Gaseous, Liquid and Solid Fuels, and Road Transportation and the LULUCF category Forest Land and Remaining Forest Land.

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[9] 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 guidelines specify that the primary purpose of quantitative uncertainty information is to assist in setting priorities to improve future inventories and to guide decisions about which methods to use. Typically, the uncertainties associated with the trends and the national totals are much lower than those associated with individual gases and sectors.

Annex 2 presents the uncertainty assessment for Canadian GHG emissions. 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 ±3%. The Energy Sector had the lowest uncertainty, at ±2%, while the Waste Sector had the highest uncertainty, at ±41%. The Industrial Processes and Product Use and Agriculture Sectors had uncertainties of ±9 and ±17%, respectively.

The categories that make the largest contribution to uncertainty at the national level are:

1. Waste – Solid Waste Disposal - Managed Waste Disposal Sites, CH_4;
2. Waste – Solid Waste Disposal - Uncategorized Waste Disposal Sites - Wood Waste Landfills, CH_4;
3. Agriculture – Direct Agriculture Soils, N_2O;
4. Agriculture – Enteric Fermentation, CH_4; and
5. Fugitives Sources – Oil & Gas, 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 0.9%. Therefore, the total increase in emissions since 1990 has a 95% probability of being in the range of 17 to 19%. The trend uncertainty, including LULUCF, was found to be 15%.

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

9 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).

under the UNFCCC. However, emissions for some categories have not been estimated or have been included with other categories due to the following:

- Categories that are not occurring in Canada;
- Data unavailability at the category level;
- Methodological issues specific to national circumstances; and/or
- Emission estimates are considered insignificant.[10]

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).

10 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 EMISSION TRENDS

2.1. Summary of Emission Trends

In 2015, Canada's greenhouse gas (GHG) emissions were 722 megatonnes of carbon dioxide equivalent (Mt CO_2 eq),[1] a net decrease of 16 Mt in total emissions or 2.2% from 2005 emissions (Figure 2–1).[2] Dating back to 1990, annual emissions steadily increased during the first 10 years of this period, fluctuated between 2000 and 2008, dropped in 2009, and gradually increased thereafter.

Emissions increases since 2009 can be attributed to increases in energy consumption and fugitive emissions from oil and gas operations (29 Mt),[3] increases in the number of heavy-duty diesel vehicles in operation (8 Mt), increased consumption of halocarbons (4 Mt), and continuous increases in the application of inorganic nitrogen fertilizers (3 Mt). During the same period, there was a 15 Mt decrease in emissions from electricity generation, which partly offset emission growth. Section 2.3 provides more detail on these and other key drivers of these trends.

The measures established through the Pan-Canadian Framework on Clean Growth and Climate

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 as rounded figures. However, all calculations (including percentages) have been performed using unrounded data.

3 Energy consumption and fugitive emissions from oil and gas operations is the sum of emissions from: Petroleum Refining Industries, Mining and Upstream Oil and Gas Production, Pipeline Transport (under Other Transportation) and Fugitive Sources (see Table 2–3).

Figure 2–1 Canadian GHG Emissions Trend (excluding LULUCF)

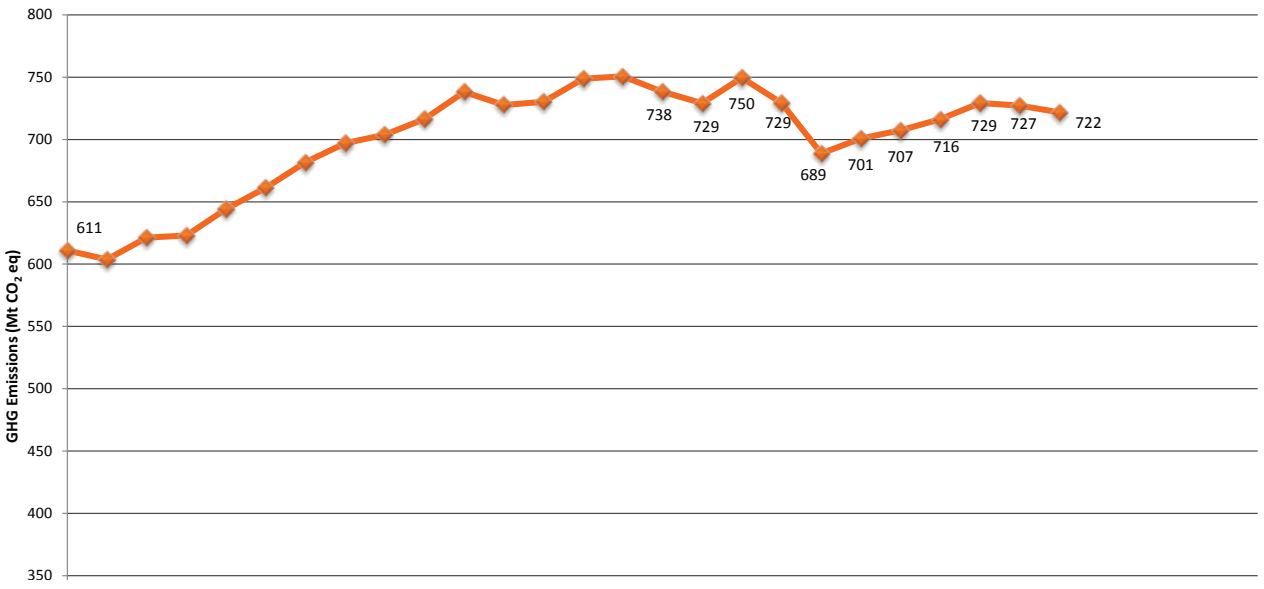
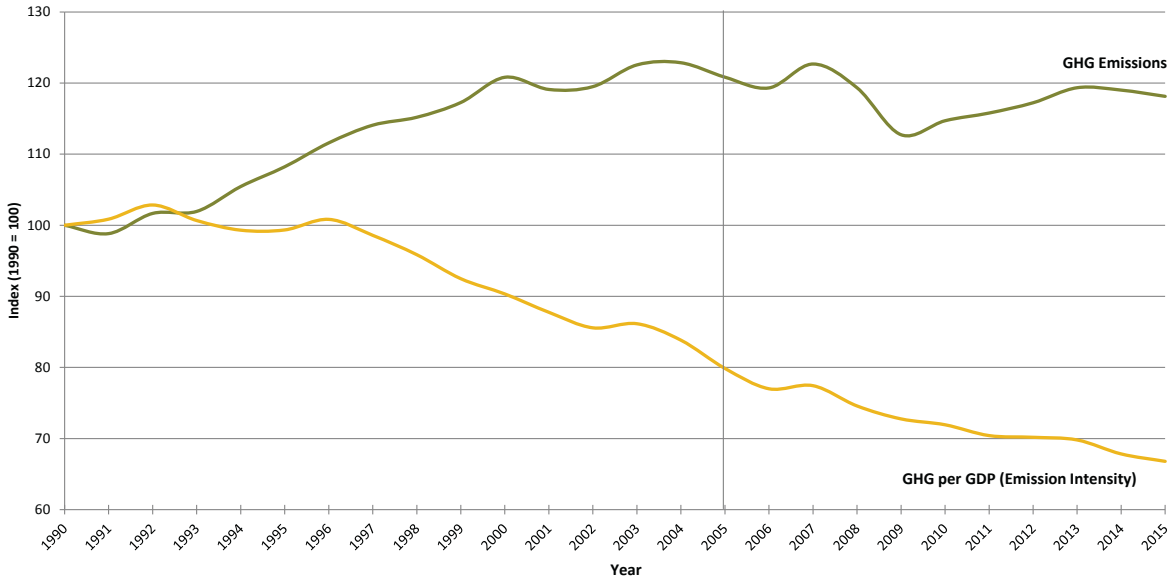


Figure 2–2 Indexed Trend in GHG Emissions and GHG Emissions Intensity (1990–2015)



GDP data source: Statistics Canada (no date [a]) Table 380-0106 - Gross domestic product at 2007 prices, expenditure-based, annual (dollars). CANSIM (database)

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

Year	1990	2005	2010	2011	2012	2013	2014	2015
Total GHG (Mt)	**611**	**738**	**701**	**707**	**716**	**729**	**727**	**722**
Change since 2005 (%)	NA	NA	-5.1%	-4.2%	-3.0%	-1.2%	-1.5%	-2.2%
Change since 1990 (%)	NA	20.8%	14.7%	15.8%	17.2%	19.3%	19.0%	18.1%
GDP (Billions 2007$)	993	1 503	1 584	1 633	1 659	1 698	1 742	1 757
Change since 2005 (%)	NA	NA	5.4%	8.7%	10.4%	13.0%	16.0%	16.9%
Change since 1990 (%)	NA	51.3%	59.4%	64.4%	67.1%	71.0%	75.4%	76.9%
GHG Intensity (Mt/$B GDP)	0.62	0.49	0.44	0.43	0.43	0.43	0.42	0.41
Change since 2005 (%)	NA	NA	-9.9%	-11.8%	-12.1%	-12.6%	-15.1%	-16.4%
Change since 1990 (%)	NA	-20.1%	-28.1%	-29.6%	-29.8%	-30.2%	-32.2%	-33.2%

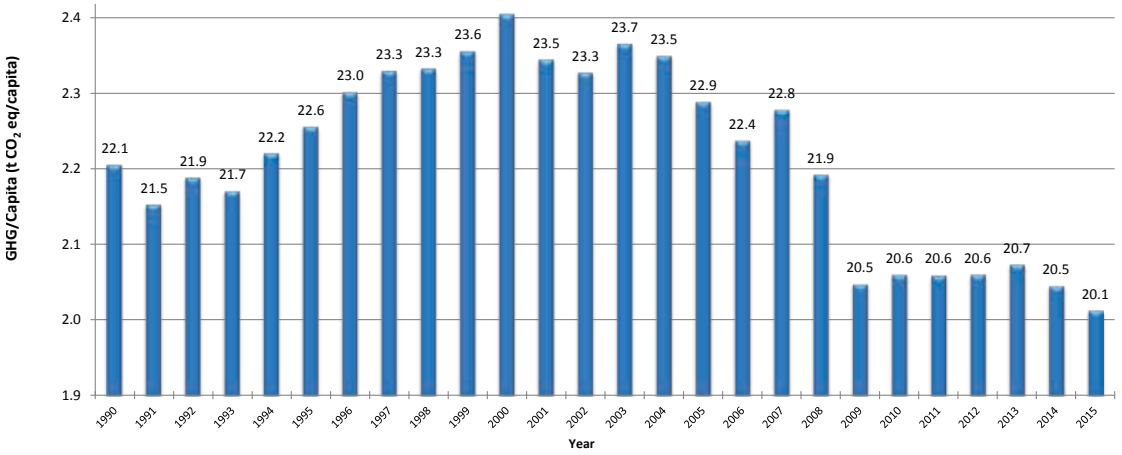
GDP data source: Statistics Canada (no date(a)) Table 380-0106 - Gross domestic product at 2007 prices, expenditure-based, annual (dollars). CANSIM (database).

Change will set emissions on a downward trajectory in all sectors. Carbon pricing will play a central and cross-cutting role, while complementary mitigation actions across all sectors will support additional emissions reductions. This will include a broad suite of measures to: further decarbonize Canada's electricity sector; reduce emissions from fuels used in transportation, buildings and industry; improve the efficiency of transportation systems, buildings and industrial operations; and, protecting and enhancing Canada's carbon sinks. In addition, support for clean technology and innovation will support new emission reduction opportunities across all sectors.

Canada's economy has grown more rapidly than its greenhouse gas emissions. As a result, the emissions intensity for the entire economy (or GHGs per GDP) has declined by 33% since 1990, and by 16% since 2005 (Figure 2–2, Table 2-1). The divergence of 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. These long term trends have led to continued reduction in emissions intensity.

Canada represented approximately 1.6% of total global GHG emissions in 2013 (CAIT 2017),

Figure 2–3 Canadian Per Capita Greenhouse Gas Emissions (1990–2015)



although it is one of the highest per capita emitters. Canada's per capita emissions have dropped substantially since 2005, when this indicator was 22.9 t. By 2009, it had dropped to 20.5 t and has remained at historic lows ever since, with 2015 seeing the lowest per capita emissions yet at 20.1 t (Figure 2–3).

2.1.1. Emission 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 greenhouse gases than those that rely more on hydroelectricity (Figure 2–4).

Historically, Alberta and Ontario have been the highest emitting provinces; after 2005, emission patterns in these two provinces diverged. Emissions in Alberta increased from 233 Mt in 2005 to 274 Mt in 2015 (18%), primarily as a result of the expansion of oil and gas operations (Table 2–2).

In contrast, Ontario's emissions have steadily decreased since 2005 (by 38 Mt or 19%), resulting in large part from the closure of its coal-fired electricity generation plants.

Emissions in Saskatchewan have increased by 7.8% (5.5 Mt) since 2005, as a result of activities in the oil and gas industry, potash and uranium mining, and transportation. Emissions in Manitoba and Newfoundland have also increased since 2005, but to a lesser extent (0.7% and 2% respectively). Provinces that have seen significant decreases in emissions include New Brunswick (31% reduction or 6.2 Mt), Nova Scotia (30% reduction or 7.0 Mt), and Prince Edward Island (14% reduction or 0.3 Mt).

Electricity production in Quebec and British Columbia relies on abundant hydroelectric resources, resulting in more stable emission patterns across the time series. Quebec experienced a 9.8% (8.7 Mt) decrease from its 2005 emissions level, while British Columbia saw a decline of 4.7% (3.0 Mt).

Figure 2–4 Emissions by Province in 1990, 2005 and 2015

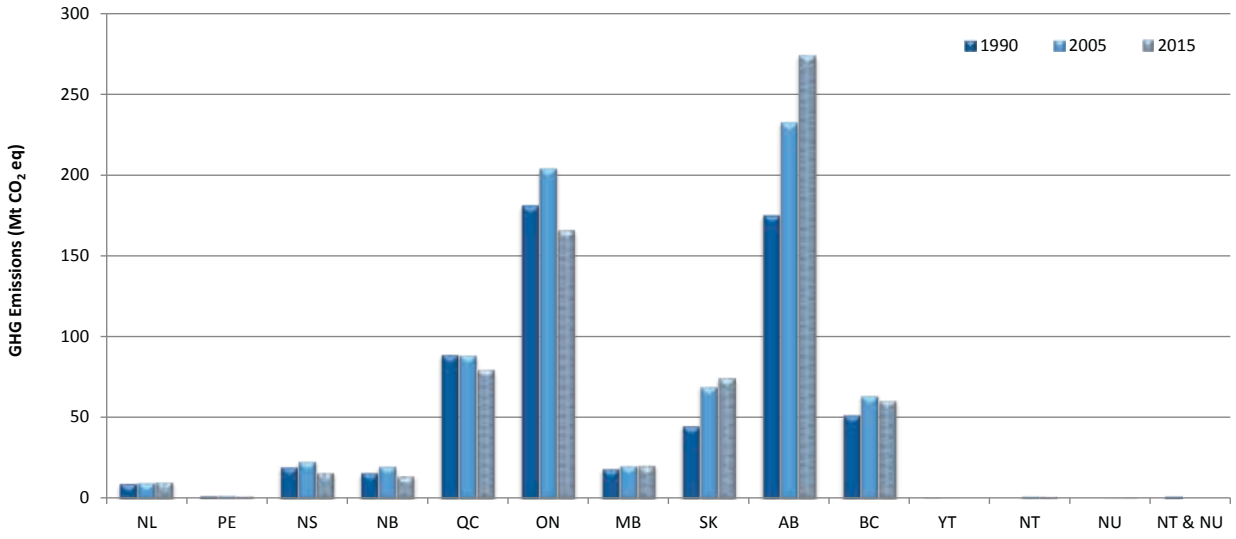


Table 2–2 GHG Emissions Provinces / Territories, Selected Years

	GHG Emissions (Mt CO_2 eq)[1]								Change (%)
Year	**1990**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2005-2015**
GHG Total (Canada)	**611**	**738**	**701**	**707**	**716**	**729**	**727**	**722**	**-2.2%**
NL	9.5	10.1	10.3	10.3	9.9	9.6	10.6	10.3	2.1%
PE	1.9	2.1	2.0	2.2	2.1	1.8	1.8	1.8	-14%
NS	20	23	20	21	19	18	16	16	-30%
NB	16	20	19	19	17	15	14	14	-31%
QC	89	89	82	84	81	82	80	80	-10%
ON	181	204	175	175	171	171	168	166	-19%
MB	19	21	20	19	21	21	21	21	0.7%
SK	45	70	70	69	72	74	75	75	7.8%
AB	175	233	241	246	260	272	276	274	18%
BC	52	64	59	60	61	62	61	61	-4.7%
YT	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	-43%
NT[2]	NA	1.6	1.3	1.4	1.5	1.4	1.3	1.4	-12%
NU[2]	NA	0.5	0.5	0.5	0.6	0.6	0.7	0.6	38%
NT & NU[2]	1.6	NA	NA	NA	NA	NA	NA	NA	-

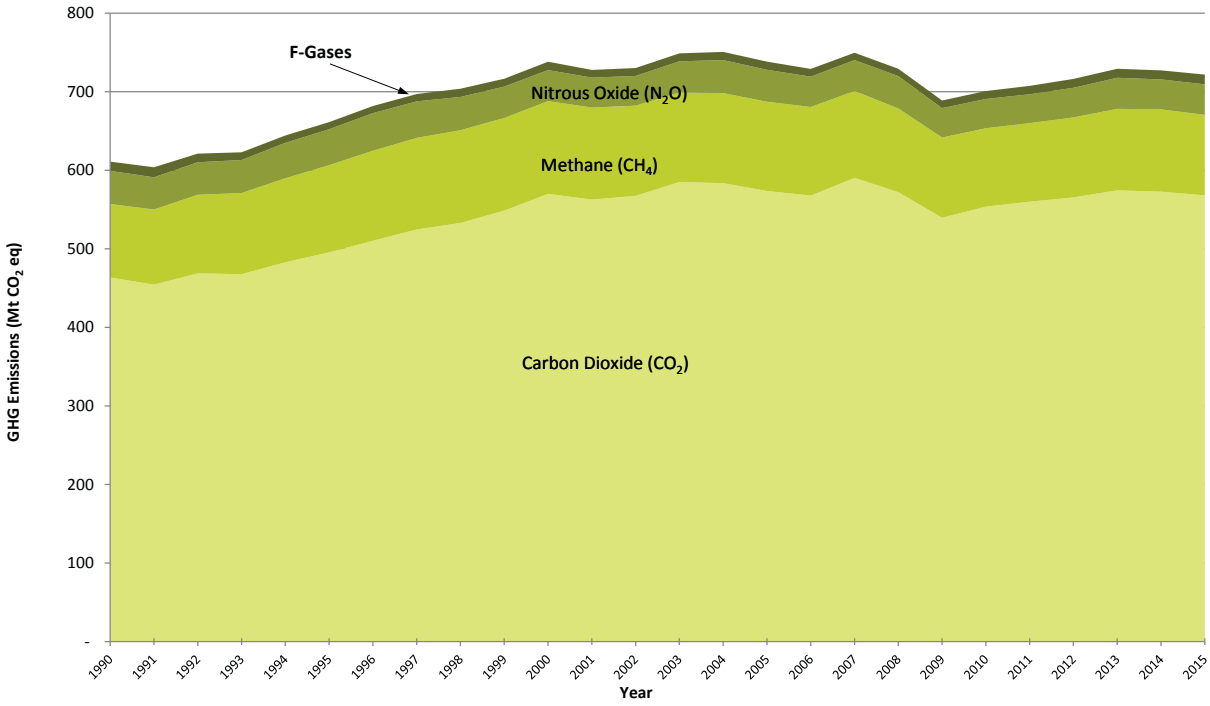
Note:
1. Totals may not add up due to rounding.
2. To account for the creation of Nunavut in 1999, a time series from 1999–2015 is provided for both Nunavut and the Northwest Territories, and the years 1990–1998 are presented as a combined region (see Annex A_{11} for more information).

2.2. Emission Trends by Gas

Canada's emissions profile is similar to that of most industrialized countries. Carbon dioxide (CO_2) is the largest contributor to Canada's GHG emissions, accounting for 568 Mt (79% of total emissions) in 2015 as such, 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 2015 amounted to 102 Mt and accounted for 14% of Canada's total emissions. These emissions are largely from fugitive sources in oil and natural gas systems (42% of total CH_4 emissions), agriculture (28% of total CH_4 emissions) and landfills (22% of total CH_4 emissions).

Figure 2–5 Trends in Canadian GHG Emissions by Gas (1990–2015)



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

Nationally, CH_4 emissions have increased by 9% (8.9 Mt) since 1990, largely due to the development of petroleum resources, although emissions have also increased in all CH_4 sources.

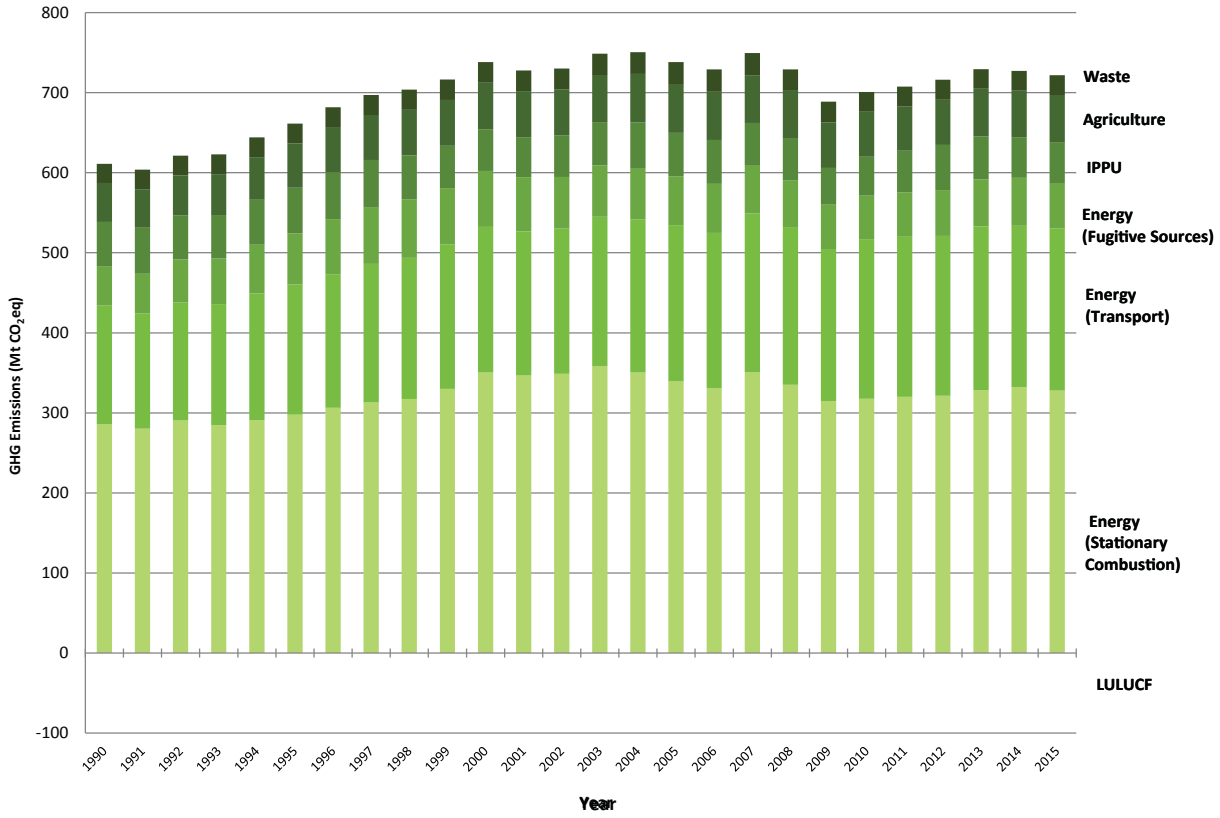
Nitrous oxide (N_2O) emissions arise from activities such as agricultural soil management and transport and accounted for 5% or 39 Mt of Canada's emissions in 2015, down 8% (3.3 Mt) from 1990 levels. In 2015, the Agriculture Sector accounted for 71% of national N_2O emissions, up from 49% in 1990. From 1990 to 2015, emissions from that sector increased 32% (22 Mt) as a result of increased fertilizer use and animal emissions. Over the same period, a 10-Mt decrease in N_2O emissions has occurred due to cessation of adipic acid production in Canada.

Together, perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and nitrogen trifluoride (NF_3) accounted for 12 Mt or slightly less than 2% of Canada's emissions in 2015. From 1990 to 2015, emissions of HFCs rose by 10 Mt (1035%), while emissions of PFCs and SF_6 decreased by 6.6 Mt (87%) and 2.8 Mt (87%), respectively. The increase in HFC emissions can be explained by the displacement of ozone-depleting substances (ODSs) by HFCs for refrigeration and air conditioning.

2.3. Emission Trends by IPCC Category

In 2015, the Energy Sector (consisting of Stationary Combustion Sources, Transport, and Fugitive Sources) accounted for the majority of Canada's total GHG emissions, at 81% or 587 Mt (Figure S-2). The remaining emissions were largely generated by the Agriculture (8%) and Industrial Processes and Product Use (IPPU) (7%) sectors, with minor contributions from the Waste Sector (3%).

Figure 2–6 Trends in Canadian GHG Emissions by IPCC Sector (1990–2015)



The Energy Sector dominated the long-term trend over the period 1990–2015, with increases of 54 Mt (36%) in Transport, 42 Mt (15%) in Stationary Combustion, and 8.1 Mt (17%) in Fugitive Sources. Over the same period, emissions in the Agriculture Sector increased by 10 Mt (22%), while the IPPU Sector saw a decrease of 5 Mt (9%). The LULUCF Sector was a sink in 2015 with net removals of 34 Mt, a 66-Mt reduction from the net removals of 99 Mt in 1990. Emissions in the Waste Sector remained relatively steady (Figure 2-6 and Table 2-3).

In the short term, emissions from Stationary Combustion, Fugitive Sources, IPPU, Agriculture, and Waste all decreased since 2005 (by 11.5 Mt, 4.0 Mt, 3.3Mt, 1.9Mt, and 1.0 Mt respectively). Emissions from Transport have increased 7.1 Mt since 2005, and LULUCF removals decreased by 3.2 Mt.

Several emissions sources, while not major contributors to Canada's overall emissions, experienced a significant change from 1990 levels. These include an increase in emissions of 1029% (or 10 Mt) from production and consumption of halocarbons, a 115% (5.8 Mt) increase from non-energy use of fuels and solvent use, a 125% (1.5 Mt) increase from use of fertilizers and lime, and a 76% (0.2 Mt) decrease in emissions from field burning of agricultural residues.

Impacts to future emissions trends resulting from measures under the Pan-Canadian Framework on Clean Growth and Climate Change are discussed in Section 2.4, Emission Trends by Canadian Economic Sector.

Table 2–3 Canada's GHG Emissions by IPCC Sector (1990–2015)

Greenhouse Gas Categories	1990	2005	2010	2011	2012	2013	2014	2015
	Mt CO_2 equivalent							
TOTAL[1, 2]	**611**	**738**	**701**	**707**	**716**	**729**	**727**	**722**
ENERGY	**483**	**595**	**571**	**575**	**578**	**592**	**594**	**587**
a. Stationary Combustion Sources	286	339	318	320	322	329	332	328
Public Electricity and Heat Production	94	122	101	94	91	88	85	84
Petroleum Refining Industries	17	20	19	19	20	19	18	17
Mining and Upstream Oil and Gas Production	41	68	81	82	91	99	102	105
Manufacturing Industries	56	48	41	44	44	45	45	43
Construction	2	1	2	1	1	1	1	1
Commercial and Institutional	26	32	28	30	28	30	32	31
Residential	47	46	43	46	42	44	46	43
Agriculture/Forestry/Fishing	2	2	3	4	4	4	4	4
b. Transport	148	195	199	200	200	204	202	202
Domestic Aviation	7	8	6	6	7	8	7	7
Road Transportation	92	134	142	143	144	147	144	144
Light-Duty Gasoline Vehicles	46	43	39	38	36	37	35	35
Light-Duty Gasoline Trucks	22	40	43	43	43	44	44	45
Heavy-Duty Gasoline Vehicles	7	12	13	12	13	14	14	14
Motorcycles	0	0	0	0	0	0	0	0
Light-Duty Diesel Vehicles	0	1	1	1	1	1	1	1
Light-Duty Diesel Trucks	0	0	0	0	0	1	1	1
Heavy-Duty Diesel Vehicles	14	37	45	49	50	51	50	49
Propane and Natural Gas Vehicles	1	0	0	0	0	0	0	0
Railways	7	7	7	8	8	7	8	7
Domestic Navigation	5	6	7	6	6	5	5	4
Other Transportation	37	41	38	38	36	37	38	39
Off-Road Agriculture & Forestry	10	13	12	13	12	12	12	11
Off-Road Commercial & Institutional	2	2	2	2	2	2	2	2
Off-Road Manufacturing, Mining & Construction	10	11	13	13	12	12	12	13
Off-Road Residential	0	1	1	1	1	1	1	1
Off-Road Other Transportation	9	4	4	4	4	3	4	4
Pipeline Transport	7	10	6	6	6	7	8	8.2
c. Fugitive Sources	49	61	54	55	57	59	60	57
Coal Mining	3	1	1	1	1	2	1	1
Oil and Natural Gas	46	59	53	54	56	57	58	56
d. CO_2 Transport and Storage	-	0	0	0	0	0	0	0
INDUSTRIAL PROCESSES AND PRODUCT USE	**56**	**54**	**48**	**52**	**56**	**54**	**51**	**51**
a. Mineral Products	8	10	8	8	8	8	8	8
b. Chemical Industry	17	9	5	6	6	6	6	7
c. Metal Production	24	20	16	17	17	15	15	14
Iron and Steel Production	10	10	9	10	10	8	9	8
Aluminum Production	10	9	7	7	6	7	6	6
SF_6 Used in Magnesium Smelters and Casters	3	1	0	0	0	0	0	0
d. Production and Consumption of Halocarbons, SF_6 and NF_3	1	5	8	9	9	9	10	11
e. Non-Energy Products from Fuels and Solvent Use	5	9	11	12	15	15	12	11
f. Other Product Manufacture and Use	0	1	0	0	0	0	0	0
AGRICULTURE	**49**	**61**	**56**	**55**	**57**	**60**	**58**	**59**
a. Enteric Fermentation	23	31	26	25	25	25	25	25
b. Manure Management	8	10	8	8	8	8	8	9
c. Agricultural Soils	17	18	20	20	21	23	22	23
d. Field Burning of Agricultural Residues	0	0	0	0	0	0	0	0
d. Liming, Urea Application and Other Carbon-containing Fertilizers	1	1	2	2	2	3	2	3
WASTE	**24**	**28**	**25**	**25**	**24**	**24**	**25**	**25**
a. Solid Waste Disposal	22	25	22	22	22	22	22	22
b. Biological Treatment of Solid Waste	1	1	1	1	1	1	1	1
c. Wastewater Treatment and Discharge	1	1	1	1	1	1	1	1
d. Incineration and Open Burning of Waste	1	1	1	1	1	1	1	1
LAND USE, LAND-USE CHANGE AND FORESTRY	**-99**	**-37**	**-28**	**-26**	**-30**	**-29**	**-33**	**-34**
a. Forest Lan	-252	-183	-159	-160	-164	-163	-166	-164
b. Cropland	9	-10	-12	-12	-12	-11	-11	-11
c. Grassland	1	1	0	1	2	1	1	1
d. Wetlands	5	3	3	3	3	3	3	3
e. Settlements	4	4	4	4	4	4	4	4
f. Harvested Wood Products	135	149	136	138	137	138	137	135

Notes:
1. National totals exclude all GHGs from the Land Use, Land-use Change and Forestry Sector
2. These summary data are presented in more detail in Annex 9

2.3.1. Energy Sector
(2015 GHG emissions, 587 Mt)

Energy consumption is by far the largest source of GHG emissions in Canada. 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
(2015 GHG Emissions, 328 Mt)

Stationary Combustion accounts for the largest portion (56%) of emissions from the Energy Sector. In 2015, emissions totaled 328 Mt, an increase of 15% from the 1990 level of 286 Mt and a decrease of 3.4% from 2005 emissions of 339 Mt (Figure 2–7, Table 2–4).

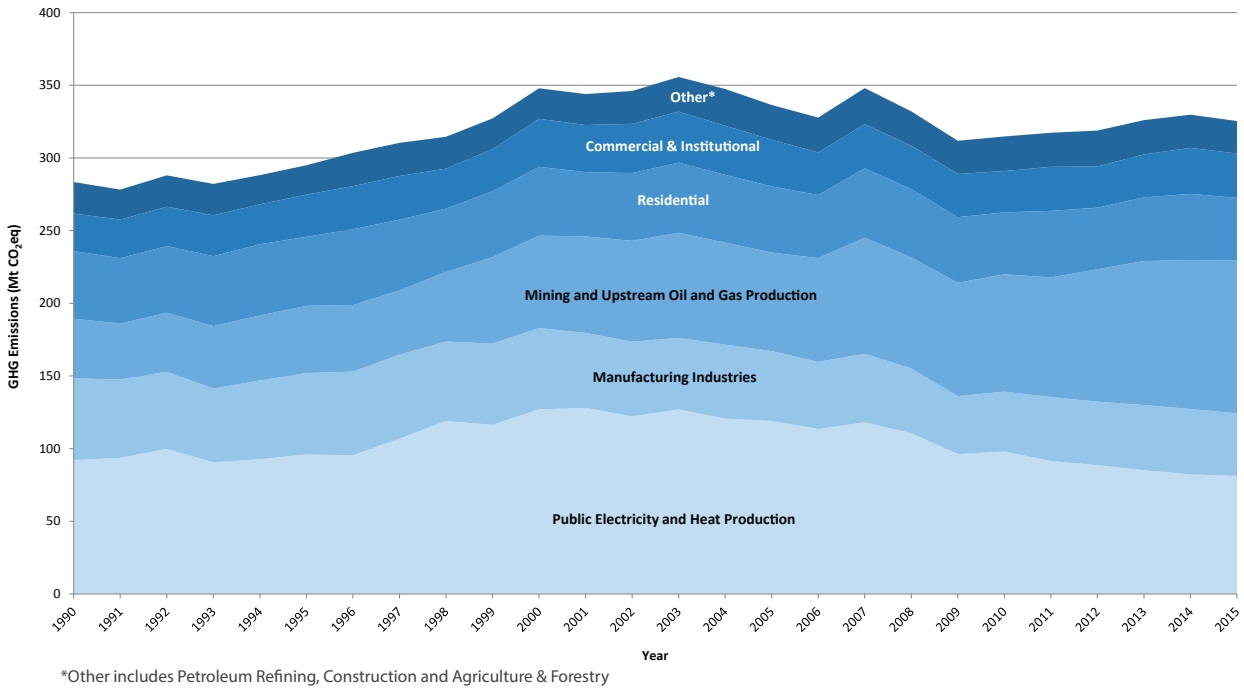
Dominant categories in Stationary Combustion are Mining and Upstream Oil and Gas Production, which contributes 32% of the total Stationary Combustion emissions, and Public Electricity and Heat Production, which contributes 26% in 2015. Manufacturing Industries and Residential each contribute 13% of the total Stationary Combustion emissions, while Commercial and Institutional contributes 9%.

Public Electricity and Heat Production (2015 GHG emissions, 84 Mt)

The Public Electricity and Heat Production category accounts for 14% (84 Mt) of the 2015 GHG emissions in the Energy Sector and saw a 11% decrease in emissions between 1990 and 2015.

Emissions from this subcategory are unique in that electricity is generated to meet an instantaneous demand; depending on the characteristics of that demand, the supply source can fluctuate between non-GHG-emitting and high GHG emitting sources. Between 1990 and 2015,

Figure 2–7 Trends in Canadian GHG Emissions from Stationary Combustion Sources (1990–2015)



*Other includes Petroleum Refining, Construction and Agriculture & Forestry

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

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2010	2011	2012	2013	2014	2015	1990-2015	2005-2015
Stationary Combustion Sources[1]	**286**	**339**	**318**	**320**	**322**	**329**	**332**	**328**	**15%**	-3%
Public Electricity and Heat Production	94	122	101	94	91	88	85	84	-11%	-31%
Petroleum Refining	17	20	19	19	20	19	18	17	-0.1%	-15%
Mining and Upstream Oil and Gas Production	41	68	81	82	91	99	102	105	156%	55%
Manufacturing Industries	56	48	41	44	44	45	45	43	-23%	-10%
Iron and Steel	4.9	5.6	5.0	5.3	5.5	5.6	6.0	5.2	6.0%	-6%
Non-ferrous Metals	3.3	3.7	3.1	3.4	3.0	3.1	2.9	2.8	-14%	-22%
Chemicals	8.3	8.3	9.9	11	11	12	12	13	53%	52%
Pulp, Paper, and Print	14.5	8.7	6.0	6.3	6.0	6.3	6.1	5.6	-61%	-36%
Cement	4.0	5.4	4.1	4.3	4.0	3.9	4.0	4.1	3.4%	-24%
Other Manufacturing	21	16	13	14	14	14	14	13	-40%	-23%
Construction	1.9	1.5	1.5	1.4	1.4	1.3	1.3	1.3	-31%	-11%
Commercial and Institutional	26	32	28	30	28	30	32	31	18%	-6%
Residential	47	46	43	46	42	44	46	43	-7.5%	-6%
Agriculture/Forestry/Fishing	2.4	2.2	3.0	3.5	3.6	3.7	3.7	3.7	54%	70%

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

electricity generation increased by 35% (Statistics Canada 1990–2004, no date[b], no date[c]), from 432 TWh to 580 TWh,[4] due to increased demand in all sectors.

Despite the increasing demand over this period, GHG emissions dropped by 11 Mt between 1990 and 2015. Likewise, electricity generation rose by 5% between 2005 and 2015, while emissions fell by 32% (38 Mt). The principal cause of the decrease in emissions is a less GHG-intensive mix of sources used to generate electricity (Figure 2–8).

For example, non combustion sources (nuclear and renewable generation, i.e. hydroelectric generation, wind turbines, solar photovoltaic cells and tidal energy) accounted for 87% of the increased generation between 1990 and 2015. Renewable sources contributed 63% of the total electricity generated in Canada in 2015, with hydroelectric generation responsible for 60% and other renewables responsible for 3%. The increased level of non-combustion sources in the generation mix in 2015 was the largest contributor to emission reductions since 1990 (18 Mt) and 2005 (29 Mt).

In addition, combustion generation sources have been steadily switching from high to low GHG-intensive fossil fuels. Between 2005 and 2015, the quantity of electricity generated by natural-gas-fired units increased by 29% (8.7 TWh), while the amount generated by coal and refined petroleum products decreased by about 34% (32 TWh) and 68% (7.3 TWh), respectively. Natural gas combustion is about half as carbon-intensive as coal and approximately 25% less carbon-intensive than most refined petroleum products. Hence, the switch from other fuels to natural gas resulted in a decrease in the GHG intensity of combustion from electricity generation. The overall impact of switching from coal and refined petroleum products to natural gas is a decrease of about 10 Mt between 1990 and 2015, and about 5 Mt between 2005 and 2015.

The efficiency of the combustion equipment has also played a role in the GHG emissions reductions. Energy efficiency improvements resulted in a 3.3-Mt reduction in GHG emissions between 1990 and 2015 and an 8.8-Mt reduction between 2005 and 2015.

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

Figure 2–8 Influence of Contributing Factors on the Change in GHG Emissions from the Public Electricity and Heat Production Category, 1990–2015 (Mt CO_2 eq)

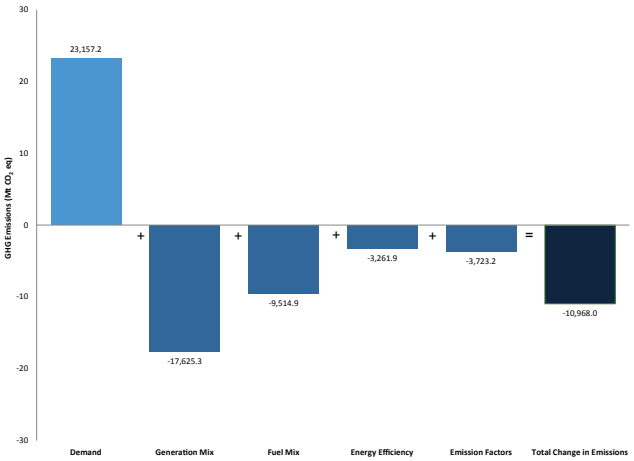
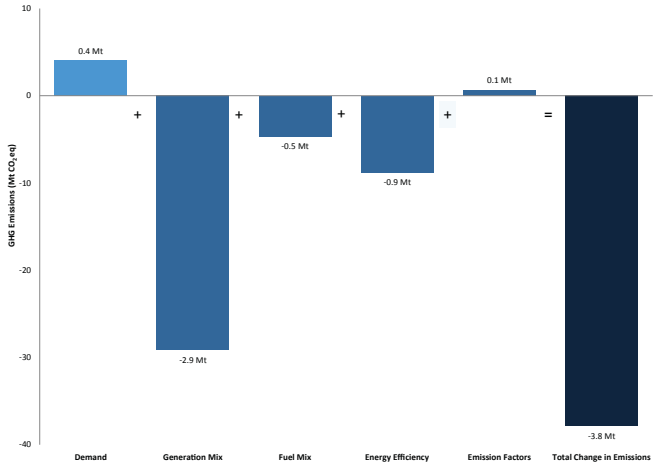


Figure 2–9 Influence of Contributing Factors on the Change in GHG Emissions from the Public Electricity and Heat Production Category, 2005–2015 (Mt CO_2 eq)



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.

Mining and Upstream Oil and Gas Production (2015 GHG emissions, 105 Mt)

Mining and Upstream Oil and Gas Production accounted for 18% (105 Mt) of Energy Sector emissions in 2015 emissions in this category saw a 156% (64 Mt) increase in emissions between 1990 and 2015 and 55% (37 Mt) between 2005 and 2015. This category includes emissions associated with the combustion of fuel in the oil, natural gas and coal extraction industries and with non-energy mining, such as iron ore, gold, diamonds, potash and aggregates.

Overall, the upstream oil and gas (UOG) industry, which includes natural gas production and processing, conventional oil production and oil sands mining, extraction and upgrading industry segments continues to see significant growth. Although natural gas production has decreased by 13% since 2005 (Statistics Canada no date [d]) andconventional oil production by 2% (Statistics Canada no date [e]), crude bitumen and synthetic crude oil production from the oil sands industry has increased by 143% (AER 2016). The increased use of more energy intensive extraction techniques, such as horizontal drilling, hydraulic fracturing, and enhanced oil recovery, has has led to increased emissions. The steam-assisted gravity drainage (SAGD) process used to extract crude bitumen involves injecting large amounts of steam into the producing formation, where the heat from the steam allows the crude bitumen to flow and be extracted. The steam is generally produced by combusting natural gas, resulting in emissions. Since 2005, total natural gas consumption in this subcategory has increased by over 75% (Statistics Canada 1991-2016), and SAGD production has increased by over 900% (AER 2016).

The 2.8-Mt increase in emissions from Mining and Upstream Oil and Gas Production between 2014 and 2015 is consistent with a 13% increase in the production of non-upgraded bitumen in Canada's oil sands area and in particular a 14% increase in SAGD production (AER 2016).

A clearer account of emissions from the Mining and Upstream Oil and Gas Production subcategory is provided in Table 2–12, where emissions are broken down by economic sectors (Natural Gas Production and Processing, Conventional Oil Production, Oil Sands, Coal Production and Non-energy Mining). Some discussion of trends in the oil and gas industry by economic sector is also presented in Section 2.4.1.

Manufacturing Industries (2015 GHG emissions, 43 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 2015, GHG emissions from the Manufacturing Industries category were 43 Mt, which represents a 23% decrease from 1990 and 10% decrease since 2005. While emissions from this category declined until 2009, they have been steadily increasing since 2009; however, they still remain below 1990 levels. This category was responsible for 7.3% of emissions in the Energy Sector in 2015.

Within the Manufacturing Industries category, the Pulp, Paper and Print subcategory showed the largest emissions decrease. Between 1990 and 2015, the emissions from this subcategory decreased by 8.9 Mt (61%). This can be attributed to closures in the industry along with substitution of biomass-based fuels in place of coal, diesel and heavy fuel oil. On the opposite end, the Chemicals subcategory showed the largest increase in emissions within the category, with emissions increasing by 4.4 Mt (53%). This is generally consistent with a 34% increase in the economic output (GDP) of the chemical industry in the same period (CIEEDAC 2016).

Residential, Commercial and Institutional (2015 GHG emissions, 74 Mt)

GHG emissions in the Residential and Commercial & Institutional subcategories come primarily from the combustion of fuel, such as natural gas, home heating oil and biomass fuels, to heat residential, commercial and institutional buildings. Emissions in these categories contributed about 74 Mt of GHG emissions in 2015, a 1.6% increase since 1990. Fuel combustion in the Residential and Commercial and Institutional categories[5] accounted for 7.3 (43 Mt) and 5.2% (31 Mt), respectively, of emissions from the Energy Sector in 2015.

Overall, residential emissions decreased by 3.5 Mt (7.5%) between 1990 and 2015, and 2.5 Mt beween 2005 and 2015. Commercial emissions increased by 4.7 Mt (18%) between 1990 and 2015, while showing a 1.8 Mt decrease between 2005 and 2015. Changes in energy efficiency, new home constructions 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 29% increase in population (Statistics Canada no date [f]) and the 29%[6] increase in floor space per capita each account for emissions increases of 11.3 Mt (Figure 2–10). (The sum of these two drivers represents the total impact of floor space at 22.6 Mt). These increases have been offset by improvements in energy efficiency, which are equivalent

5 Commercial & institutional subcategory emissions are based on fuel use as reported in the *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada 1990–2016) for the Commercial and Other Institutional, and Public Administration subcategories. The former is a catch-all subcategory that includes fuel used by service industries related to mining, wholesale and retail trade, financial and business services, education, health and social services, and other industries that are not explicitly included elsewhere.

6 Lam M. 2017. Personal communication (email from Lam M. to Tracey K., Program Engineer, PIRD dated January 13, 2017). Office of Energy Efficiency, Natural Resources Canada

Figure 2–10 Influence of Contributing Factors on the Change in Stationary GHG Emissions from the Residential Subcategory between 1990 and 2015

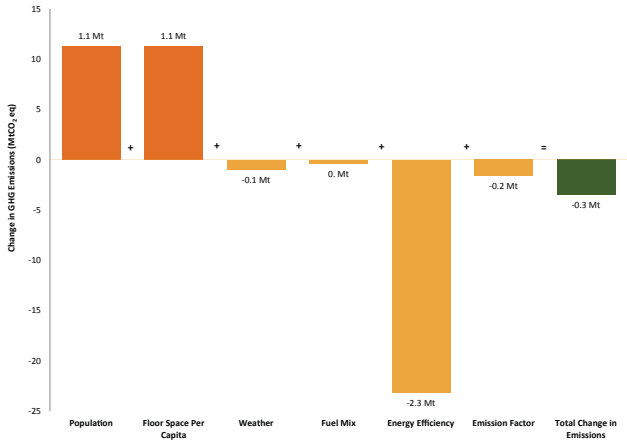
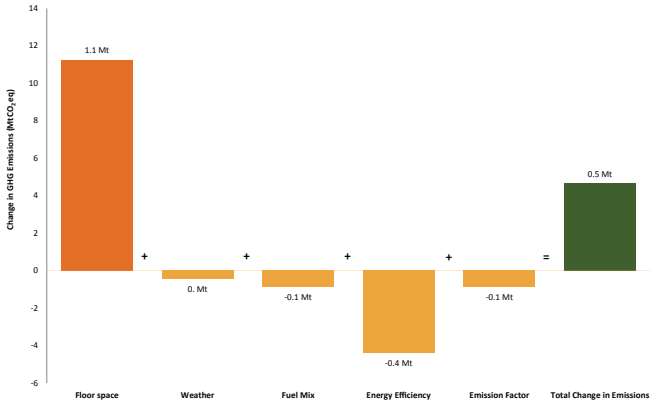


Figure 2–11 Influence of Contributing Factors on the Change in Stationary GHG Emissions from the Commercial and Institutional Subcategory between 1990 and 2015



Notes:
Floor space and population – Floor space refers to the change in floor space 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.

to a 23-Mt decrease in emissions between 1990 and 2015. This pattern of increasing population and floor space per capita being offset by improvements in energy efficiency is also demonstrated between 2005 and 2015.

In the Commercial and Institutional subcategory, GHG emissions increased by 10 Mt between 1990 and 2003. This was followed by a slight decrease until 2006, and have since fluctuated around 30Mt. Floor space was the most significant upward driver between 1990 and 2015, having increased by 50%,[7] associated with an11.3-Mt increase in emissions (Figure 2–11). These impacts are partially offset by improvements in energy efficiency, equivalent to a 4.4-Mt decrease in GHG emissions. Between 2005 and 2015, floor space was also the most significant upward driver, having increased by 17% since 2005. However, overall emissions decreased by 1.8 Mt, mainly due to offsets from energy efficiency iniatives and switching to less carbon-intensive fuels.

Weather patterns can have a non-negligible effect on emissions from one year to the next, as suggested by the close tracking between heating degree days (HDDs) and GHG emissions (Figure 2–13). The influence that weather can have on space heating requirements and demand for fuels results in emission patterns that mirror the variability of weather.

Other Stationary Combustion Sources (2015 GHG emissions, 22 Mt)

Other Stationary Combustion Sources comprise fuel combustion emissions from the Petroleum Refining category, as well as the Construction and Agriculture, Forestry/Fishing subcategories. Overall, this group exhibited increases in GHG emissions of 3.2% (0.70 Mt) from 1990 to 2015.

7 Brugger M. 2016. Personal communication (email from Brugger M. to Tracey K., Program Engineer, PIRD dated February 2, 2016). Economic Analysis Directorate, Environment and Climate Change Canada.

Figure 2–13 GHG Emissions and Heating Degree-Days (HDDs) from the Residential and Commercial & Institutional Subcategories, 1990–2015

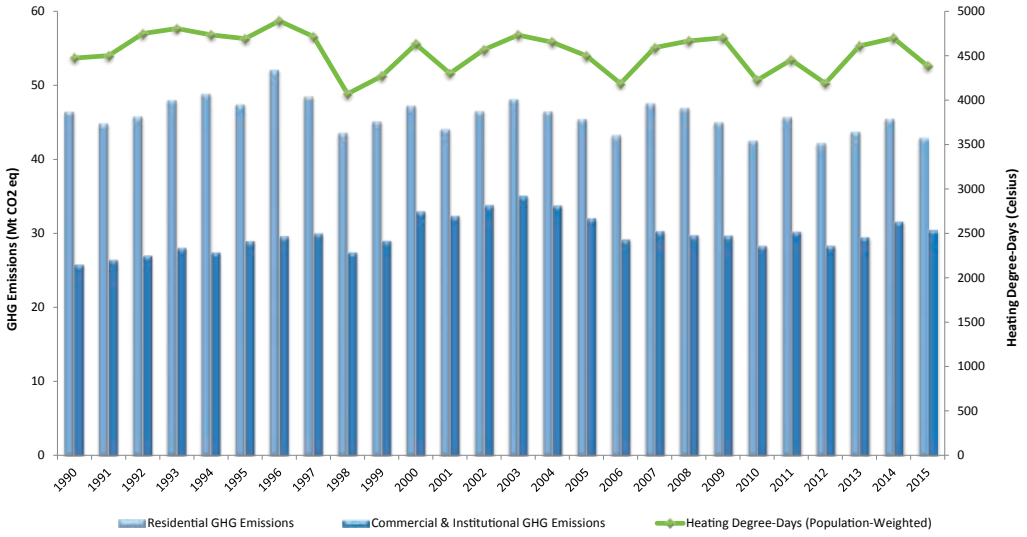
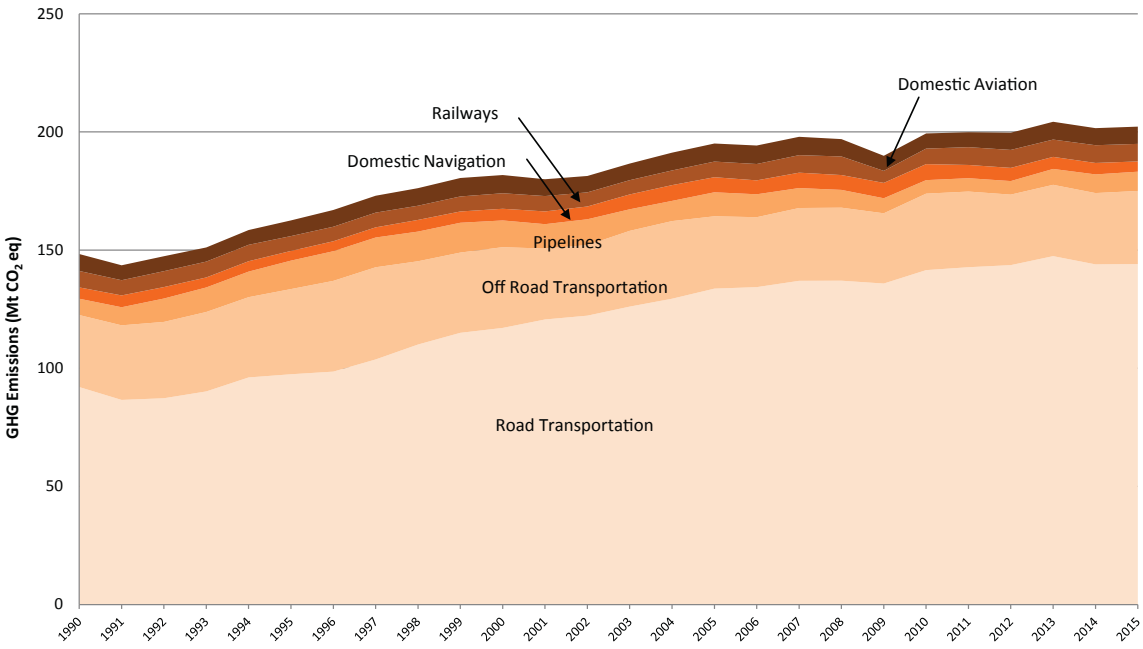


Figure 2–12 Trends in Canadian GHG Emissions from Transport (1990–2015)



2.3.1.2. Transport

(2015 GHG emissions, 202 Mt)

Transport is a large and diverse subsector, accounting for 202 Mt of GHG emissions or 34% of Canada's Energy Sector emissions in 2015. 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 2015, Transport emissions rose 36% (54 Mt), accounting for a significant portion of Canada's emissions growth.

Table 2–5 GHG Emissions from Transport, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2010	2011	2012	2013	2014	2015	1990-2015	2005-2015
Transport	148	195	199	200	200	204	202	202	36%	4%
Domestic Aviation	7.2	7.6	6.4	6.3	7.3	7.5	7.2	7.3	2%	-5%
Road Transportation	92	134	142	143	144	147	144	144	57%	8%
Light-Duty Gasoline Vehicles	46	43	39	38	36	37	35	35	-25%	-19%
Light-Duty Gasoline Trucks	22	40	43	43	43	44	44	45	101%	13%
Heavy-Duty Gasoline Vehicles	6.8	12.1	12.9	12.4	13.2	13.7	13.7	13.9	104%	15%
Motorcycles	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	180%	31%
Light-Duty Diesel Vehicles	0.5	0.6	0.7	0.8	0.8	0.9	0.8	0.8	69%	36%
Light-Duty Diesel Trucks	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.6	246%	73%
Heavy-Duty Diesel Vehicles	14	37	45	49	50	51	50	49	241%	30%
Propane and Natural Gas Vehicles	1.4	0.4	0.1	0.1	0.0	0.0	0.0	0.0	-99%	-96%
Railways	6.9	6.6	6.6	7.5	7.6	7.3	7.5	7.4	7%	12%
Domestic Navigation	4.8	6.4	6.8	5.6	5.6	5.1	4.8	4.3	-9%	-32%
Other Transportation	37	41	38	38	36	37	38	39	5%	-4%
Off-Road Agriculture & Forestry	10	13	12	13	12	12	12	11	13%	-10%
Off-Road Commercial & Institutional	2	2	2	2	2	2	2	2	38%	11%
Off-Road Manufacturing, Mining & Construction	10	11	13	13	12	12	12	13	31%	17%
Off-Road Residential	0.2	0.6	0.6	0.7	0.7	0.6	0.7	0.7	195%	2%
Off-Road Other Transportation	9	4	4	4	4	3	4	4	-56%	-13%
Pipeline Transport	6.9	10.2	5.7	5.6	5.7	6.7	7.9	8.2	18%	-20%

Emissions from Transport result primarily from Road Transportation, which includes personal transportation (light-duty gasoline vehicles and trucks) and heavy duty diesel trucks (Figure 2–12). Off-road is the second largest subcategory, accounting for 15% of Transport emissions, mainly through diesel fuel combustion. The Domestic Aviation, Domestic Navigation and Railways categories combined contributed to approximately 9% of the Transport emissions in 2015 and, overall, have been stable over the 1990–2015 time series.

Road Transportation (2015 GHG emissions, 144 Mt)

The growth in road transport emissions is largely due to more driving as measured in vehicle kilometres travelled (VKTs) in both the light- and heavy-duty subclasses. The total vehicle fleet has increased by 66% since 1990 (19% 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 of vehicles was greater from 2005-2015 compared with the 1990-2005 interval. Despite a reduction in kilometres driven per vehicle, the total kilometres travelled for the light-duty vehicle fleet increased by 58% over the same time period.

Light-duty gasoline vehicles (2015 GHG emissions, 35 Mt)

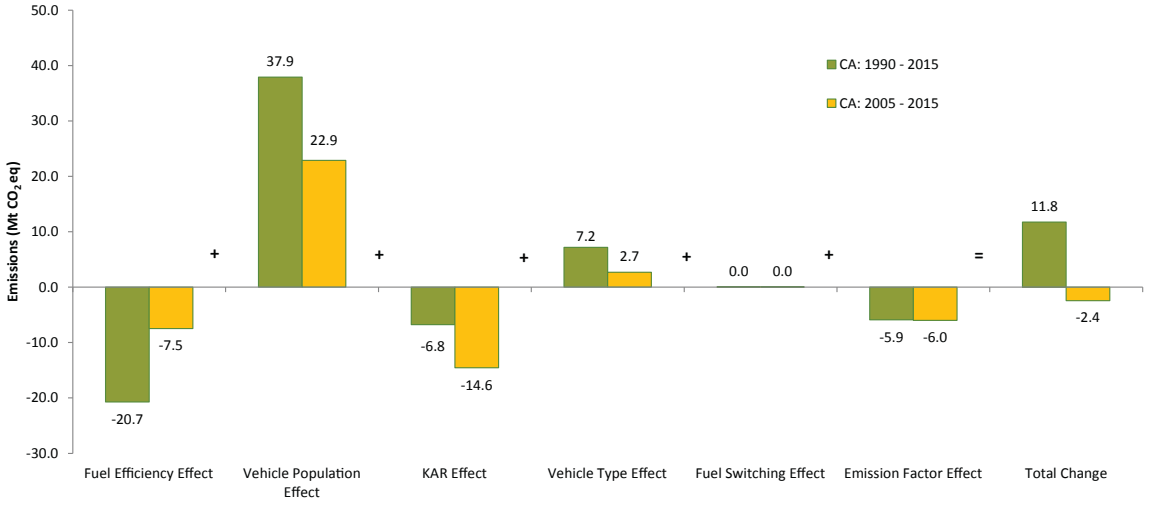
Within the light-duty gasoline vehicle (LDGV) subcategory, the total number of vehicles and VKTs increased, while the fleet average fuel consumption ratio decreased, resulting in a net emissions decrease of 25% (from 46 Mt in 1990 and 43 Mt in 2005 to 35 Mt in 2015). Total light-duty vehicle emissions are influenced by several factors including total vehicle kilometres travelled, vehicle type, fuel efficiency, fuel type, emissions control technology and biofuel consumption. 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).

Table 2–6 Trends in Vehicle Populations for Canada, 1990–2015

Year	Number of Vehicles (000s)			
	Light-Duty Vehicles		Heavy-Duty Vehicles	All Vehicles
	Cars	Trucks		
1990	10 755	3 371	968	15 410
2005	11 008	6 877	1 690	20 072
2010	12 014	8 919	2 155	23 720
2011	11 909	9 272	2 142	23 961
2012	11 894	9 622	2 268	24 451
2013	12 269	10 238	2 360	25 543
2014	12 299	10 766	2 421	26 190
2015	12 381	11 238	2 469	26 808
Change since 1990	14%	204%	144%	66%
Change since 2005	8%	35%	27%	19%

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

Figure 2–14 Contributing Factors on Change in Light-Duty Vehicle Emissions, 1990-2015 and 2005–2015



Notes:
Total change is the difference in total emissions over the selected time periods, 1990–2015and 2005–2015.
Fuel efficiency effect[1] refers to the change in emissions due to the change in fuel consumption ratios (expressed as liters/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 effect[2] 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.

1. Fuel economy, fuel efficiency and fuel consumption ratio are all metrics which describe the efficacy with which a vehicle can obtain energy from the fuel, typically presented in either the volume of fuel needed to move a vehicle a prescribed distance (l/100 km) or the distance a vehicle can travel for a prescribed amount of fuel (miles per gallon – mpg).
2. 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 (VKT) 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.

Implementation of emission control technologies and increased use of biofuels since the 1990s have also resulted in decreased emissions.

Light-duty gasoline trucks (2015 GHG emissions, 45 Mt)

On average, light-duty trucks—including sport utility vehicles (SUVs), many pickups and all minivans—emit 31% more GHGs per kilometre than cars. Emissions from the Light-duty Gasoline Trucks

(LDGTs) subcategory increased 101% between 1990 and 2015 (from 22 Mt in 1990 to 45 Mt in 2015). While a decrease in the associated fleet fuel consumption ratios was observed between 1990 and 2015, 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 (2015 GHG emissions, 49 Mt)

In 2015, emissions from heavy-duty diesel vehicles (HDDVs) contributed 49 Mt to Canada's total GHG emissions (an increase of about 241% from 1990 and 30% from 2005). While there are difficulties in obtaining accurate and complete data for the freight transport mode, the trends in data from major for-hire truck haulers in Canada show conclusively that freight hauling by heavy trucks has increased substantially and that this activity is the primary task performed by heavy-duty vehicles (Statistics Canada no date [i]). 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) (2015 GHG emissions, 31 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; tractors and combines; recreational vehicles such as snowmobiles and all-terrain vehicles (ATVs); and residential equipment such as lawnmowers and trimmers. In 2015, off-road manufacturing, mining and construction and off-road agriculture and forestry represented 42% and 37% of off-road emissions, respectively. While there has been some variation in emissions within the off-road subcategories, the net emissions for the whole category have been essentially contant across the timeseries.

Other Transportation (Pipeline Transport) (2015 GHG emissions, 8.2 Mt)

Pipeline emissions are combustion emissions arising primarily from natural gas transport. From 2005 to 2011, emissions decreased by 4.5 Mt (44%) as natural gas throughput volumes decreased by approximately 32% (Statistics Canada no date [g]). Even though overall natural gas consumption has increased by around 9% since 2005 (Statistics Canada 1991-2016), the national natural gas supply system has changed significantly over the past decade. Historically, large amounts of natural gas produced in western Canada (Alberta, British Columbia and Saskatchewan) were transported from west to east to be consumed in eastern Canada. While this still occurs, the amount of gas being transported from western Canada has decreased significantly due to the increase in imports of shale gas from the United States into Ontario and Quebec, displacing natural gas produced in western Canada (Statistics Canada 1991-2016).

In the past few years, this trend has started to reverse. Since 2011, emissions from Pipeline Transport have increased by 44%, while imports to Ontario have decreased by 33% and inter-regional transfers have increased by almost 200% (Statistics Canada 1991-2016).

2.3.1.3. Fugitive Sources (2015 GHG Emissions, 57 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) are also considered fugitive emissions. Fugitive Sources are broken down into two main

Figure 2–15 Trends in Canadian GHG Emissions from Fugitive Sources (1990–2015)

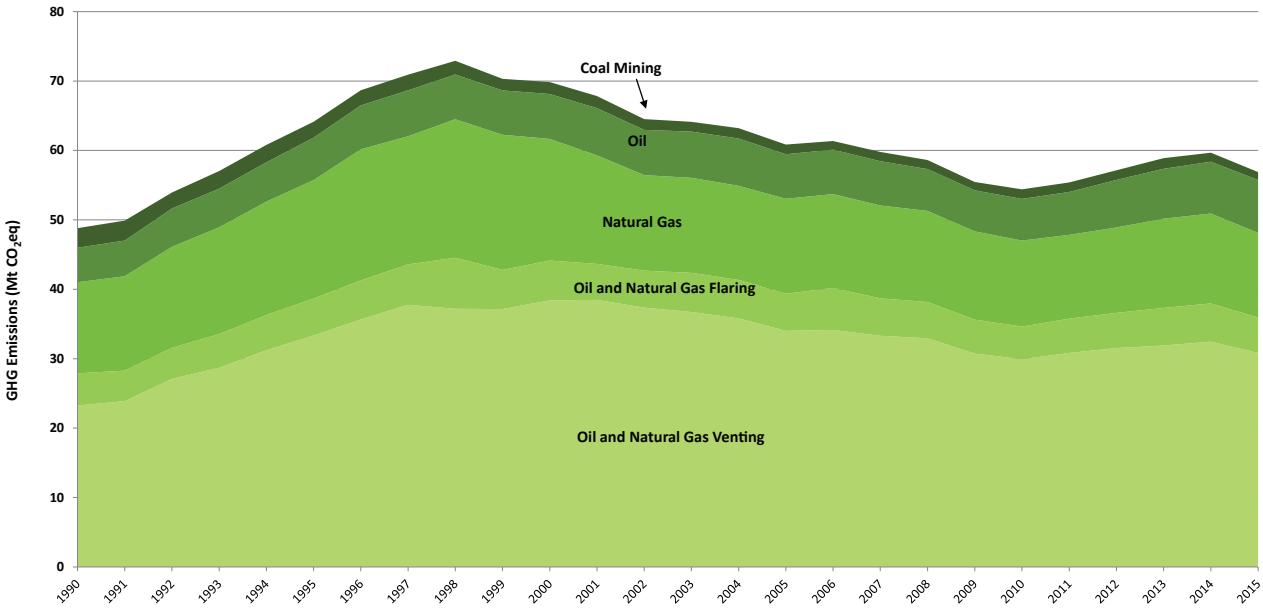


Table 2–7 GHG Emissions from Fugitive Sources, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2010	2011	2012	2013	2014	2015	1990–2015	2005–2015
Fugitive Sources[1]	49	61	54	55	57	59	60	57	17%	-7%
Coal Mining	3	1	1	1	1	2	1	1	-60%	-18%
Oil and Natural Gas	46	59	53	54	56	57	58	56	21%	-6%
Oil[2]	5	6	6	6	7	7	7	8	54%	19%
Natural Gas[2]	13	14	12	12	12	13	13	12	-7.1%	-11%
Venting	23	34	30	31	32	32	32	31	33%	-9%
Flaring	5	5	5	5	5	5	6	5	10%	-5%

Notes:
1. Totals may not add up due to rounding.
2. These categories represent fugitive releases due to leakage from oil and natural gas systems.

categories: Coal Mining and Oil and Natural Gas (Table 2–7). Emissions from the Oil and Natural Gas category contributed 98% of the total fugitive emissions in 2015, with Coal Mining accounting for the remaining 2%. Overall, these sources constituted about 10% of Energy Sector emissions in 2015 and alone contributed 7% to the growth in emissions between 1990 and 2015 (Figure 2–15).

Fugitive emissions grew by 17% between 1990 and 2015, from 49 to 57 Mt (Table 2–7). Fugitive emissions from Oil and Natural Gas alone increased by 21% (9.8 Mt), while releases from Coal Mining decreased by 60% (1.7 Mt) because of mine closures in eastern Canada.

The 21% growth in Oil and Natural Gas fugitive emissions (Figure 2–15) is a result of increased activity in the oil and gas sector. Since 1990, over 380,000 oil and gas wells have been drilled, and the number of producing oil and gas wells has increased by 190% (CAPP 2016). 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. Fugitive emissions peaked in the late 1990s; since then,

the combined effect of improved inspection and maintenance programs, better industry practices, technological improvements and regulations have effectively controlled and even reduced emissions.

For example, in 1999, the province of Alberta introduced the *Directive 060* regulations to reduce flaring and venting emissions from its oil and gas industry (AER 2014). In 2006, leak detection and repair best management practices were added to *Directive 060* to reduce emissions from fugitive equipment leaks. Between 2005 and 2010, these measures contributed to a reduction in fugitive emissions of 6 Mt (11%), particularly from venting and flaring.

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* (Directive S-10) (Sask ECON 2015), both of which are similar to *Directive 060*.

Between 2014 and 2015, fugitive emissions dropped by 2.6 Mt (4.5%). The significant decline in the price of crude oil between 2014 and 2015 resulted in a 50% decrease in the number of wells drilled and a 10% drop in the number of operating wells (CAPP 2016), which are responsible for the decrease in oil and gas fugitive emissions. Even though the oil sands increased production by 9.5% between 2014 and 2015 and account for approximately 61% of total oil production, they account 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.

2.3.2. Industrial Processes and Product Use

(2015 GHG emissions, 51 Mt)

The Industrial Processes and Product Use (IPPU) Sector includes GHG emissions that result from manufacturing processes and use of products. Subsectors include Mineral Products, Chemical Industry, Metal Production, Production and Consumption of Halocarbons, SF_6 and NF_3, Non-Energy Products from Fuels and Solvent Use, and Other Product Manufacture and Use.[8] Emissions from the IPPU Sector contributed 51 Mt (7%) to Canada's 2015 emissions, compared with 56 Mt (9%) in 1990, a decrease of approximately 5 Mt or 9%. 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), 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),[9] and Production and Consumption of Halocarbons (HFCs) (Figure 2–16 and Table 2–8).

In 2015, the largest contributions to emissions in the sector originated from the consumption of halocarbons and the non-energy use of fuels (11 Mt each – Table 2.8).

8 Other Product Manufacture and Use is a small contributor to the overall emissions and trends and therefore not discussed in this chapter; refer to Chapter 4 for more detail on this subsector.

9 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 2–16 Trends in Canadian GHG Emissions from IPPU Sources (1990–2015)

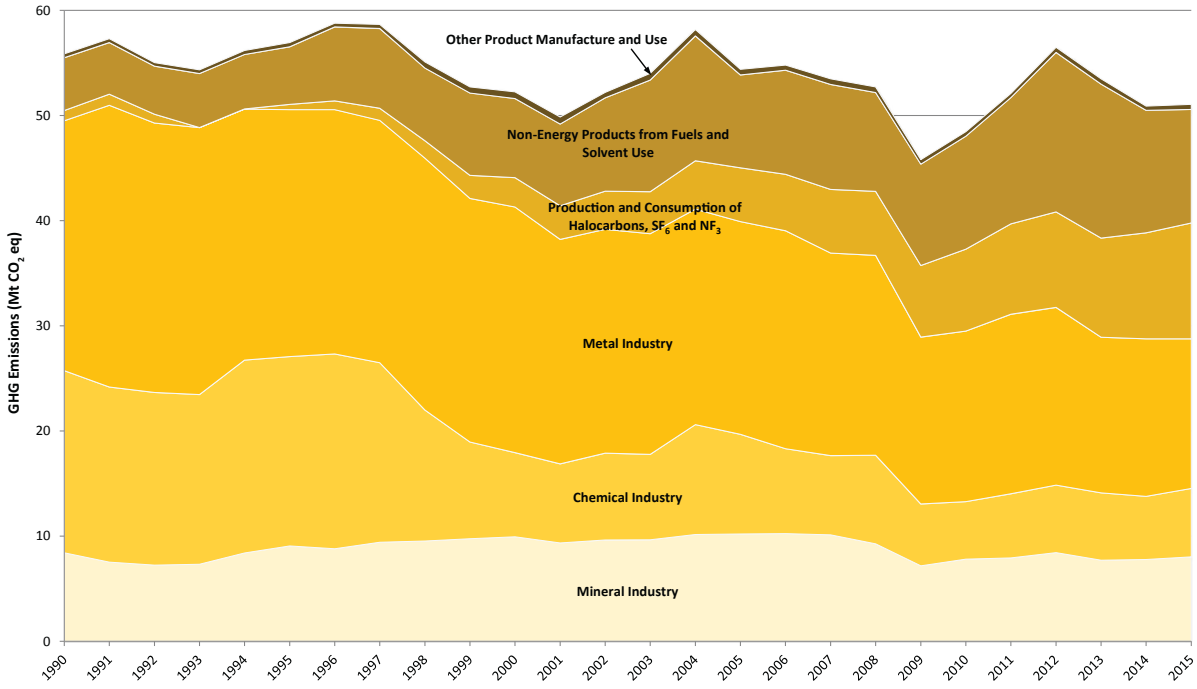


Table 2–8 GHG Emissions from IPPU Categories, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2010	2011	2012	2013	2014	2015	1990-2015	2005-2015
Total - Industrial Processes	56	54	48	52	51	56	53	51	-8.9%	-6.4%
Mineral Products	8.4	10	7.8	7.9	8.5	7.7	7.8	8.0	-4.7%	-21%
Cement Production	5.8	8	6.0	6.1	6.6	6.0	5.9	6.3	8.8%	-18%
Lime Production	1.8	2	1.4	1.4	1.4	1.4	1.5	1.3	-24%	-22%
Mineral Product Use	0.9	1	0.4	0.5	0.4	0.4	0.4	0.4	-52%	-52%
Chemical Industry	17	9.5	5.5	6.1	6.4	6.4	6.0	6.5	-62%	-31%
Ammonia Production	2.8	3	2.5	2.9	3.0	2.9	2.5	2.9	2.8%	5.3%
Nitric Acid Production	1.0	1.2	1.1	1.1	1.1	1.0	1.0	1.1	14%	-7.7%
Adipic Acid Production	10	3	-	-	-	-	-	-	-100%	-100%
Petrochemical Production & Carbon Black Production	3.3	3.0	1.9	2.1	2.3	2.5	2.4	2.5	-22%	-16%
Metal Production	24	20	16	17	17	15	15	14	-40%	-30%
Iron and Steel Production	10	10	9.2	10	10	8.0	8.9	8.0	-24%	-22%
Aluminium Production	10	9	6.9	6.8	6.5	6.5	5.8	6.0	-42%	-31%
SF_6 Used in Magnesium Smelters and Casters	3.0	1.2	0.2	0.2	0.2	0.2	0.2	0.2	-93%	-82%
Production and Consumption of Halocarbons, SF_6 and NF_3	1.0	5	7.8	8.6	9.1	9.4	10	11	1029%	116%
Non-Energy Products from Fuels and Solvent Use	5.0	9	11	12	15	15	12	11	115%	22%
Other Product Manufacture and Use	0.4	0.5	0.4	0.4	0.5	0.5	0.4	0.5	29%	-9.3%

Note: Totals may not add up due to rounding.

2.3.2.1. Mineral Products

(2015 GHG Emissions, 8.0 Mt)

Mineral Products include cement production, lime production, and uses of carbonates (magnesite, soda ash, and limestone). This subsector experienced a decrease in emissions of 0.4 Mt (4.8%) from 1990 to 2015. Emissions associated with lime production and mineral product use accounted for a decrease of 0.9 Mt, which was offset by a

0.5-Mt increase in cement production. Emissions from the Cement Production category dropped significantly by 22.8% in 2009 to 5.4 Mt as a result of a sector-wide reduction in clinker capacity and the closure of a plant. Since 2009, emissions from this category have been fairly consistent (5.9 to 6.6 Mt).

2.3.2.2. Chemical Industry

(2015 GHG Emissions, 6.5 Mt)

A decrease of 10.8 Mt (62.4%) from 1990 to 2015 is observed for the Chemical Industry as a whole. The main driver of emission reductions in this industry was the closure of the sole Canadian adipic acid plant in 2009; this alone represents a decrease of 10.3 Mt from 1990.[10] Changes also included emission reductions (0.7 Mt) in petrochemical production and small increases (0.08 Mt and 0.14 Mt) in ammonia production and nitric acid production, respectively.

2.3.2.3. Metal Production

(2015 GHG Emissions, 14 Mt)

Emission reductions in the production of magnesium, aluminium, and iron and steel contributed to Metal Production overall reductions of 9.5 Mt (40%) between 1990 and 2015 and of 6.0 Mt (30%) between 2005-2015.

The aluminium industry decreased its perfluorocarbon (PFC) emissions by 6.6 Mt (87%), while increasing production by 84% between 1990 and 2015 (AAC 2015), 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 2015, emissions in the iron and steel industry decreased by 2.3 Mt (22%). The main driver behind the decrease in emissions was reductions in overall production levels (Statistics Canada 2004-2012, CSPA 2013-2015).

2.3.2.4. Production and Consumption of Halocarbons, SF_6 and NF_3

(2015 GHG Emissions, 11 Mt)

HFC-23 was produced as a by-product of HCFC-22 production, which ended in 1992. There has been no other production of HFCs in Canada. Hence, all emissions in the category of production and consumption of halocarbons are associated with consumption only. The consumption of hydrofluorocarbons (HFCs) has accounted for a an 11-Mt increase in emissions from 1995 to 2015 or a 5.1 Mt (216%) from 2005 to 2015.This can be explained by the displacement of ozone-depleting substances (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 emission 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

(2015 GHG Emissions, 11 Mt)

The Non-energy Products from Fuels and Solvent Use category is one of the largest emission sources in the IPPU Sector, with emissions increasing by 5.8 Mt (115%) from 1990 to 2015. The observed change is mostly attributable to the emissions from the feedstock use of waxes, paraffin, and unfinished products, which increased by 5.8 Mt (1144%) over the period.

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

2.3.3. Agriculture Sector
(2015 GHG Emissions, 59 Mt)

In 2015, emissions from the Agriculture Sector accounted for 59 Mt or 8% of total 2015 GHG emissions for Canada, down 2 Mt from their peak in 2005, but nonetheless an increase of 10 Mt or 22% since 1990 (Figure 2-17, Table 2-9). In 2015, the Agriculture Sector accounted for 28% of national CH_4 emissions and 71% of national N_2O emissions, up from 49% 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 (Industrial Processes and Product Use) of this report.

The main activities in Canadian agriculture are livestock and crop production. Greenhouse gas emissions from the livestock sector include enteric fermentation emissions (CH_4) and all emissions

Figure 2–17 Trends in Canadian GHG Emissions from Agriculture Sources (1990–2015)

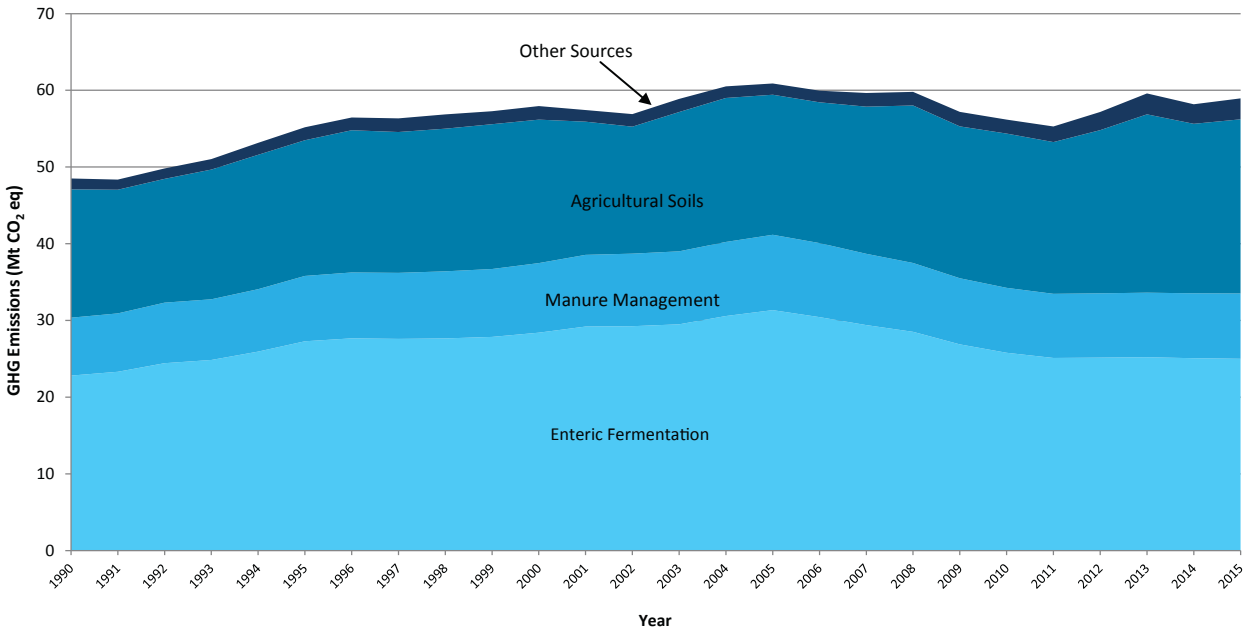


Table 2–9 GHG Emissions from Agriculture, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2010	2011	2012	2013	2014	2015	1990-2015	2005-2015
Agriculture	**49**	**61**	**56**	**55**	**57**	**60**	**58**	**59**	**22%**	-3%
Enteric Fermentation	23	31	26	25	25	25	25	25	10%	-20%
Manure Management	7.5	9.8	8.5	8.4	8.4	8.4	8.5	8.5	13%	-13%
Agricultural Soils	17	18	20	20	21	23	22	23	36%	24%
Field Burning of Agricultural Residues	0.23	0.05	0.03	0.03	0.04	0.05	0.05	0.05	-76%	19%
Liming, Urea Application and Other Carbon-containing Fertilizers	1.2	1.4	1.8	2.0	2.3	2.7	2.5	2.7	125%	88%

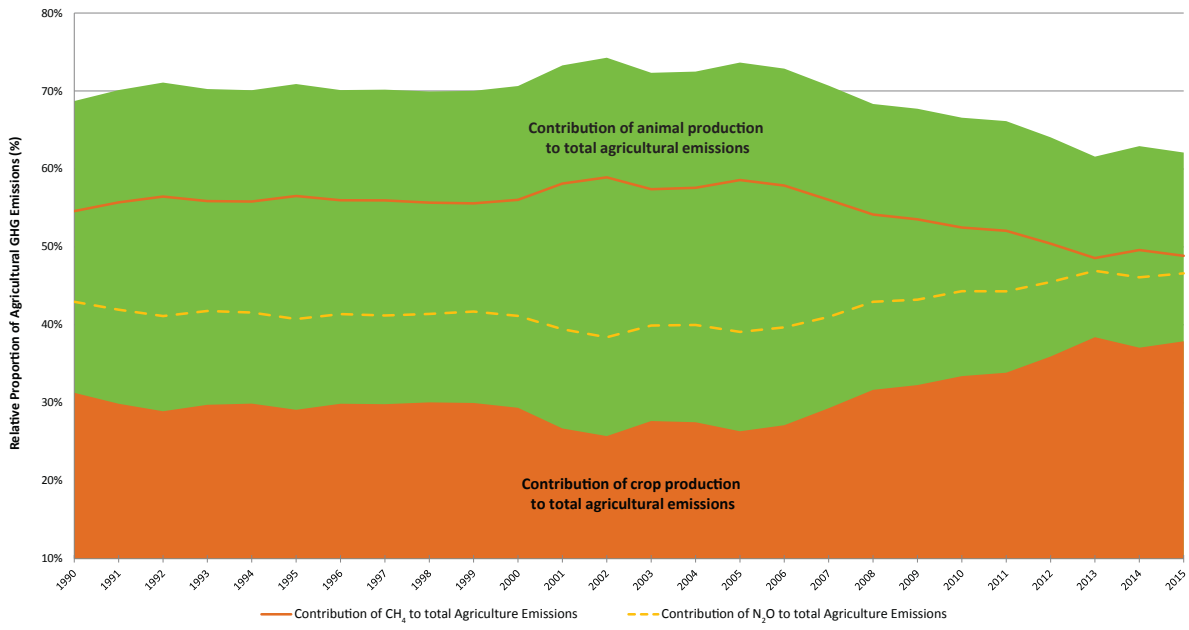
Note: Totals may not add up due to rounding.

(CH_4 and N_2O) from the storage and handling of animal manure. The crop production sector includes: N_2O emissions from the application of inorganic nitrogen fertilizers, crop residue decomposition, animal manure 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. 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, which peaked in 2005, and continuous increases in the application of inorganic nitrogen fertilizers in the Prairie provinces. Beef, swine and poultry populations in Canada are 10%, 28% and 39% higher, respectively, than in 1990, a result of strong commodity prices from 1990 to 2003 (Statistics Canada 2009). Nitrogen fertilizer sales have increased steadily throughout the entire reporting period and are currently 117% higher than in 1990 due to increases in cropping intensity resulting from changes in land management and commodity price trends.

Since 2005, there has been an important change in the emission profile of agriculture with a downward shift in the importance of grazing cattle production relative to the production of annual crops. With the decline in cattle populations and continued increase in fertilizer use, emissions from livestock dropped to their lowest proportion of total agricultural emissions in the reporting period (≈62% of total emissions), considerably lower than the proportion in 2005 (74% of total emissions) (Figure 2-18). As a result of this shift, total agricultural emissions now consist of nearly equivalent proportions of CH_4 (from livestock production) and N_2O (mainly from crop production). The shift in the industry from grazing cattle production to the production of annual crops is also reflected in a decreased carbon sink in agricultural soils observed in a land management change from perennial to annual crops reported in the LULUCF Sector.

Figure 2–18 Proportions of Canadian Agricultural Greenhouse Gas Emissions Emitted as Methane and Nitrous Oxide, or attributed to Livestock and Crop Production (1990–2015)



2.3.3.1. Enteric Fermentation

(2015 GHG Emissions, 25 Mt)

In 2015, enteric fermentation emissions represented 42% of agricultural emissions. These emissions originate almost entirely (96%) from cattle production in Canada. From 1990 to 2015, emissions increased from 23 Mt to 25 Mt, or 10%. The CH_4 emitted from enteric fermentation makes up 87% of total agricultural CH_4 and 24% of total CH_4 reported in the national inventory. Emissions increased from 1990 to 2005 mainly as a result of an increase in the population of beef cattle, driven by high commodity prices. Furthermore, emissions increased at greater rates than cattle populations as herd improvements resulted in an increase in live weight. 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 the past three years, animal commodity prices have increased, and animal populations and livestock emissions have stabilized.

Increases from beef production were, however, partially offset by a 30% reduction in the dairy cow population from 1990 to 2015 (Statistics Canada no date [h]). Emissions associated with dairy cows have fallen by approximately 20% since 1990, but this reduction in emissions from the dairy herd has also been partly offset by a 41% increase in average milk production, due to improved genetics and changes in feeding and/or management practices. The average dairy cow produces more milk today than in 1990, consumes more feed and, as a result, emits more GHGs.

2.3.3.2. Manure Management

(2015 GHG emissions, 8.5 Mt)

Emissions from animal manure management systems represented 14% of total agricultural emissions and increased from 7.5 Mt in 1990 to 8.5 Mt in 2015 (13%), driven by increases in livestock populations of beef, swine and poultry, but partially offset by the decline in dairy populations. The storage of manure results in both CH_4 (13% total agricultural CH_4) and N_2O (17% total agricultural N_2O). Beef and poultry production produce mainly N_2O, whereas pork production produces mainly CH_4, and dairy is equally divided between N_2O and CH_4. As a result, N_2O emissions closely follow the trend in beef populations, increasing from 4.1 Mt in 1990 to 5.5 Mt (36%) in 2005 and subsequently declining to 4.8 Mt (14%) in 2015. As was the case with enteric fermentation, the increase in beef cattle weights also contributed to the increase in N_2O emissions. Methane emissions correspond closely to swine populations, increasing from 3.5 Mt in 1990 to 4.3 Mt in 2005 (23%) and subsequently declining to 3.8 Mt (12%).

2.3.3.3. Agricultural Soils

(2015 GHG Emissions, 23 Mt)

Emissions from agricultural soils represent 39% of total agricultural emissions. They originate from the application of inorganic nitrogen fertilizers and crop residue decomposition and are modified by crop management practices. Emissions increased from 17 Mt in 1990 to 23 Mt in 2015, an increase of 36%, due mainly to an increase in inorganic nitrogen fertilizer use.

Emissions from the application of inorganic nitrogen fertilizers increased from 5.7 Mt in 1990 to 11 Mt in 2015, an increase of 94%, 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 2015. The first period was a result of the intensification of cropping systems and the reduction of summerfallow 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 1.5-Mt (190%) increase in emissions of CO_2 from urea-based carbon containing fertilizers.

Emissions from crop residue decomposition ranged from a minimum of 3.2 Mt in 2002 (a drought year) to a maximum of 6.4 Mt in 2013, depending mainly on weather conditions and their impact on crop yield. Though crop production demonstrates high interannual variability, production has tended to increase over the reporting period.

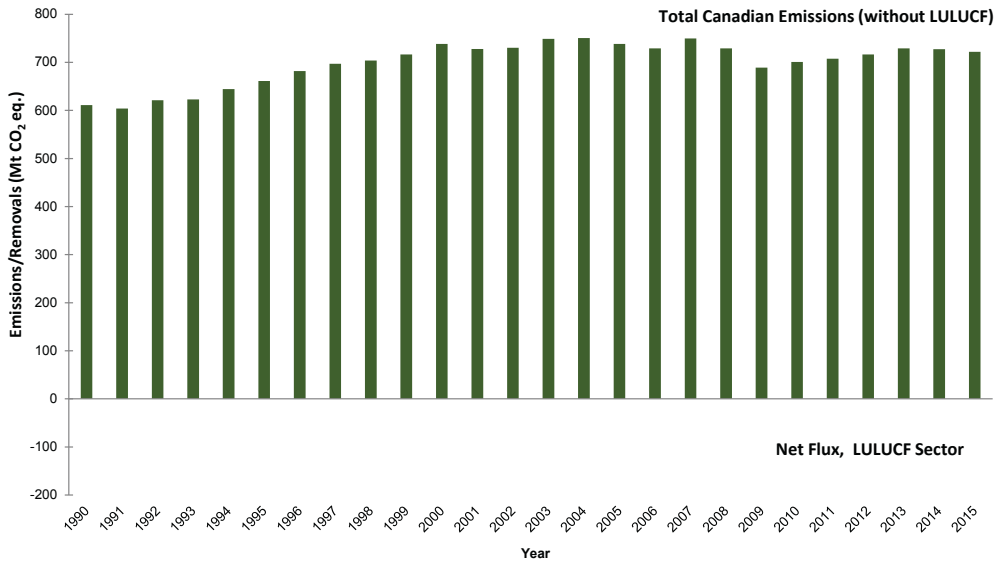
Emissions from cropland management practices including summerfallow, tillage and irrigation decreased from emission of 1.3 Mt in 1990 to a reduction in emissions of 0.85 Mt in 2015 – a reduction of 160% due mainly to continued efforts in the adoption of conservation tillage (over 15 million hectares of cropland since 1990) and intensification of cropping systems by reducing summerfallow (88%).

2.3.4. Land Use, Land-use Change and Forestry Sector (2015 Net GHG Removals, 34 Mt, Not Included in National Totals)

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. 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 and CO_2 removals from the atmosphere.

In 2015, this net flux amounted to removals of 34 Mt, 66 Mt lower than removals of 99 Mt in 1990, and 3 Mt lower than removals of 37 Mt in 2005. The trend in net removals is mainly driven by a

Figure 2–19 Net Flux from LULUCF Relative to Total Canadian Emissions, 1990–2015



decrease in net CO_2 removals from Forest Land (Figure 2–19 and Table 2–10), partially attenuated by an increase in net CO_2 removals in Cropland and reduced emissions from the conversion of forest to other land use.

All emissions and removals in the LULUCF Sector are excluded from the national totals. However, if included, the estimated net removals would decrease Canada's total GHG emissions by about 16%, 5.0% and 4.6%, in 1990, 2005 and 2015, respectively.

2.3.4.1. Forest Land and Harvested Wood Products (HWP)

(2015 GHG Removals, 33 Mt)

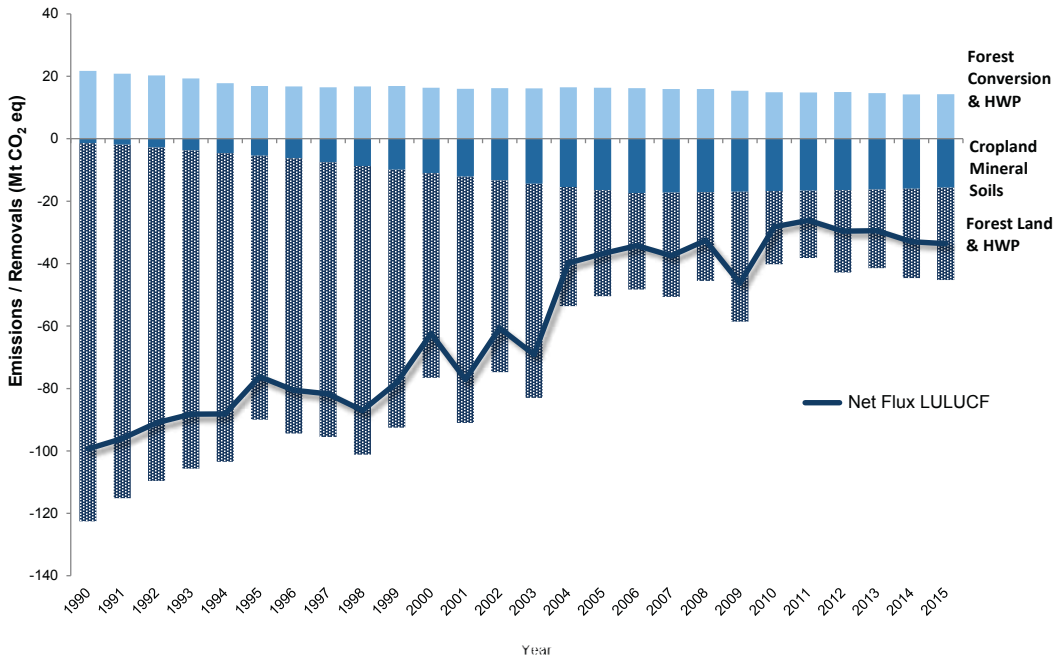
The Forest Land and Harvested Wood Products (HWP) categories combined include GHG fluxes between the atmosphere and Canada's managed forests and emissions from harvested wood products originating from harvesting activities. The total net flux from managed forests and HWP amounted to removals of 33 Mt in 2015 (Figure

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

Sectoral Category	Net GHG Flux (Mt CO_2 eq)[2]								Change Mt	
	1990	2005	2010	2011	2012	2013	2014	2015	1990–2015	2005-2015
Land Use, Land-use Change and Forestry TOTAL[1]	**- 99**	**- 37**	**- 28**	**- 26**	**- 30**	**- 29**	**- 33**	**- 34**	**66**	3.2
a. Forest Land	- 250	- 180	- 160	- 160	- 160	- 160	- 170	- 160	88	19
b. Cropland	8.9	- 10	- 12	- 12	- 12	- 11	- 11	- 11	- 20	-0.6
c. Grassland	0.6	0.9	0.3	0.6	1.6	0.7	0.7	0.7	0.0	-0.2
d. Wetlands	4.9	3.0	2.8	2.7	3.1	2.8	2.6	2.7	- 2.2	-0.3
e . Settlements	4.0	3.7	3.8	3.8	3.9	3.7	3.7	3.6	- 0.5	-0.2
f. Harvested Wood Products	130	150	140	140	140	140	140	130	0.4	-14

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

Figure 2–20 LULUCF Sector Net GHG Flux and Major Emission and Removal Components, 1990–2015



2-20), which combines net removals of 160 Mt from Forest Land and net emissions of 130 Mt from HWP.

Net removals from Forest Land—excluding direct emissions from severe natural disturbances—decreased from 250 Mt in 1990 to 160 Mt in 2008. 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. In recent years, net overall removals have begun to increase, most notably in 2009, when harvest rates reached the lowest point in the 25-year time series. Harvest levels in 2015 are still 28% below their peak in 2004. This trend is driven by the reduced global demand for Canadian lumber and pulp and paper products (NRCan 2015).

The decrease in forest removals nationally is dominated by trends in the Montane Cordillera and Boreal Plains reporting zones, namely increases in emissions between 2001 and 2011 in the Montane Cordillera and large reductions in GHG removals between 1998 and 2008 in the Boreal Plains. Severe insect outbreaks in the Montane Cordillera and the 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 resulted in significant increases in emissions of CO_2 from decomposition. On the Boreal Plain, sustained harvest, insects 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 that is large enough to influence the national trend.

Emissions from HWP reflect the long-term storage of carbon in wood harvested from Canada's forests. Approximately one-quarter of HWP emissions (26% in 2015) result from the decay of 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, make up 30% and 34%, respectively, of HWP emissions in 2015. Together, they more closely track recent trends in forest harvest rates. Emissions from HWP fluctuated between 122 Mt in 2009, the lowest harvest year, and a peak of 153 Mt in 1995 and 2000.

2.3.4.2. Forest Conversion[11]

(2015 GHG Emissions, 14 Mt)

Forest conversion 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 22 Mt in 1990 to 14 Mt in 2015.

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, 1.3 million hectares of forest have been converted to other land uses in Canada. Geographically, the highest average rates of forest conversion occur in the Boreal Plains (23 kha per year) and the Boreal Shield East (8 kha per year), which account for 46% and 16%, respectively, of the total loss of forest area in Canada since 1990.

11 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 2–21 Trends in Annual Rates of Forest Conversion to Cropland, Wetlands and Settlements

With a current annual conversion rate of 22 kha, Forest Land conversion to Settlements accounts for the largest share of forest loss, comprising 61% in 2015, up from 33% in 1990. Forest clearing for agricultural expansion (Cropland) is the second largest driver of forest conversion, representing 34% of all forest area lost in 2015. Annual rates dropped from 42 kha in 1990 to 12 kha in 2015, 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, see Figure 2–21). Cumulative areas of forest converted for the creation of hydro reservoirs and the associated infrastructure equal 161 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.

2.3.4.3. Cropland

(2015 GHG Removals, 10.9 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.

The trend in Cropland emissions and removals shows a steady decrease in the net CO_2 flux, notably in the period 1990–2009, from a net source of 8.9 Mt in 1990 to a net sink of 11.7 Mt in 2009, a total change of 20 Mt (Table 2-10). This trend is a result of changes in agricultural land management practices in western Canada that conserve carbon in soils, such as the extensive adoption of conservation tillage practices (≈15 million hectares of cropland since 1990) and an 88% reduction in summerfallow by 2015.

Since 2006, net removals have gradually declined to 10.9 Mt mainly due to the net conversion of perennial to annual crops on the prairies, but also due to soil carbon approaching equilibrium from conventional to conservation tillage and

reduction of summerfallow. The increase in the conversion of perennial to annual crops since 2006 coincided with a reduction in grazing cattle populations on the prairies. A decline in emissions from Forest Land converted to Cropland has also contributed to this trend (see Section 2.3.4.2).

2.3.4.4. Other LULUCF Sources/Sinks

(2015 GHG emissions, 7.0 Mt)

Other LULUCF sources/sinks comprise Settlements, Wetlands and Grassland, which contributed 3.6 Mt, 2.7 Mt and 0.7 Mt, respectively, to the net emissions of 7.0 Mt reported in 2015, down from 9.6 Mt in 1990. The Settlements category includes the growth of urban trees (annual removals of 2.4 Mt throughout the reporting period) and land converted to Settlements. The Wetlands category includes emissions from peatlands managed for peat extraction and from flooding of land (hydroelectric reservoirs). Trends in this category are mainly driven by the creation of large reservoirs before 1990, resulting in higher emissions over the period 1990–1993. More specific details on the trend in emissions from Forest Land converted to Settlements and flooded land can be found in Section 2.3.4.2

2.3.5. Waste Sector

(2015 GHG Emissions, 25 Mt)

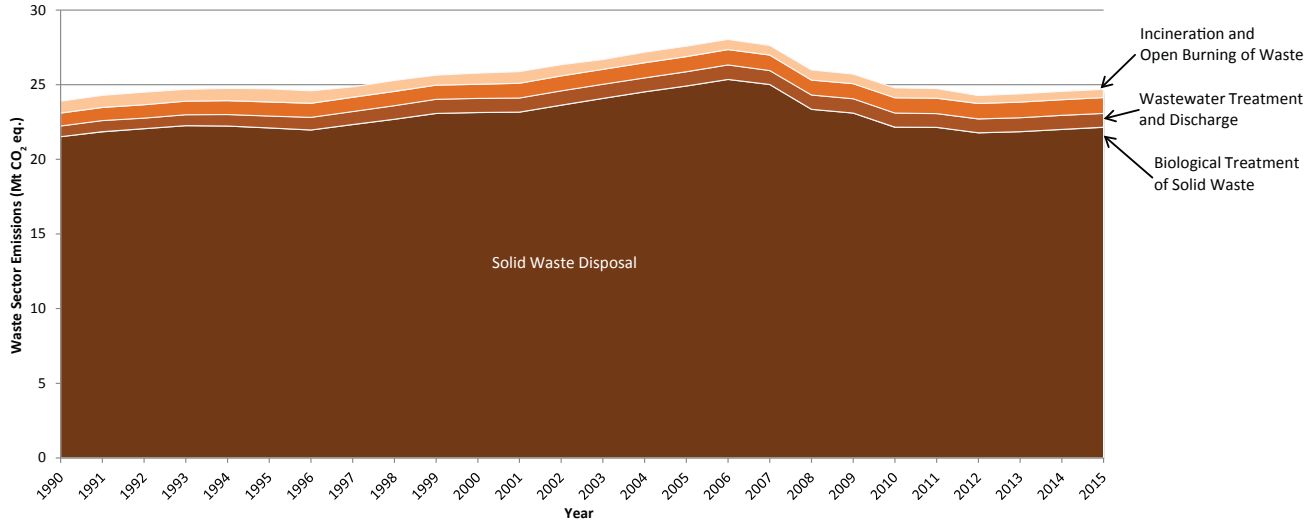
The Waste Sector includes GHG emissions from the treatment and disposal of liquid and solid wastes. Emissions from the Waste Sector contributed 25 Mt (3.4%) to Canada's total emissions in 2015, compared with 24 Mt (3.9%) in 1990 and 28 Mt (3.7%) in 2005 (Figure 2-22 and Table 2-11). Over the same period, total national GHG emissions grew by 18% and the population grew by 29%. Of the total emissions of 25 Mt from this sector in 2015, Solid Waste Disposal, which includes municipal solid waste (MSW) landfills and wood waste landfills, accounted for 22 Mt (or 90% of Waste Sector emissions), while Biological Treatment of Solid Waste (composting), Wastewater Treatment and Discharge, and Incineration and Open Burning of Waste (excluding emissions from incineration of biomass material) contributed 0.94 Mt, 1.06 Mt and 0.55 Mt, respectively.

2.3.5.1. Solid Waste Disposal

(2015 GHG Emissions, 22 Mt)

Emissions from Solid Waste Disposal were estimated for two solid waste emission sources: MSW (19 Mt in 2015) and wood waste landfills (4 Mt in

Figure 2–22 Trends in Canadian GHG Emissions from Waste (1990–2015)



2015). The CH_4 production rate at a landfill is a function of several factors, including the mass and composition of biomass being landfilled, the landfill temperature, and the moisture entering the site from rainfall. Methane emissions produced by the decomposition of biomass in MSW landfills are responsible for 75% of the emissions from this sector.

Methane emissions from MSW landfills increased 5% between 1990 and 2015. Of the 30 Mt CO_2 eq of CH_4 generated by MSW landfills in 2015, only 19 Mt (or 62% of generated emissions) were actually emitted to the atmosphere. The other 11 Mt were captured and combusted at 81 landfill gas collection sites. The quantity of captured CH_4 increased from 21% of the generated emissions in 1990 to 38% in 2015. Of the total amount of CH_4 collected in 2015, 51% (5.6 Mt) was utilized for various energy purposes and the remainder was flared (Environment Canada 2014).

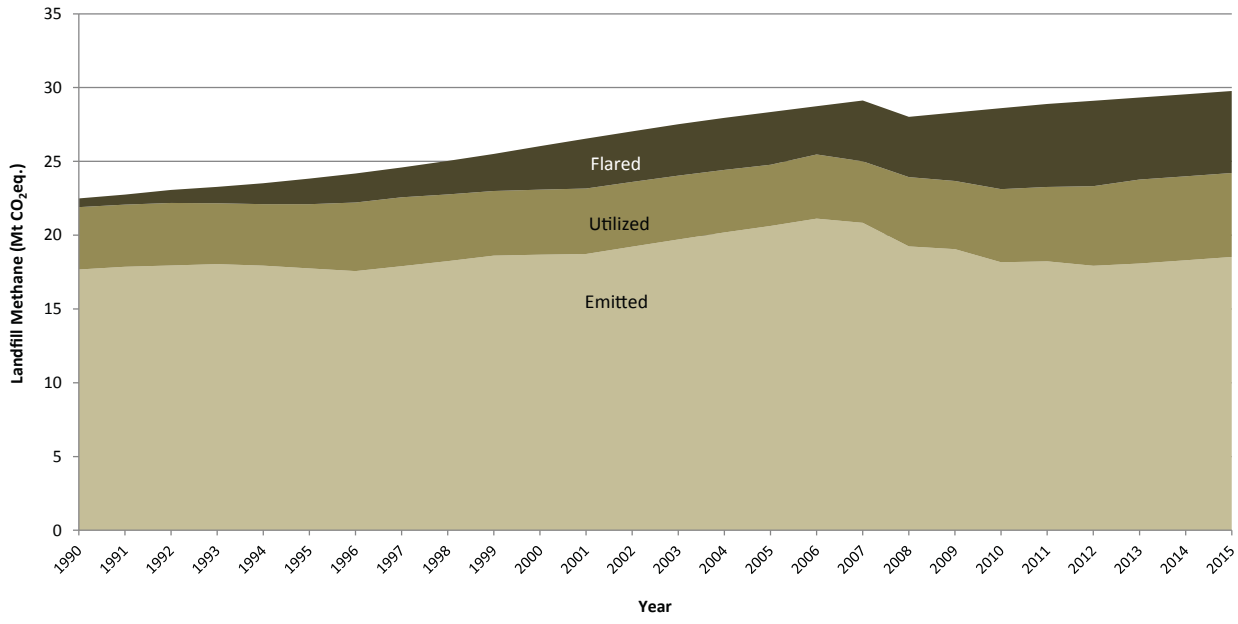
Landfill gas capture contributed to containing the growth in CH_4 emissions from MSW landfills to 5% above their 1990 levels and to actual emission reductions in this category from 2006 to 2012. There was a gradual increase in emissions from 2012 to 2015, due to a plateauing of the number of active landfills and of the quantities of landfill gas collected (Figure 2–23).

Table 2–11 GHG Emissions from Waste, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)	
	1990	2005	2010	2011	2012	2013	2014	2015	1990-2015	2005-2015
Waste Sector	24	28	25	25	24	24	25	25	3.3%	-10%
Solid Waste Disposal	22	25	22	22	22	22	22	22	2.9%	-11%
Biological Treatment of Solid Waste	0.72	0.97	0.96	0.93	0.94	0.94	0.95	0.94	31%	-2.8%
Wastewater Treatment and Discharge	0.87	1.02	1.03	1.04	1.04	1.05	1.06	1.06	22%	4.5%
Incineration and Open Burning of Waste	0.79	0.70	0.66	0.65	0.53	0.55	0.55	0.55	-30%	-21%

Note: Totals may not add up due to rounding.

Figure 2–23 Proportion of Landfill Gas Utilized vs Flared



2.3.5.2. Other Waste sources (2015 GHG Emissions, 2.6 Mt)

Over the 1990–2015 time series, emissions from the Biological Treatment of Solid Waste (composting) and Wastewater Treatment and Discharge (municipal and industrial wastewater treatment) showed increases in GHG emissions of 31% and 22%, respectively, while emissions from Incineration and Open Burning emissions decreased by 30% (Figure 2–22 and Table 2–11). The growth in Wastewater Treatment and Discharge emissions reflects the increase in the Canadian population (29%). The 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.

2.4. Emissions by Canadian Economic Sector

In this report, emissions estimates are primarily grouped into the activity sectors defined by the IPCC: Energy, Industrial Processes and Product Use (IPPU), Agriculture, Land Use, Land-use Change and Forestry (LULUCF), and Waste. While this categorization is consistent with the UNFCCC reporting guidelines, it is also useful to reallocate emissions into economic sectors, since this is more suitable for the purposes of analyzing trends and policies as most people associate GHG emissions with 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,[12] Buildings, Agriculture, and Waste and Other.

This re-allocation simply re-categorizes 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 emission profile for a specific economic sector. This is the approach that has been taken for reporting emission projections and progress towards Canada's 2020 GHG reduction target in *Canada's 2016 GHG Emissions Reference Case*, past *Canada's Emissions Trends* reports and in the Biennial Reports to the UNFCCC (ECCC 2016). Examining the historical path of Canadian GHG emissions by economic sectors allows 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 that taken in the Pan-Canadian Framework on Clean Growth and Climate Change.

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 in mobile farming machinery or mining trucks would be reflected in the economic sector estimates for Agriculture or Heavy Industry (mining).

Annex 10 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 (1990–2015) and the relationship between

12 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.

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 exploitation, 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.

2.4.1. Emission Trends by Canadian Economic Sector

Oil and Gas

In 2015, the Oil and Gas sector produced the largest share of GHG emissions in Canada (26%). Between 1990 and 2015, emissions from this sector increased by 82 Mt. The majority of this increase (50 Mt) occurred between 1990 and 2005 as the sector expanded and adopted new extraction processes. However, growth in GHG emissions from the oil and gas sector slowed between 2005 and 2015 due to the gradual exhaustion of traditional natural gas and oil resources in Canada (see text box below).

As outlined in the pan-Canadian Framework on Clean Growth and Climate Change, the development of regulations to reduce methane emissions from the oil and gas sector, including offshore activities, by 40-45 percent by 2025, as well as by the development of a clean fuel standard, improved energy efficiency, and support for clean technology and innovation will contribute to reducing emissions in this sector.

Transportation

Canada's Transportation sector is the second-largest contributor to Canada's GHG emissions, representing 24% of total emissions in 2015. Between 1990 and 2010 emissions rose by 49 Mt (41%), but since then, emissions from this sector have leveled off. Section 2.3 discusses the main drivers of historical emissions trends associated with passenger and freight transport.

Actions under the Pan-Canadian Framework on Clean Growth and Climate Change will reduce emissions in this sector over time. These actions will include: setting increasingly stringent emission standards for light- and heavy-duty vehicles, as well as taking action to improve efficiency and support fuel switching in the rail, aviation, marine, and off-road sectors; developing a zero-emissions vehicle strategy by 2018 and investing in infrastructure to support zero-emissions vehicles; and investing in infrastructure to support shifts from higher- to lower-emitting modes of transportation. The development of a clean fuel standard will also influence future trends in this sector.

Electricity

In 2015, the Electricity sector (excluding industrial and commercial cogeneration) contributed 11% to total Canadian emissions. Emissions from the Electricity sector increased in parallel with the

rising demand for electricity both domestically and to satisfy export 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.

The Pan-Canadian Framework on Clean Growth and Climate Change will continue to drive down emissions from electricity, through a mix of regulations and investments. This will include new regulations to accelerate the phase-out of traditional coal units by 2030 and performance standards for natural gas-fired electricity. These actions will be complemented by investments to modernize Canada's electricity systems, including in smart grid and energy storage technologies, and new and enhanced transmission lines to connect clean power with the places that need it.

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 11 Mt between 2005 and 2015.

Commitments in the pan-Canadian Framework on Clean Growth and Climate Change to: develop a clean fuel standard; improve energy efficiency; accelerate fuel-switching; and, finalize regulations to phase down the use of hydrofluorocarbons in line with the Kigali Amendment to the Montreal Protocol, will contribute to reducing emissions in this sector.

Buildings

GHG emissions from the Buildings sector have increased with population 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 73 Mt to 86 Mt (17%).

Measures identified in the Pan-Canadian Framework on Clean Growth and Climate Change will reduce emissions in this sector, including by developing "net-zero energy ready" building codes that can be adopted by 2030 for new buildings; retrofitting existing buildings and providing businesses and consumers with information on energy performance; and improving energy efficiency of appliances and equipment. The development of a clean fuel standard will also influence future trends in this sector.

Agriculture and Waste & Other

Emissions from the Agriculture sector continued a slow upward trend throughout the reporting period, rising from 60 Mt in 1990 to 73 Mt in 2015. This increase in emissions is due primarily to increases in livestock and crop production. Emissions from the Waste and Other sector remained relatively stable. Overall emissions decreased over the time series, from a high of 57 Mt in 1990 to 48 Mt in 2015.

TRENDS IN THE OIL AND GAS SECTOR

In the economic sector representation of the oil and gas (O&G) industry, all combustion-related emissions (stationary combustion, off-road transportation, utility and industrial generation of electricity and steam) are combined with fugitive and industrial process emissions to show a complete emissions profile of the industry.

In 2015, the largest contributor to O&G emissions was the Oil Sands category (71 Mt, or 37%) followed by Natural Gas Production and Processing (56 Mt, or 29%), Conventional Oil Production (31 Mt, or 16%) and Petroleum Refining (21 Mt, or 11%). The primary drivers of emissions within the O&G sector are production growth and production characteristics (intensity, defined as the average amount of GHG emissions generated per barrel of oil equivalent).

Production Growth

From 1990 to 2015, the production of total crude oil increased by 131% (Statistics Canada no date [e]). The increase was driven almost entirely by Canada's oil sands operations, where total output (non-upgraded bitumen and synthetic crude oil production) has increased by almost 590%, with most of the growth occurring from 1996 onward (AER 2016). Consistent with the production increases, emissions from total crude oil production increased by 62 Mt (about 155%), with oil sands alone increasing by 55 Mt (360%).

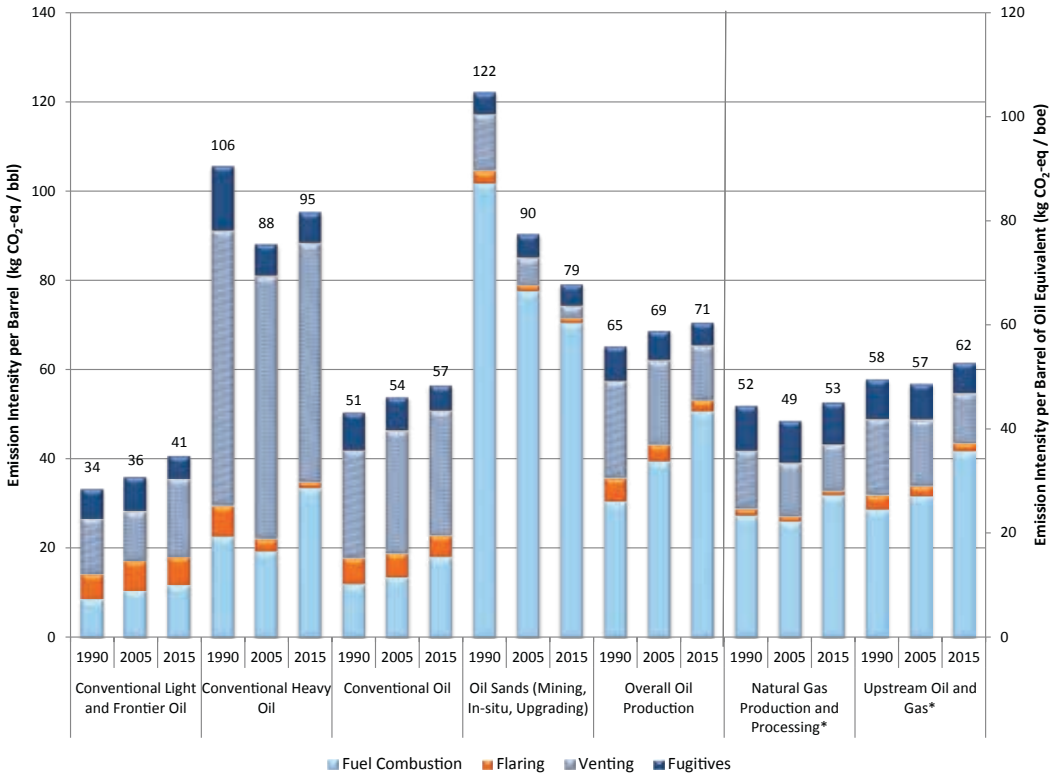
Production Characteristics (Emission Intensity)

The emission intensity of overall oil production in Canada increased by about 8% between 1990 and 2015, from 65 to 71 kg CO_2 eq per barrel (Figure 2–24). Contributors to this trend in emission intensity include decreasing reserves of easily removable crude oil, along with increasing reliance on reserves requiring more energy and GHG-intensive extraction methods. These include 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. 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 (Allen et al. 2013).

The rising quantity of petroleum extracted from Canada's oil sands has had the largest impact on increasing the emission intensity of overall oil production. However, the intensity of oil sands operations themselves declined steadily from 1990 (122 kg CO_2 eq per barrel) until about 2005 (90 kg CO_2 eq per barrel). From 2005 to 2010, the intensity remained relatively flat. Since 2010, emission intensity in the oil sands has continued to decline as the industry has reduced the fuel combustion requirements per barrel of oil extractedu. The venting emisisons per barrel extracted at in-situ bitumen facilities has also decreased due to the impact of Alberta's *Directive 60: Upstream Petroleum Industry Flaring, Incinerating, and Venting*, which aims to increase gas conservation and reduce venting and flaring (AER 2015). 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 the overall emission intensity decreases. This was particularly evident between 2010 and 2015, when non-upgraded bitumen

production increased by over 100% while SCO production increased by only 21%. The trend causes the additional energy required to process the crude bitumen (and resulting emissions) to be transferred downstream, mainly to export markets where the bitumen is processed at petroleum refineries.

Figure 2–24 Emission Intensity by Source Type for Oil and Gas (1990, 2005 and 2015)



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. 1 barrel (bbl) = 0.159 m^3

Production data from Statistics Canada (2016e) and AER (2016).

Table 2–12 Details of Trends in GHG Emissions by Economic Sector[1]

	1990	2005	2010	2011	2012	2013	2014	2015
					Mt CO_2 eq			
NATIONAL GHG TOTAL	**611**	**738**	**701**	**707**	**716**	**729**	**727**	**722**
Oil and Gas	**108**	**158**	**160**	**161**	**174**	**185**	**190**	**189**
Upstream Oil and Gas	88	134	136	139	150	161	167	167
Natural Gas Production and Processing	36	57	49	49	53	57	57	56
Conventional Oil Production	24	30	27	27	29	31	33	31
Conventional Light Oil Production	12	12	11	12	14	15	15	14
Conventional Heavy Oil Production	12	17	14	14	15	15	16	15
Frontier Oil Production	0	2	2	2	1	2	2	2
Oil Sands (Mining, In-situ, Upgrading)	15	35	53	55	60	64	68	71
Mining and Extraction	5	10	14	14	15	16	17	18
In-situ	5	11	20	22	25	28	30	34
Upgrading	6	14	19	19	20	20	20	19
Oil and Natural Gas Transmission	12	12	7	7	8	9	10	10
Downstream Oil and Gas	20	24	23	22	24	24	23	22
Petroleum Refining	18	22	22	21	23	23	22	21
Natural Gas Distribution	2	1	1	1	1	1	1	1
Electricity	**94**	**117**	**96**	**89**	**85**	**82**	**80**	**79**
Transportation	**122**	**163**	**171**	**171**	**173**	**176**	**173**	**173**
Passenger Transport	78	93	92	90	90	92	89	91
Cars, Trucks and Motorcycles	71	85	85	83	83	84	82	83
Bus, Rail and Domestic Aviation	7	7	7	7	7	8	7	7
Freight Transport	34	64	73	75	77	78	77	76
Heavy Duty Trucks, Rail	27	56	65	69	71	72	71	71
Domestic Aviation and Marine	6	8	8	7	7	6	6	5
Other: Recreational, Commercial and Residential	10	7	7	6	6	6	6	6
Heavy Industry	**97**	**86**	**73**	**80**	**79**	**77**	**77**	**75**
Mining	7	7	8	8	8	8	8	8
Smelting and Refining (Non Ferrous Metals)	17	14	11	11	10	11	10	10
Pulp and Paper	15	9	7	7	7	7	6	6
Iron and Steel	16	16	14	17	17	15	16	14
Cement	10	13	10	10	11	10	10	10
Lime & Gypsum	3	3	3	3	3	2	3	2
Chemicals & Fertilizers	29	23	21	23	24	24	24	25
Buildings	**73**	**85**	**81**	**87**	**85**	**85**	**88**	**86**
Service Industry	27	40	38	40	42	41	41	41
Residential	47	46	43	46	43	45	47	45
Agriculture	**60**	**74**	**70**	**70**	**71**	**74**	**72**	**73**
On Farm Fuel Use	12	14	14	15	14	14	14	14
Crop Production	15	16	19	19	21	23	22	22
Animal Production	33	45	37	37	37	37	37	37
Waste & Others	**57**	**54**	**50**	**50**	**49**	**49**	**48**	**48**
Waste	24	28	25	25	24	24	25	25
Coal Production	4	2	3	3	3	3	2	2
Light Manufacturing, Construction & Forest Resources	29	24	22	23	22	22	21	21

Note:
Totals may not add up due to rounding.
Estimates presented here are under continual improvement. Historical emissions may be changed in future publications as new data becomes available and methods and models are refined and improved.
* Less than 0.5 Mt CO_2-eq
1. 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.

2.5. Pathway to Canada's 2030 target

To achieve its target, Canada must reduce its total economy-wide emissions to 523 Mt in 2030. The Government of Canada uses a recognized energy and macroeconomic modeling framework to produce emissions projections to 2030, which are published on an annual basis. The most recent emissions projections, published in December 2016 (insert link), indicate that with federal, provincial and territorial policies and measures that have legislated or funding certainty and were in place as of November 1st, 2016, (just prior to the release of the Pan-Canadian Framework) total Canadian GHG emissions would be 742 megatonnes of carbon dioxide equivalent (Mt CO_2 eq) in 2030.

The federal, provincial and territorial policies within the pan-Canadian Framework that have been modelled are projected to decrease Canada's emissions by 175 Mt. This includes the estimated impacts of carbon pricing, proposed regulations (e.g., clean fuel standard, accelerated coal phase-out, vehicle efficiency standards, regulations for methane and HFCs), and some additional actions in electricity, buildings, transportation and industry.

This estimate of 175 Mt does not include the full suite of commitments under the Pan-Canadian Framework. Specifically, the emission reductions associated with the unprecedented levels of investment in public transit, green infrastructure, innovation and clean technologies have not yet been estimated or modelled. Emissions reductions from these investments will be assessed and quantified as specific projects are identified and programs are implemented.

Additionally the potential increases in stored carbon (carbon sequestration) in forests, soils and wetlands have not been included in the projected emissions reductions figure of 175 Mt. For a country such as Canada carbon sequestration could make an important contribution to the achievement of the 2030 target.

Finally, this projected emissions reduction figure assumes that no new mitigation policies or measures will be implemented by the provinces and territories between now and 2030.

Figure 2–25 Pathway to Canada's 2030 target

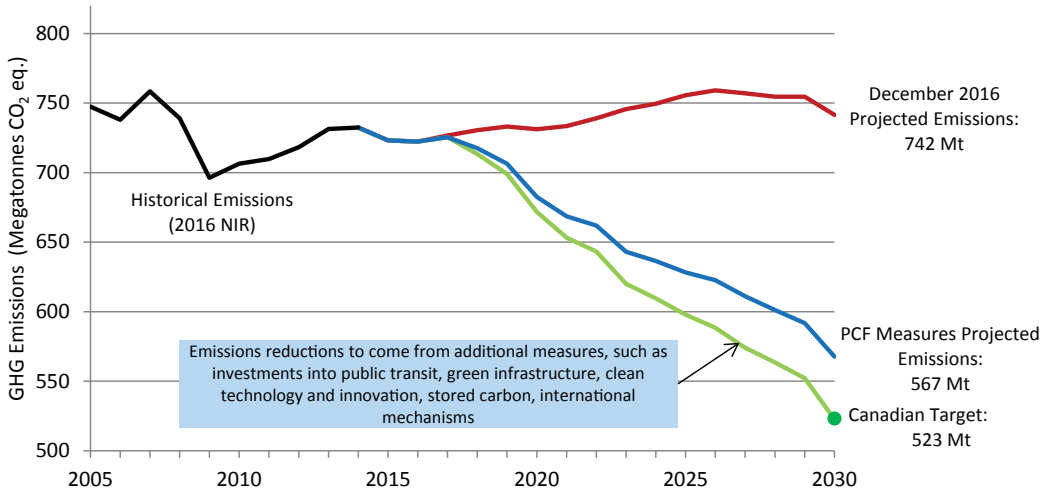
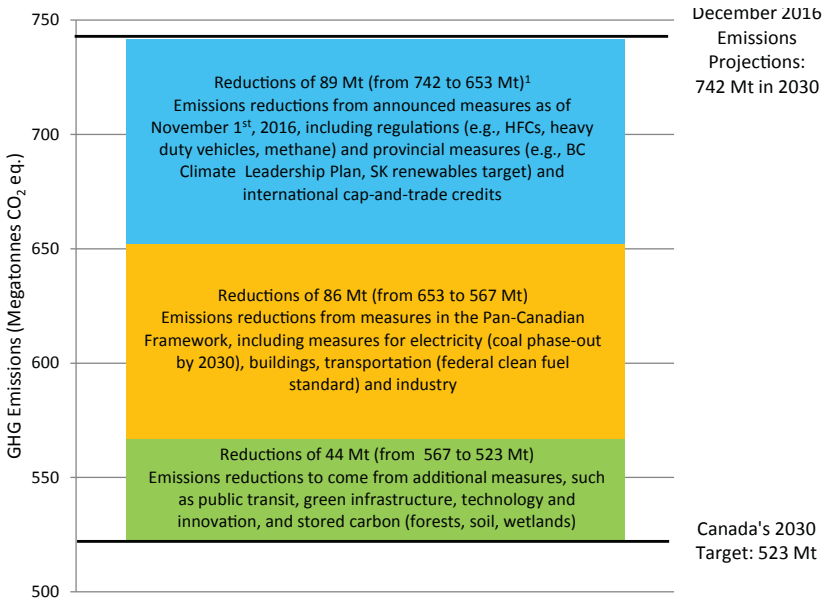


Figure 2–26 Emissions Reductions from the Pan-Canadian Framework



Note: Reductions from carbon pricing are built into the different elements depending on whether they are implemented, announced, or included in the Pan-Canadian Framework. The path forward on pricing will be determined by the review to be completed by early 2022.

1. Estimates assume purchase of carbon allowances (credits) from California by regulated entities under Quebec and Ontario's cap-and-trade system that are or will be linked through the Western Climate Initiative.

The measures and investments outlined in the Pan-Canadian Framework will enable Canada to meet or even exceed its 2030 target and provide a strong foundation to achieve deeper emissions reductions over time and build a highly competitive, low-carbon economy. Many of the policies and measures in the Framework are intended to be scalable to enable increasing ambition over time, and will be subject to rigorous and ongoing evaluation in order to ensure that Canada is well-positioned to meet its current and future climate change commitments. Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, which was released in November 2016, describes various pathways for innovative and creative solutions to low-carbon development. This long-term perspective will help to guide the elaboration of policies and investments under the Pan-Canadian Framework, as Canada continues to take action to significantly reduce emissions by 2030 and on an ongoing basis.

The Pan-Canadian Framework commits to ongoing monitoring and reporting on results, in order to ensure that policies are effective, take stock of progress achieved, and to inform Canada's future national commitments in accordance with the Paris Agreement. This will include annual reporting to the Prime Minister of Canada and provincial and territorial Premiers, engagement with external experts, and an interim review of carbon pricing approaches by 2020. In addition, the Government of Canada will continue to regularly evaluate regulatory approaches, track and report on progress. These and other mechanisms for transparency and accountability will enable Canada to track progress towards its target and adjust policies and approaches over time as needed.

Chapter 3

ENERGY
(CRF SECTOR 1)

3.1. Overview

In 2015, the Energy Sector accounted for 587 Mt (or 81%) of Canada's total greenhouse gas (GHG) emissions (Table 3–1). The Energy Sector includes all GHG (carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)) emissions from stationary and transport fuel combustion activities as well as fugitive emissions from the fossil fuel industry.[1]

Emissions resulting from fuel combustion include the use of fossil and biomass fuels by the electricity generating industry, the oil and gas industry, the manufacturing and construction industry, and the residential and commercial sectors. Only CH_4 and N_2O emissions resulting from the combustion of biomass fuels, such as residential fuel wood and spent pulping liquor, are accounted for in the Energy Sector, whereas CO_2 emissions resulting from the combustion of biomass are reported as a memo item in the Common Reporting Format (CRF) tables.

GHG emissions from the combustion (and evaporation) of fuel for all transport activities, such as Domestic Aviation, Road Transportation, Railways, Domestic Navigation, Pipeline Transport and Other Transportation (Off-road), are included in the Transport category. Emissions from International Aviation and International Navigation bunker activities are reported as a memo item in the CRF tables. Starting with this submission, some of the off-road emissions from vehicles and machinery that had been historically reported under Other Transportation/Other (1.A.3.e.ii) are now reported under separate and distinct mobile categories within Manufacturing Industries and Construction (1.A.2) or Other Sectors (1.A.4) to meet CRF standards. Note that emissions presented in Chapter 3 are consistent with IPCC/CRF categorization and will differ from the categorization of summary tables in Annex 9 and Annex 11.

Fugitive emissions associated with the fossil fuel industry are the intentional (e.g. venting) or

1 Emissions associated with the non-energy use of fossil fuels are allocated to the Industrial Processes and Product Use Sector.

Table 3–1 GHG Emissions from Energy, Selected Years

GHG Source Category	GHG Emissions, kt CO_2 eq								
	1990	2000	2005	2010	2011	2012	2013	2014	2015
Energy Sector	**483 000**	**602 000**	**595 000**	**571 000**	**575 000**	**578 000**	**592 000**	**594 000**	**587 000**
Fuel Combustion Activities (1.A)	**434 000**	**532 000**	**535 000**	**517 000**	**520 000**	**521 000**	**533 000**	**534 000**	**530 000**
Energy Industries (1.A.1)	146 000	198 000	191 000	165 000	158 000	159 000	157 000	154 000	151 000
Manufacturing Industries and Construction (1.A.2)[1]	74 900	81 800	79 700	90 900	95 300	100 200	107 000	109 000	113 000
Transport (1.A.3)	126 000	154 000	169 000	171 000	171 000	173 000	178 000	175 000	175 000
Other Sectors (1.A.4)	86 600	98 300	95 300	89 200	94 900	88 600	91 500	95 300	91 400
Fugitive Emissions from Fuels (1.B)	**49 000**	**70 000**	**61 000**	**54 000**	**55 000**	**57 000**	**59 000**	**60 000**	**57 000**
CO_2 Transport and Storage (1.C)	**NO**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.1**	**0.2**

Note:
1. Manufacturing Industries and Construction (1.A.2) includes emissions from mining, as per IPCC Guidelines. In Annex 9 and Annex 10, mining has been aggregated with Oil and Gas Extraction since the majority of emissions in this category are from oil sands mining and extraction.

NO = Not Occuring

0 value indicates emissions truncated due to rounding.

Table 3–2 GHG Emission Change due to Recalculation

IPCC Categories	1990	2000	2005	2010	2011	2012	2013	2014
1 Energy Sector				*GHG Emissions, Mt CO_2 eq*				
2016 Inventory Submission	482	603	597	570	574	576	590	594
2017 Inventory Submission	483	602	595	571	575	578	592	594
Total change due to recalculations	**0.8**	**-1.3**	**-1.9**	**1.2**	**1.7**	**2.0**	**1.8**	**-0.3**
1.A. Fuel Combustion	0.8	-1.3	-1.9	1.2	1.7	2.2	1.3	-0.4
1.B – Fugitive and 1.C – CO_2 Transport & Storage	0.0	0.0	0.0	0.0	0.0	-0.1	0.5	0.1

Note:
Totals may not add up due to rounding.

unintentional releases (e.g. leaks, accidents) of GHGs that may result from production, processing, transmission and storage activities. Emissions from flaring activities by the oil and gas industry are reported in the Fugitive Emissions from Fuels category, since their purpose is not to produce heat or to generate mechanical work (IPCC 2006).

In this year's inventory, several recalculations were implemented as a result of continuous methodological improvements and revised activity data. Table 3–2 presents a summary of the GHG magnitude change due to recalculations for the Energy Sector.

Overall, recalculations resulted in a decrease of 0.3 Mt compared to last year's submitted value for 2014. This year, recalculations activities occurred as a result of the following changes:

Activity data: Revisions to the following activity data resulted in recalculations:

- 2014 Report on Energy Supply and Demand (RESD) data, which has (as per standard practice) been incorporated as an update to the preliminary data utilized in last year's inventory;[2]
- 2005-2014 RESD data were revised for propane, butane, diesel and motor gasoline, to account for previously missing data; and
- residential fuelwood data, which were revised to account for territory consumption that was historically not included.

Emission factors: Revisions to the following emission factors resulted in recalculations:

- revised emission factors for Canadian Bituminous, Lignite and Sub-bituminous coals, based on data from a study commissioned by ECCC (*Updated Coal Emission, Energy Conversion and Oxidation Factors* (ECCC 2016);
- revised oxidation factors for all combusted coals, based on data from a study commissioned by ECCC (*Updated Coal Emission, Energy Conversion and Oxidation Factors* (ECCC 2016);
- revised CO_2 emission factors for Still Gas – Refineries for 1990 to 1995 and 2010 to 2015, in order to correct an error identified in these years;
- revised CO_2 emission factor for Petroleum Coke – Refineries and others for 2014, based on finalized feeder data; and,
- revised CO_2 emission factor for Residential Fuelwood combustion, in order to correct an error identified with this emission factor.

Methodology: Changes to the following methods resulted in recalculations:

- corrections to the re-allocation model for solid wood waste and spent pulping liquor in 1996, 2001, 2002, 2013 and 2014, in order to correct an error identified in these years; and
- a new transport estimation model; refer to Section 3.2.6.6 for additional details.

A summary of recalculations for all sectors is provided in Chapter 8.

2 Statistics Canada annually publishes a revised, final version of the previous year's (preliminary) energy data. Currently, energy data for 2015 represents preliminary data (which will be revised in 2018).

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

Emission sources in the Fuel Combustion Activities category include all emissions from the combustion of fossil fuels. Major categories include Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors (which include the residential and commercial subcategories). Methods used to calculate emissions from fuel combustion are consistent throughout and are presented in Annex 3.1, Methodology and Data for Estimating Emissions from Fossil 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 2015, about 530 Mt (73%) of Canada's GHG emissions were from the combustion of fossil and biomass fuels (Table 3-1). Overall GHG emissions from Fuel Combustion Activities have increased by 22% since 1990. Between 1990 and 2015, emissions from the Energy Industries (1.A.1), Manufacturing Industries and Construction (1.A.2) and Other Sectors ((1.A.4)) increased by 16% (47.7 Mt) and emissions from the Transport (1.A.3) category increased by 38% (48.6 Mt), (Figure 3–1).

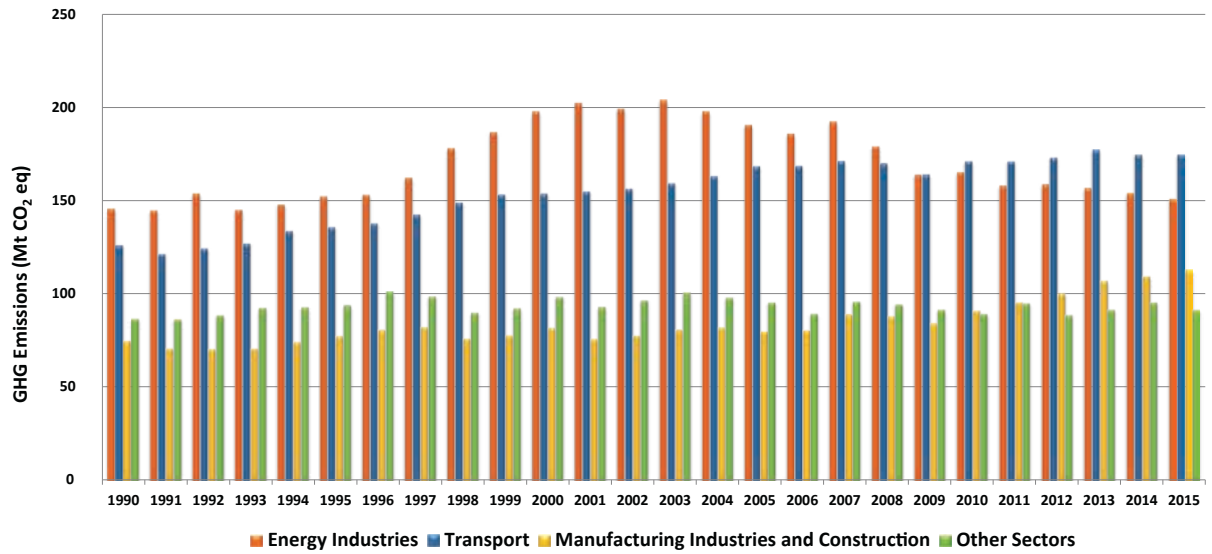
3.2.1. Comparison of the Sectoral Approach with the Reference Approach

A full discussion of this topic is included in Annex 4.

3.2.2. International Bunker Fuels

According to the 2006 IPCC Guidelines, emissions resulting from fuels sold for International Navigation and International Aviation should not be included in national inventory totals, but should be estimated and reported separately as emissions from International Bunkers.

Figure 3–1 GHG Emissions from Fuel Combustion, 1990–2015



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

Emissions (Table 3Table 3–3-3) have been 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 or not a flight stage is domestic or international. This method greatly improves the allocation between domestic and international flights.

Care should be exercised when comparing emission estimates in this category against those reported by the International Energy Agency (IEA). The method employed in the national inventory uses detailed domestic and international movements based on a 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 will not align either.

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

Emissions (Table 3–4) have been calculated using the same methods listed in the Domestic Navigation section (see Section 3.2.6.2). Fuel-use data are reported as foreign marine in the RESD (Statistics Canada 1990–). For marine fuels, it is not clear whether all of the fuel sold to foreign-registered carriers in Canada is used for international transport. More importantly, not all of the fuels sold to domestically registered carriers are consumed within the country, leading to challenges in developing accurate emission estimates.

3.2.3. Feedstocks and Non-Energy Use of Fuels

Reported emissions in the Energy Sector include those resulting from the combustion of fossil fuels for generating heat or work and fugitive releases from the production of these fuels. Note that

Table 3–3 GHG Emissions from Domestic and International Aviation

GHG Source Category	GHG Emissions, kt CO_2 eq							
	1990	2005	2010	2011	2012	2013	2014	2015
International Aviation	6 200	10 100	9 300	9 700	10 900	11 400	11 400	11 500
Domestic Aviation	7 200	7 600	6 400	6 300	7 300	7 500	7 200	7 300
Total	**13 300**	**17 800**	**15 700**	**16 000**	**18 200**	**18 900**	**18 700**	**18 800**

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	2010	2011	2012	2013	2014	2015
International Navigation	3 100	3 100	2 400	1 700	1 400	1 500	1 300	600
Domestic Navigation	4 800	6 400	6 800	5 600	5 600	5 100	4 900	4 400
Total	**7 900**	**9 400**	**9 200**	**7 400**	**7 000**	**6 700**	**6 100**	**5 000**

Note: Totals may not add up due to rounding.

emissions from the flaring of fossil fuels by the oil and gas industry are included in the Fugitive Emissions from Fuels category, section 3.3.

Aside from energy production, fossil fuels are also used for non-energy purposes, such as producing waxes, solvents, lubricants and feedstocks (including those for the manufacturing 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 is divided into the following three subcategories: Public Electricity and Heat Generation, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries.

In 2015, the Energy Industries category accounted for 151 Mt (over 21%) of Canada's total GHG emissions, with a 3.6% increase in total GHG emissions since 1990. The Public Electricity and Heat Generation subcategory accounted for 55.4% (83.7 Mt) of the GHG emissions from Energy Industries, while the Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries subcategories contributed 11.5% (17.3 Mt) and 33.1% (50.1 Mt), respectively (Table 3–5). Additional discussions on trends in emissions from the Energy Industries category are to be found in the Emission Trends chapter (Chapter 2).

The Energy Industries category includes all of the GHG emissions from stationary fuel combustion sources related to utility electricity generation and combined heat and power generation, as well as many of the GHG emissions from the production, processing and refining of fossil fuels. Specifically, the Manufacture of Solid Fuels and Other Energy Industries subcategory includes the GHG emissions associated with *own fuel consumption* by the oil and gas industries (e.g. natural gas industry burning natural gas that it produced or a coal mine burning coal that it produced). Emissions *from the consumption of purchased fuels* by the same oil and gas industries are included in Other – Mining (Excluding Fuels) and Quarrying (1.A.2.g.iii) and Off-road Vehicles and Other Machinery (1.A.2.g.vii) under the Manufacturing Industries and Construction category, and in Pipeline Transport (1.A.3.e.i) under the Other Transportation subcategory. Emissions are allocated in this way because fuel consumption data at a lower level of disaggregation are not available for the '*total mining and oil and gas extraction*' fuel consumption line in the RESD. Combustion emissions associated with the pipeline transmission of oil and natural gas are included under Other Transportation, consistent with the 2006 IPCC Guidelines.

Although actually associated with the Energy Industries, emissions from venting and flaring activities related to the production, processing and

Table 3–5 Energy Industries GHG Contribution

GHG Source Category	GHG Emissions, kt CO_2 eq								
	1990	2000	2005	2010	2011	2012	2013	2014	2015
Public Electricity and Heat Generation	94 300	130 000	122 000	101 000	94 100	91 300	87 600	84 700	83 700
Petroleum Refining	17 000	17 000	20 000	19 000	19 000	20 000	19 000	18 000	17 000
Manufacture of Solid Fuels and Other Energy Industries[1]	34 300	51 100	48 700	45 300	45 700	48 100	50 600	51 700	50 100
Energy Industries TOTAL (1.A.1)	146 000	198 000	191 000	165 000	158 000	159 000	157 000	154 000	151 000

Note: Totals may not add up due to rounding.
1. A portion of emissions from oil and gas extraction are included in the Manufacturing Industries and Construction - Mining (excluding fuels) and Quarrying category.

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 have been 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 from wind, tidal and solar resources is relatively small compared with that from Canada's significant hydro and nuclear installations. Nuclear, hydro, wind, solar and tidal electricity generators only emit small quantities of GHGs, generally from the use of diesel generators as 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. Therefore, the GHG estimates in this category largely 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 are fired with coal, petroleum coke, heavy fuel oil, natural gas or biomass. Reciprocating engines can use natural gas and/or a combination of refined petroleum products (RPPs). Gas turbines are also fired with natural gas or RPPs.

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

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

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

The Manufacture of Solid Fuels and Other Energy Industries subcategory comprises own fuel combustion emissions associated with the crude oil, natural gas, oil sands mining, bitumen extraction and upgrading, and coal mining industries. Emissions from purchased fuel associated with coal mining and oil and gas extraction (which includes oil sands mining, extraction and upgrading) are reported under the Manufacturing Industries and Construction category in the Mining (Excluding Fuels) and Quarrying subcategory (1.A.2.g.ii), whereas emissions associated with pipeline transmission (1.A.3.e.i) and with the use of transport fuels (such as gasoline and diesel) in off-road applications in the mining and oil and gas mining and extraction industry are reported under Manufacturing Industries and Construction (CRF Category 1.A.2.g.vii). This breakdown is dictated by limitations of the fuel data in Statistics Canada's national energy balance (i.e. RESD), which cannot be further disaggregated.

Upgrading facilities are responsible for producing synthetic crude oil based on 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 for their operation, which result in both combustion- and fugitive related emissions.

3.2.4.2. Methodological Issues

Emissions for all source categories are calculated following the methodology described in Annex 3.1 and are primarily based on fuel consumption statistics 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)

Statistics Canada fuel-use data in the RESD differentiates industrial electricity generation from utility generation, but aggregates industrial generation data into one category titled Industrial Electricity Generation. The GHG emissions from industrial electricity generation are reallocated to their respective industrial subcategories using the detailed industry information which feed the RESD. The methodology is described in greater detail in Annex 3.1.

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). Statistics Canada fuel-use data in the RESD is not distinguished on the basis of these subcategories; rather, they are aggregated into one category titled Electricity by Utilities. The GHG emissions from the RESD Electricity by Utilities category is disaggregated into the Electricity Generation and Combined Heat and Power Generation CRF subcategories using the RESD input data. The methodology is described in greater detail in Annex 3.1.

Statistics Canada fuel-use data include industrial wood wastes and spent pulping liquors combusted for energy purposes, aggregated 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)

Emissions for this subcategory are calculated using all fuel use attributed to the petroleum refining industry and include all petroleum products (including still gas, petroleum coke and diesel) 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 (refer to Section 3.3.2). The fuel use and emission data associated with flaring are subtracted to avoid double counting. See Annex 3.2, Section 3.2.2.6, 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 own fuel use attributed to fossil fuel producers (including petroleum coke, still gas, natural gas, natural gas liquids and coal). 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. The fuel-use and emission data associated with flaring are subtracted to avoid double counting. See Annex 3.2, Section 3.2.2.6, for more details.

Additionally, non-marketable natural gas has a higher emission factor than marketable natural gas (see Annex 6), since it consists of natural gas and other complex hydrocarbons resulting in higher carbon content. Likewise, the energy content of non-marketable natural gas is higher than that of marketable natural gas. These differences are taken into account when estimating emissions from own fuel use of 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 activity data collection procedures and the representativeness of specific fuels' emission factors. Commercial fuel volumes and properties are generally well known, while greater uncertainty surrounds both the reported quantities and properties of non-marketable fuels (e.g. own use of natural gas from the producing wells and the use of still gas). 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 (±136%) and N_2O (±185%) 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. Discussion of RESD activity data is presented in Section 3.2.4.5, Recalculations.

Approximately 82% of the 2015 emissions from the Manufacture of Solid Fuels and Other Energy Industries subcategory are associated with the consumption of natural gas in the natural gas production and processing, conventional crude oil and in situ bitumen extraction industries. The uncertainty for this fuel is influenced by the CO_2 (±6%) and CH_4 (0% to +240%) emission factors for the consumption of unprocessed natural gas. Provincially weighted natural gas emission factors were used to estimate emissions for the natural gas industry 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

Quality control (QC) checks were done in a form 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 collects GHG emission estimates from facilities that produce releases of 50 kt CO_2 eq or more in any given year. Where coverage of a specific sector is complete or close to complete, the GHG reporting program data is used to compare industry-reported values to the Canadian inventory emission estimates. This is possible for the Petroleum Refining and Public Electricity

subcategories. Additionally, reported emissions from oil sands mines and upgraders are used to compare emission estimates for this industry.

3.2.4.5. Recalculations

Several improvements have contributed to increased data accuracy, as well as comparability and consistency with the 2006 IPCC Guidelines and UNFCCC reporting guidelines. Emissions estimates have been revised for all years, with estimates for 2014 decreasing by 45 kt CO_2 eq over the previous submission, as a result of:

- revised coal emission factors;
- revised coal oxidation factors; and
- revised RESD data.

Refer to Section 3.1 for additional details.

3.2.4.6. Planned Improvements

Environment and Climate Change Canada, Natural Resources Canada and Statistics Canada are collaborating to continuously improve the underlying quality of the national energy balance and to further disaggregate fuel-use information. For example, a study is underway to evaluate and assess the availability of regional (provincial and territorial) natural gas energy conversion factors from 1990 onward, to accurately track energy density change at the national level. Going forward, the focus will be on the development of representative regional natural gas heating values for use in new energy-based CO_2 emission factors, as per expert review team (ERT) recommendation. The next step in this improvement activity is collecting fuel properties and volumetric flow data by region to determine representative heating values and carbon contents.

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 that emissions from privately-owned Combined Heat and Power Generation and Heat Plants are correctly allocated.

Investigation continues on a method that allocates purchased fuels consumed in the oil and gas industry to the Manufacture of Solid Fuels and Other Energy Industries subcategory. As stated previously, emissions from these fuels are currently reported in the Manufacturing Industries and Construction – Mining (Excluding Fuels) and Quarrying subcategory due to activity data limitations.

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 UNFCCC has assigned six subcategories under the Manufacturing Industries and Construction category; these are presented separately in the following subsections.

In 2015, the Manufacturing Industries and Construction category accounted for 113 Mt (15.6%) of Canada's total GHG emissions, with a 50.3% (37.7 Mt) increase in overall emissions since 1990 (refer to Table 3–6 for more details). Within the Manufacturing Industries and Construction category, 82.1 Mt (72.9%) of the GHG emissions are from the Other subcategory, which is made up of mining, construction and other manufacturing activities. This subcategory is followed (in order of decreasing contributions) by Chemicals (13 Mt, 11.3%), Pulp, Paper and Print (5.6 Mt, 5%), Iron and Steel (5.2 Mt, 4.7%), Non-metallic Minerals

Table 3–6 Manufacturing Industries and Construction GHG Contribution

GHG Source Category	GHG Emissions, kt CO_2 eq								
	1990	2000	2005	2010	2011	2012	2013	2014	2015
Iron and Steel	4 950	6 210	5 550	4 980	5 290	5 510	5 590	6 040	5 240
Non-ferrous Metals	3 310	3 580	3 660	3 070	3 360	2 970	3 100	2 920	2 840
Chemicals	8 300	11 000	8 300	9 900	11 000	11 000	12 000	12 000	13 000
Pulp, Paper and Print	15 000	13 000	8 700	6 000	6 300	6 000	6 300	6 100	5 600
Food Processing, Beverages and Tobacco[1]	IE	IE	IE	IE	IE	IE	IE	IE	IE
Non-metallic Minerals	3 980	4 650	5 430	4 070	4 300	4 020	3 850	4 050	4 110
Other	39 800	44 000	48 000	62 900	65 000	70 600	76 500	77 700	82 100
Mining[2]	6 800	12 470	19 130	35 470	36 570	43 070	48 460	50 700	55 170
Construction	1 880	1 080	1 460	1 520	1 370	1 390	1 290	1 300	1 290
Off-road Manufacturing, Mining and Construction	10 000	12 000	11 000	13 000	13 000	12 000	12 000	12 000	13 000
Other Manufacturing	21 200	18 200	16 400	13 200	13 800	14 200	14 400	13 500	12 600
Manufacturing Industries and Construction TOTAL (1.A.2)	74 900	81 800	79 700	90 900	95 300	100 200	107 000	109 000	113 000

Note:
1. Food Processing, Beverages and Tobacco emissions are included under Other Manufacturing.
2. Mining is included under Manufacturing Industries and Construction as per IPCC guidelines. In Annex 9 and Annex 10 mining has been aggregated with Oil and Gas Extraction since the majority of emissions in this category are from oil sands mining and extraction.

IE = included elsewhere.
Totals may not add up due to rounding.

(4.1 Mt, 3.7%); and Non-ferrous Metals (2.8 Mt, 2.5%) 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 fuel-use data not being available at the appropriate level of disaggregation.

GHG emissions resulting from fuel combustion for the generation of electricity or steam by an industry have been assigned to their corresponding industrial subcategory. GHG emissions generated from the use of fossil fuels as feedstocks or chemical reagents, such as for use as metallurgical coke during the reduction of iron ore, are reported under the Industrial Processes and Product Use Sector to ensure that the emissions are not double counted.

3.2.5.2. Methodological Issues

GHG emissions from fuel combustion for each subcategory within the Manufacturing Industries and Construction category are calculated using 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 are reported separately in the UNFCCC CRF tables as a memo item.

Methodological issues specific to each manufacturing subcategory are identified below.

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. Since the plants are integrated, all the produced coke oven gas is used in the mills and reported in the RESD. Determining the amount of coke oven gas lost as fugitive emissions from flaring is not feasible owing to the nature of fuel consumption reporting by the iron and steel industry. However, Statistics Canada reports that the amount of fuel flared is included in the energy statistics (RESD), indicating that these fugitive emissions are being captured as well.

All emissions associated with the use of metallurgical coke as a reagent for the reduction of iron ore in blast furnaces are allocated to the Industrial Processes and Product Use Sector.

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

All fuel-use data for this subcategory are obtained from the RESD.

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

Emissions resulting from fuels used as feedstocks are reported under the Industrial Processes and Product Use Sector.

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

All fuel-use data for this subcategory are obtained from the RESD.

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)

All fuel-use data for this category are obtained from the RESD, with the exception of waste fuel, which is obtained from the Canadian Industrial Energy End-Use Analysis Centre, based on annual data provided by the industry.

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.

Starting with this submission, related on-site off-road emissions that had been historically reported under Other Transportation/Other (1.A.3.e.ii) are now 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. Coal CO_2 emission factor uncertainties were updated with 95% confidence intervals (see Section 3.2.4.3).

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. A discussion on updated RESD fuel-use data is presented in Section 3.2.4.5, Recalculations.

3.2.5.4. QA/QC and Verification

QC checks were done in a form 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 were completed on the entire stationary combustion GHG estimation model, which included checks of emission factors, activity data and CO_2, CH_4 and N_2O estimates for the entire time series. 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 in electronic form.

3.2.5.5. Recalculations

Emissions estimates have been revised for all years, with estimates for 2014 increasing by 11.9 Mt CO_2 eq over the previous submission, as a result of:

- revised coal emission factors;
- revised still gas and petroleum coke emission factors;
- revised coal oxidation factors;
- revised allocation of solid wood waste and spent pulping liquor data; and
- revised RESD data.

Refer to Section 3.1 for additional details.

3.2.5.6. Planned Improvements

Environment and Climate Change Canada, Natural Resources Canada and Statistics Canada are working jointly to continuously improve the underlying quality of the national energy balance and to further disaggregate fuel-use information.

In addition, the 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, Statistics Canada does not currently disaggregate fuel-use data to this level of detail. Additional data sources and methods are being investigated with the eventual goal of reallocating the data, as required.

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

Transport-related emissions total 175 Mt, accounting for 24.3% of Canada's total GHG emissions (Table 3-7). The greatest 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 100% (22Mt) for LDGTs, 246% (0.4 Mt) for LDDTs and 241% (34 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 12.9 Mt since 1990. Emissions from the Transport category have increased 38% and have contributed the equivalent of 44% 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 has been divided into six distinct categories:

Table 3–7 Transport GHG Contribution

GHG Source Category	GHG Emissions, kt CO_2 eq								
	1990	2000	2005	2010	2011	2012	2013	2014	2015
Transport	**126 000**	**154 000**	**169 000**	**171 000**	**171 000**	**173 000**	**178 000**	**175 000**	**175 000**
Domestic Aviation	7 200	7 700	7 600	6 400	6 300	7 300	7 500	7 200	7 300
Road Transportation	92 000	117 000	134 000	142 000	143 000	144 000	147 000	144 000	144 000
Light-Duty Gasoline Vehicles	46 500	43 500	43 200	39 400	37 600	36 400	36 800	35 000	35 000
Light-Duty Gasoline Trucks	22 400	33 800	39 600	42 800	42 600	43 000	44 500	44 000	44 900
Heavy-Duty Gasoline Vehicles	6 830	11 100	12 100	12 900	12 400	13 200	13 700	13 700	13 900
Motorcycles	99.3	131	212	257	257	266	268	268	278
Light-Duty Diesel Vehicles	494	618	613	673	802	803	861	827	834
Light-Duty Diesel Trucks	162	326	324	405	464	454	512	530	561
Heavy-Duty Diesel Vehicles	14 200	27 000	37 300	45 000	48 500	49 500	50 800	49 600	48 600
Propane and Natural Gas Vehicles	1 400	600	410	57	59	44	27	24	18
Railways	6 900	6 600	6 600	6 600	7 500	7 600	7 300	7 500	7 400
Domestic Navigation	4 800	4 900	6 400	6 800	5 600	5 600	5 100	4 800	4 300
Other Transportation	16 000	18 000	14 000	10 000	9 000	9 000	10 000	11 000	12 000
Off-Road Other Transportation	8 600	6 600	4 300	4 500	3 500	3 500	3 400	3 600	3 800
Pipeline Transport	6 910	11 300	10 200	5 720	5 650	5 730	6 720	7 890	8 150

Note: Totals may not add up due to rounding.

- 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 AGEM. These models incorporate a version of the IPCC-recommended methodology for vehicle modelling (IPCC 2006) and are used to calculate all transport emissions with the exception of those associated with marine navigation, railways, and pipelines (i.e. the energy necessary to transport liquid or gaseous products through pipelines). Refer to Annex 3.1 for a detailed description of Transport methodologies.

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

This subcategory includes all GHG emissions from domestic air transport (commercial, private, agricultural, etc.). In accordance with the 2006 IPCC Guidelines (IPCC 2006), military air transportation emissions are reported in the Other (Not specified elsewhere) – Mobile subcategory (CRF category 1.A.5.b). Emissions from transport fuels used at airports for ground transport are reported under Other Transportation/Other (1.A.3.e.ii). Emissions arising from flights that have their origin in Canada and destination in another country are considered to be 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 based on the reported quantities of aviation gasoline and turbo fuel consumed 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 early 2016, and in response to an ERT concern, an investigation into the activity and related GHG emissions attributable to steam train operations in Canada was conducted 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 ½ kt CO_2 eq including any CO_2 from biomass. Canada therefore declares GHG emissions from this specific source category insignificant (CI) and will continue to ignore their presence when estimating total transportation emissions in Canada.

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

This subcategory includes all GHG emissions from domestic marine transport. Emissions arising from fuel sold to foreign marine vessels are considered to be international bunkers and are reported separately under Memo Items – International Bunkers (CRF Category 1.D.1.b). Fuel use by Canada's national defence (military) and Coast Guard are reported under Public Administration in the RESD and is not reported separately due to confidentiality. Consequently, these emissions are included in transportation (for diesel and gasoline fuel) or Stationary Combustion (for light fuel oil and heavy fuel oil).

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, reported as domestic marine, are multiplied by country-specific emission factors.

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

Pipelines[3] represent the only non-vehicular transport in this sector. They use fossil-fuelled combustion engines to power motive compressors that propel hydrocarbon-based products. The fuel used is primarily natural gas in the case of natural gas pipelines. Oil pipelines tend to use electric motors to operate pumping equipment, but some refined petroleum, such as diesel fuel, is also consumed 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.

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

Off-Road

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[4] (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 as well as 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

The Transport category employed a Monte Carlo uncertainty analysis which uses, in part, results reported in *Quantitative Assessment of Uncertainty in Canada's National GHG Inventory Estimates for 2001* (ICF Consulting 2004). Generally, for the Transport category, the ICF Consulting study incorporated uncertainty values for CO_2, CH_4 and N_2O emission factors from two other reports: McCann (2000) and SGA Energy Ltd. (2000). The ICF Consulting study included values determined in these reports, along with expert elicitations addressing the uncertainty of the activity data contributing to the Transport category estimates within its Monte Carlo analysis.

Modifications to the original assessment include the addition of biofuel emission factor uncertainties based on the assumption of similarities in emission control technologies between conventional transport fuels and biofuels. Biofuel activity data uncertainties were based on expert judgement. Aviation turbo fuel CH_4 and N_2O emission factor uncertainties have been updated to better reflect the improvements made by implementing AGEM. A number of on-road CH_4 and N_2O emission factor uncertainties have also been modified based on recent laboratory data. Additionally, a thorough verification of the 2004 ICF Consulting report revealed a number of discrepancies in referenced uncertainty ranges. In these instances, the discrepancy was corrected to coincide with the original reference. Finally, some default CH_4 and N_2O emission factors were revised to comply with the 2006 IPCC Guidelines (IPCC 2006), resulting in updated uncertainty values. The subcategories affected include domestic and international navigation, railways and other transportation, specifically the subcategory off-road diesel.

Transport

The overall uncertainty of the 2015 estimates for the Transport category (not including pipelines) was estimated to be ±3.1%.

Emissions from Domestic Aviation

The uncertainty associated with overall emissions from domestic aviation was estimated to be within the range of -1% to +5%. This implied that the source category was more likely underestimated than overestimated. The Domestic Aviation

4 Referred to as non-road or off-road vehicles. The terms "non-road" and "off-road" are used interchangeably.

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%, 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 due to their comparatively minor contributions to the inventory.

Emissions from Railways

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

Emissions from Domestic Navigation

The uncertainty associated with emissions from the domestic navigation source category was estimated to be ±3%. 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%. Specific uncertainties from pipelines by GHGs can be found in Table A2-1 and Table A2-2.

Emissions from Off-road

The Off-road subcategory includes both off-road gasoline and off-road diesel fuel consumption. The uncertainty associated with the off-road transport sources was estimated to be ±18%. The main influence on the uncertainty for this sector is the N_2O emission uncertainty for gasoline (-90% to +900%) and diesel fuel (-50% to +200%). Approximately 15% of the Transport category's GHG emissions were attributable to off-road transportation and therefore its uncertainty has a significant effect on the overall uncertainty analysis.

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 partnerships have been developed among Environment and Climate Change Canada, Transport Canada and Natural Resources Canada 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). This broader perspective fosters a better understanding of actual

vehicle use and subsequently should promote better modelling and emission estimating.

3.2.6.5. Recalculations

Transportation estimates were revised for the 1990–2014 period, and significant updates were made to the Transport category for this inventory. Changes include: (i) adoption of MOVES2014 on an energy basis for on-road emissions; (ii) a new Tier 3 methodology for off-road emissions; and (iii) a new normalization approach for reconciling bottom-up emissions estimates with top-down fuel availability. Annex 3.1 provides more information on how these updates were implemented.

i. **Adoption of MOVES2014**: the MOVES model replaces Canada's Mobile GHG Emission Model (MGEM) as the method used to calculate GHG emissions for on-road transportation. In this submission, MOVES was used to calculate energy consumption for the entire vehicle fleet, on the basis of a range of distinct vehicle classes. Given that the country-specific emission factors, vehicle populations and driving rates are consistent with the previous submission, the primary influence of the new model is in the use of different fuel consumption rates. The fuel consumption rates used in MOVES are believed to be more representative of actual fleet use when compared with the previous method.

ii. **Tier 3 methodology for off-road**: the previous Tier 1/Tier 2 methodology for off-road emissions is updated to a new methodology that uses off-road equipment populations and related activity (e.g., hours of use) which is modelled in a Canadianized version of the U.S. EPA model NONROAD. This approach had been previously developed for Canada's Air Pollutant Emissions Inventory (APEI) and is applied to GHG emissions for the first time in this submission. Similar to the adoption of MOVES, NONROAD model outputs of energy/fuel consumption are applied to country-specific emission factors. The same emission factors as the previous submission are used in the current inventory.

iii. **Fuel Normalization**: normalization refers to the process of aligning Tier 3 (bottom-up) methods to fuel volumes reported in the RESD (top-down). The previous inventory used a balancing algorithm that adjusted on-road emissions based on provincial fuel sales tax data which had been assumed to be representative of on-road fleet. The benefit of this approach was to compensate for a lack to data specific to the off-road sector. However, with the development of a Tier 3 methodology for off-road emissions this approach was abandoned in favour of direct normalization by aligning both the on- and off-road emissions proportionally to provincial fuel volumes.

Both MOVES and NONROAD are U.S. EPA models that can be customized to accept Canadian inputs and account for Canadian-specific circumstances. The change was implemented in order to make use of higher resolution data and to align model methodologies with other emission inventories produced by Environment and Climate Change Canada. For example, adoption of NONROAD will allow Canada to estimate emissions for off-road activities in construction and residential sectors, which was not possible with MGEM.

As the three method changes were implemented simultaneously, the individual impact of implementing MOVES, NONROAD and normalization relative to the previous submission was not calculated. However, in terms of recalculations, the primary impact of these methodological updates is a reallocation of emissions within the various transportation subcategories (as opposed to an absolute change in total category emissions). This is because, excluding the standard annual fuel and activity updates as noted below, the total fuel volume for the entire Transport category is fixed. The most notable change within the transportation subcategories is an increase in emissions for heavy-duty gasoline trucks (HDGV), offset by a decrease in off-road emissions. Using 2014 values, HDGV increased by 5.8 Mt and off-road emissions decreased by 4.7 Mt compared with the previous submission.

Other recalculations in the Transport category included:

1. Navigation: inclusion of kerosene fuel for navigation in the year 2014.
2. Aviation fuel data: recalculations to aviation emissions for the years 2009–2011 based on updated fuel information.

3. Biofuels: updates to biofuel (ethanol and biodiesel) fuel volumes for consistency with the APEI.
4. Propane and natural gas equipment in off-road: new emissions for off-road propane and natural gas equipment for the entire 1990–2015 time series.
5. RESD: recalculations due to changes in the RESD; this includes updates for the year 2014 as preliminary data was finalized as well as minor revisions back to 2005 that updated both propane fuel information and fuel use in the territory of Nunavut.
6. Fleet corrections (25+ years): revisions to the fleet data for vehicles >25 of age which had incorrectly been omitted from the previous inventory.

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 $MOVES_{2014}$ 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.

On the basis of previous ERT reviews, Canada investigated improvement towards better fuel allocation between domestic and international navigation used in emission estimates. Currently, this split is based on the flag of the ship and not the intended use of the fuel. In a previous investigation, tax data were reviewed under the assumption that fuel purchased for international travel would be exempt from any imposed tax (similar to aviation). This investigation did not yield new information for the purposes of the National Inventory due to inconsistencies in the application of provincial excise tax data (the tax data are a combined total of federal and provincial sources). Additionally, there is no federal excise tax on heavy fuel oil (HFO), the predominant marine fuel in Canada at this time. Starting in year 2015, Canada will be implementing a North America-wide Emission Control Area (ECA) of 200 nautical miles around Canada's coasts that may require ships to switch from burning HFO to diesel, which may result in a future data source. At this time, however, there is no known Canadian data set to inform the domestic/international split that affects navigation and fishing. Any updates will be reported in future submissions.

In another planned improvement, Statistics Canada has reported its intention to update energy conversion factors for motor gasoline and diesel fuel. Environment and Climate Change Canada has initiated a project to collect and analyze fuel samples at retail locations across Canada, an initiative that will also support this objective. Any further progress will be updated in future inventory submissions.

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 (in the form of firewood). Firewood is used as a primary or supplementary heating source for many Canadian homes. Combustion of firewood results in CO_2 as well as CH_4 and N_2O emissions, which are considered technology-dependent. The main types of residential wood combustion devices are stoves, fireplaces, furnaces and other equipment (e.g. pellet stoves). Biomass used to generate electricity

Table 3–8 Other Sectors GHG Contribution

GHG Source Category	GHG Emission, kt CO_2 eq								
	1990	2000	2005	2010	2011	2012	2013	2014	2015
Other Sectors TOTAL (1.A.4)	**86 600**	**98 300**	**95 300**	**89 200**	**94 900**	**88 600**	**91 500**	**95 300**	**91 400**
Commercial/Institutional	27 400	35 000	34 200	30 500	32 300	30 300	31 500	33 700	32 600
Commercial and Other Institutional	23 900	30 700	30 300	26 600	28 400	26 600	27 900	30 000	28 900
Public Administration	1 990	2 300	2 070	1 820	1 920	1 760	1 630	1 660	1 660
Off-road Commercial & Institutional	1 500	1 900	1 900	2 100	2 000	1 900	2 000	2 100	2 100
Residential	46 700	47 900	46 200	43 300	46 500	43 000	44 500	46 300	43 700
Stationary Combustion	46 500	47 400	45 600	42 700	45 800	42 300	43 800	45 600	43 000
Off-road Residential	230	460	650	600	690	670	640	650	660
Agriculture/Forestry/Fishing	12 500	15 500	14 900	15 500	16 100	15 400	15 500	15 300	15 100
Forestry	58	77	159	189	136	137	168	106	113
Agriculture	2 300	2 500	2 000	2 800	3 400	3 500	3 500	3 600	3 600
Off-Road Agriculture/Forestry/Fishing	10 000	13 000	13 000	12 000	13 000	12 000	12 000	12 000	11 000

Note: Totals may not add up due to rounding.

is a small source of emissions in the Commercial/Institutional subcategory. Emissions from CH_4 and N_2O were included in the subcategory estimates, while CO_2 emissions were reported separately in the CRF tables as memo items and were not included in Energy Sector totals.

In 2015, the Other Sectors category contributed 91.4 Mt (12.7%) of Canada's total GHG emissions, with overall growth of about 5.5% (4.8 Mt) since 1990. Within the Other Sectors category, the Residential subcategory contributed emissions of about 43.7 Mt (47.8%), followed by the Commercial/Institutional subcategory with emissions of 32.6 Mt (35.7%) and the Agriculture/Forestry/Fishing subcategory with 15.1 Mt (16.5%). Since 1990, GHG emissions have grown by 19.1% (5.2 Mt) in the Commercial/Institutional and 20.6% (2.6 Mt) in the Agriculture/Forestry/Fishing subcategory, while GHG emissions in the Residential subcategory have declined by about 6.5% (3 Mt). Refer to Table 3-8 for additional details. Additional discussion of trends for the Other Sectors category is presented in Chapter 2.

3.2.7.2. Methodological Issues

Emissions from these source categories are calculated consistently using the methodology described in Annex 3.1, which is an IPCC Tier 2 approach, with country-specific emission factors. Methodological issues specific to each category are described below. Emissions from the combustion of transportation fuels (e.g. diesel and gasoline) are all allocated to the Transport category.

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

Emissions are based on fuel-use data reported as commercial and public administration in the RESD and, in the case of landfill gas (LFG), volumes collected for the Waste Sector. CH_4 and N_2O emissions from the combustion of LFG are included, while CO_2 emissions are excluded from totals, but reported separately in the UNFCCC CRF tables as a memo item.

Starting with this submission, related on-site off-road emissions that had been historically allocated under Other Transportation/Other (1.A.3.e.ii) are now reallocated here 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 included here.

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

Emissions are based on fuel-use data reported as residential in the RESD, with the exception of biomass, which is collected by Natural Resources Canada under a periodic stand-alone survey. The methodology for biomass combustion from residential firewood is detailed in Annex 3.1. The CH_4 and N_2O emissions are reported here, and CO_2 emissions, while not accounted for in the national residential GHG total, are reported as a memo item.

Starting with this submission, related on-site off-road emissions that had been historically allocated under Other Transportation/Other (1.A.3.e.ii) are now reallocated here 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 included here.

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

This subcategory includes emissions from fuel combustion in the agriculture and forestry industries. However, emission estimates are included for the agriculture and forestry portion only. Fishery emissions are currently included under either the Transport category or the Other Manufacturing (i.e. food processing) subcategory. Emissions from on-site machinery operation and heating are based on fuel-use data reported as agriculture and forestry in the RESD.

Starting with this submission, related on-site off-road emissions for agriculture and forestry that had been historically allocated under Other Transportation/Other (1.A.3.e.ii) are now reallocated here under Off-road Vehicles and Other Machinery (1.A.4.c.ii) 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 can be accurately tracked, as compared to residential biomass information. The overall non-CO_2 emissions uncertainty is 11% for the Residential subcategory due to higher uncertainty associated with biomass emission factors (CH_4 with -90% to +1500% and N_2O with -65% to +1000%) as compared to 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. A discussion of fuel-use data is presented in Section 3.2.4.3, Recalculations.

3.2.7.4. QA/QC and Verification

The Other Sectors category underwent QC checks in a manner consistent with the 2006 IPCC Guidelines. No mathematical or referencing errors were observed during the QC checks, while minor data errors were discovered and corrected. The data, methodologies, and changes related to the QC activities are documented and archived in electronic form.

3.2.7.5. Recalculations

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

- revised coal emission factors;
- revised coal oxidation factors;
- revised allocation of solid wood waste and spent pulping liquor data;
- revised residential fuelwood activity data;
- revised RESD data.

In addition, revised CO_2 emission factors for residential fuelwood impacts the biomass CO_2 included as a memo item. Refer to Section 3.1 for additional details.

3.2.7.6. Planned Improvements

Environment and Climate Change Canada, Natural Resources Canada and Statistics Canada are working jointly to continuously improve the underlying quality of the national energy balance and to further disaggregate fuel-use information.

In addition, long-term improvement plans for the Other Sectors category include studies on biomass parameters such as moisture content, void space, 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). As in previous submissions, emissions related to military vehicles have been included in the Transport category, whereas stationary military fuel use has been included under the Commercial/Institutional subcategory (Section 3.2.7) due to fuel data allocation in the RESD (Statistics Canada 1990–). This is a small source; emissions were <100 kt CO_2 eq in 2015.

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

Fugitive emissions from fossil fuels are intentional or unintentional releases of GHGs from the

Table 3–9 Fugitive GHG Contribution

GHG Source Category	GHG Emissions, kt CO_2 eq								
	1990	2000	2005	2010	2011	2012	2013	2014	2015
Fugitive Emissions from Fuels (1.B)	49 000	70 000	61 000	54 000	55 000	57 000	59 000	60 000	57 000
Solid Fuels—Coal Mining (1.B.1)	3 000	2 000	1 000	1 000	1 000	1 000	2 000	1 000	1 000
a. Coal Mining and Handling	3 000	2 000	1 000	1 000	1 000	1 000	2 000	1 000	1 000
i. Abandoned Underground Mines	200	500	200	100	100	100	100	100	100
Oil and Natural Gas (1.B.2)	46 000	68 000	59 000	53 000	54 000	56 000	57 000	58 000	56 000
a. Oil1	5 000	6 500	6 400	6 000	6 200	6 800	7 200	7 500	7 600
b. Natural Gas[1]	13 000	18 000	14 000	12 000	12 000	12 000	13 000	13 000	12 000
c. Venting and Flaring[2]	28 000	44 000	39 000	35 000	36 000	37 000	37 000	38 000	36 000
i. Venting	23 000	38 000	34 000	30 000	31 000	32 000	32 000	32 000	31 000
ii. Flaring	4 600	5 700	5 300	4 700	4 900	5 100	5 400	5 500	5 100
CO_2 Transport and Storage (1.C)3,4	**NO**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.1**	**0.2**

Notes:
1. All other fugitives except venting and flaring.
2. Both oil and gas activities.

NO = Not occurring.

Totals may not add up due to rounding.

production, processing, transmission, storage and delivery of fossil fuels.

Released gas that is combusted before disposal (e.g. flaring of natural gases at oil and gas production facilities) is considered a fugitive emission. However, if the heat generated during combustion is captured for use (e.g. heating) or sale, then related emissions are reported in the appropriate fuel combustion category.

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

In 2015, the Fugitive Emissions from Fuels category accounted for about 57 Mt (7.9%) of Canada's total GHG emissions, with 16.6% (8.1 Mt) growth in emissions since 1990. Between 1990 and 2015, fugitive emissions from oil and natural gas increased 21.2% to 56 Mt, and those from coal decreased to approximately 1.1 Mt from 2.8 Mt in 1990. The oil and gas production, processing, transmission and distribution activities contributed 98% of the fugitive emissions. Refer to Table 3–9 for more details.

3.3.1. Solid Fuels

(CRF Category 1.B.1)

3.3.1.1. Source Category Description

The only significant source of fugitive emissions from solid fuel transformation in Canada is from coal mining. This includes emissions from both active coal mines and abandoned mines. Emissions from coke manufacturing (such as losses from the opening of metallurgical coking oven doors) and briquette manufacturing are not estimated due to a lack of data. Other sources of solid fuel transformation emissions are not known and are 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.

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 Canada, emissions from abandoned mines were 53 kt CO_2 eq in 2015, while emissions from the two active underground mines were estimated at only 84 kt CO_2 eq. See Table 3–9 for additional data.

3.3.1.2. Methodological Issues

Coal Mining and Handling

King (1994) developed an inventory of fugitive emissions from coal mining operations, which is one of the bases for the coal mining fugitive emissions estimates. Emission factors were calculated by dividing the emission estimates from King (1994) by the appropriate coal production data.

The method used by King (1994) to estimate emission rates from coal mining (emission factors in Annex 3) was based on a modified procedure from the Coal Industry Advisory Board. It is a hybrid IPCC Tier 3 and Tier 2 methodology, depending on the availability of mine-specific data. Underground mining activity emissions and surface mining activity emissions were separated, and both include post-mining activity emissions. A more detailed description of the methodology is presented in Annex 3.2, Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution.

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). Data from this field testing was used to modify the CH_4 emission factors of 7 of the 23 producing mines in Canada. Additional discussion of the methodology can be found in Annex 3.2, Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution.

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:

1. Time since abandonment
2. Coal type and gas absorption characteristics
3. Mine flooding
4. Methane flow characteristics of the mine
5. Openings and restrictions such as vent holes and mine seals

Yearly variations in emissions are driven by changes in the number of abandoned mines and the effects of the applied decline curve. Further discussion of the methodology can be found in Annex 3.2, Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution.

3.3.1.3. Uncertainties and Time-Series Consistency

Coal Mining and Handling

The CH_4 uncertainty estimate for fugitive emissions from coal mining is estimated to range from -30% to +130% (ICF Consulting 2004). The production data have low uncertainty (±2%), while emission factors have high uncertainty (-50% to +200%). IPCC default uncertainty values were assumed for Canada's country-specific emission factors, and these will need to be reviewed. The use of IPCC default values will not result in a representative uncertainty estimate where country-specific information is available.

Abandoned Underground Mines

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

3.3.1.4. QA/QC and Verification

The CH_4 emissions from coal mining were identified as 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. No mathematical errors were found during the QC checks. The data and methods related to the QC activities are documented and archived in electronic

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

3.3.1.5. Recalculations

Coal Mining and Handling

A 2014 recalculation was necessary because of a revision, by Statistics Canada, of activity data for one producing mine in western Canada.

Abandoned Underground Mines

No recalculations were undertaken.

3.3.1.6. Planned Improvements

Coal Mining and Handling

There are currently no planned improvements.

Abandoned Underground Mines

Improvement plans for this sector include ongoing reviews of the activity data underlying the emissions estimates.

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, Mining, 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, bitumen extraction and 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 sources of emissions have been divided into 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. Even though 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 to be 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: This type of production is defined by wells producing light- or medium-density crude oils (i.e. density < 900 kg/m^3). The emissions are from the 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 is defined as having a density above 900 kg/m3. Production of this viscous liquid requires a 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, including primary production methods (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, satellite 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 and are considered in conjunction with gas processing. The largest source of emissions is equipment leaks.

Natural Gas Transmission: Virtually all of the natural gas produced in Canada is transported from the processing plants to the gate of the local distribution systems by pipelines. The volumes transported by truck are insignificant and assumed to be negligible. The gas transmission system emission sources are from equipment leaks and process vents. Process vents include 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) (by both surface transport and high-vapour-pressure pipeline systems), pentane-plus systems (by 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.

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.

Emissions related to methanogenic bacteria in the tailings ponds continue to be studied by the operators. It is believed that with the planned implementation of new bitumen recovery techniques, the lighter hydrocarbons in the waste streams of the current processes will be reduced, and the emissions will be correspondingly lowered.

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. The emissions have been divided into two major groups:

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 are the result of 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). GHG emissions from the combustion of fuel for energy purposes are reported under the Energy Industries category.

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

3.3.2.2. Methodological Issues

Upstream Oil and Gas

Fugitive 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 of the industry 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. and which is referred to here as the UOG study (Environment Canada 2014).

The CAPP study provided a detailed emission inventory for the UOG industry for the year 2000. Similarly, the UOG study estimated emissions for the years 2005 and 2011. For both studies, the respective 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. Emissions from flaring, venting, equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses and accidental releases were estimated.

A multitude of data were collected and used in both studies. These included activity data from the facilities, such as production accounting (e.g. volumes flared and vented) and equipment data. Emission factors were obtained from a variety of sources, including published reports, equipment manufacturers' data, observed industry values, measured vent rates, simulation programs and other industry studies. A list of data and emission factors can be found in Volume 5 of the CAPP study (CAPP 2005) and Volume 4 of the UOG study (Environment Canada 2014).

The 1990–1999 fugitive emissions were estimated using annual industry activity data and the 2000 emission results. The 1990–1999 estimates and method are presented in Volume 1 of the CAPP study. The 2001–2004 fugitive emissions were estimated using the 2000 (CAPP 2005) and 2005 (Environment Canada 2014) emission results along with annual industry activity data and interpolation techniques. Similarly, the 2006–2010 emissions were estimated using the 2005 and 2011 (Environment Canada 2014) emission results with annual industry activity data and interpolation techniques. From 2012 on, the 2011 (Environment Canada 2014) emission results are used in conjunction with annual activity data to estimate emissions. A more detailed description of the methodology can be found in Annex 3.2.

Natural Gas Transmission

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 is considered to follow a rigorous IPCC Tier 3 approach in estimating GHG emissions. Fugitive emission estimates for 1997–1999 were estimated based on length of natural gas pipeline and leakage rates, as developed based on the results of the original study. For the year 2000 onwards, emissions are based on data from the UOG study (Environment Canada 2014), following an IPCC Tier 3 approach that rolled up the reported GHG emissions from individual natural gas companies. Input data for the natural gas transmission and storage industry was compiled by ORTECH Consulting Inc. (2013) for the Canadian Energy Partnership for Environmental Innovation (CEPEI). Data for the years 2000–2004, 2006–2010 and 2012–2014 were provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2015 are estimated using length of natural gas transmission pipeline. The complete methodology can be found in Annex 3.2.

Oil Sands/Bitumen

Fugitive GHG emissions from oil sands mining, bitumen extraction, heavy oil/bitumen upgraders and integrated cogeneration facilities are from the bitumen study, *An Inventory of GHGs, CACs, and H_2S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP 2006). The bitumen study is a compilation of GHG emissions from the following companies: Suncor Energy Inc., Syncrude Canada Ltd., Shell Canada Ltd. and Husky Energy Inc. Methods used to estimate fugitive emissions from

in-situ bitumen extraction are from the CAPP study (CAPP 2005) (see Section 3.3.2.1).

In general, the IPCC Tier 3 approach was used by each operator to develop a bottom-up approach in estimating GHG emissions. Facilities' inventories were reviewed to ensure that each facility's estimates were complete, accurate and transparent; where gaps existed, estimates were developed and provided to each operator for review. QA/QC and an uncertainty analysis following the IPCC Good Practice Guidance (IPCC 2000) were also performed.

A bitumen estimation model (hereafter referred to as the bitumen model) was developed to allow annual updating of fugitive emissions from oil sands mining and bitumen/heavy oil upgrading activities from 2004 onwards. The bitumen model was developed based on relevant parameters and results from the original bitumen study, along with annual activity data. The activity data required by the model are published in the following two reports: *Alberta Mineable Oil Sands Plant Statistics* from the Alberta Energy Regulator (AER 2016) and the National Energy Board's (NEB 1998–2015) online statistics, *Estimated Production of Canadian Crude Oil and Equivalent*. These data are updated annually and used to estimate GHG emissions. Refer to both the bitumen study (CAPP 2006) and the bitumen model (Environment Canada 2007) for a detailed description of the methodology. A summary of the estimation method of the bitumen model is also presented in Annex 3.

Emissions for oil sands facilities not included in the original bitumen model, such as the CNRL Horizon Mine and Upgrader, Nexen Long Lake Upgrader, Shell Jackpine Mine, and Imperial Oil Kearl Lake Mine, have been estimated using activity data from the AER (2016) and emission factors from similar facilities.

Downstream Oil and Gas Production

Fugitive emissions from refineries are based on 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. Historical fuel, energy and emission data were gathered both from the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC) and directly from refineries for the years 1990 and 1994–2002. Fugitive, venting and flaring emissions for the years 1991–1993 were interpolated and emissions for 2003–2012 were extrapolated, using data in the CPPI report and the petroleum refinery energy consumption and production data from the RESD (Statistics Canada 1990–). A detailed description of the methodology used to estimate emissions from 1991 to 1993 and from 2003 onward can be found in Annex 3.

Natural Gas Distribution

The emission estimates for the 1990–1999 time 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 based on 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 based on the study data (CGA 1997; GRI 2000) and on gas distribution

pipeline distances by province provided by Statistics Canada.

For the year 2000 onwards, emissions are based on data from the UOG study (Environment Canada 2014), following an IPCC Tier 3 approach that rolled-up the reported GHG emissions from individual natural gas companies. Input data for the natural gas distribution industry was compiled by ORTECH Consulting Inc. (2013) for the Canadian Energy Partnership for Environmental Innovation (CEPEI). Data for the years 2000–2004, 2006–2010 and 2012–2014 were provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2015 are estimated using length of natural gas distribution pipeline. More details on the methodology used to estimate fugitive emissions from natural gas distribution systems are presented in Annex 3.2.

3.3.2.3. Uncertainties and Time-Series Consistency

Upstream Oil and Gas

The overall uncertainty for the 2015 upstream oil and gas fugitive emissions is -11.4% to + 13.3%. The uncertainties for specific UOG categories are listed in Table 3-10. Note that the gas transportation industry includes natural gas transmission, storage and distribution. Accidents and equipment failures 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. Only the last two sources of uncertainty were considered in the analysis; it was assumed that the uncertainties from the definitions were negligible, as they were adequately controlled through QA/QC procedures.

Oil Sands/Bitumen

The overall uncertainty for the 2015 oil sands/bitumen fugitive emission estimates has been estimated to be ± 6.1%, on the basis of a study conducted in 2006.[5] 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 the bitumen study (CAPP 2006) and the bitumen model (Environment Canada 2007). Facility-level uncer-

5 Some changes have occurred in the industry since that time, but uncertainty has not been reassessed

Table 3–11 Uncertainty in Oil Sands / Bitumen Fugitive Emissions

GHG Source Category	Uncertainty (%)
	Oil Sands/Bitumen
Flaring	±17.7
Fugitive	±11.5
Venting	±4.1
Overall	**±6.1**

Table 3–10 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
Flaring	±7.6	-6.5 to + 6.4	-17.2 to +16.2	—	-21.3 to +19.3
Fugitive	±15.9	± 29.2	-22.0 to +23.6	± 52.6	-28.4 to +31.1
Venting	-14.0 to +14.1	-23.6 to +38.5	-14.9 to +17.6	—	-33.1 to +38.0
Total	**-10.4 to + 10.5**	**-18.6 to +29.6**	**-16.4 to +17.8**	± 52.6	-20.0 to +18.2

Table 3–12 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

tainties were aggregated to determine uncertainties by emission source as shown in Table 3–11.

Downstream Oil and Gas

The emission data used in the inventory for fugitive emissions from refineries for 1990 and for 1994–2002 are taken directly from the CPPI (2004) study. There is greater uncertainty for the 1991–1993 and the 2003–2012 periods due to the available level of disaggregation of the activity data. Tier 1 and Tier 2 uncertainty analyses of the emission factors and activity data were performed, for comparison purposes, for an overall CO_2 uncertainty in the 2002 data (CPPI 2004).

For the Tier 1 analysis, the overall uncertainty was ±8.3%. The Tier 2 analysis determined that the overall uncertainty was ±14%. The difference between the Tier 1 and Tier 2 uncertainties may be due to the high level of variability in some of the emission factors. The uncertainty results can be found in Table 3–12.

3.3.2.4. QA/QC and Verification

To ensure that the results were correct in the CAPP and UOG studies (CAPP 2005; Environment Canada 2014) the following QA/QC procedures were performed. First, all results were reviewed internally by senior personnel to ensure that there were no errors, omissions or double counting. The report was also reviewed by individual companies for comment. A second level of review was performed by the project steering committee and nominated experts. Furthermore, 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 and coal mining activities were revised for the 2005–2014 period. As methods did not change, revised activity data was the sole source of changes to the estimates. The impacts of the recalculations are summarized in Table 3–2

The changes in the Fugitive Emissions from Fuels category were caused by the following:

- Activity data: Statistical data from CAPP, Statistics Canada and provincial sources which is used to estimate emissions for years not covered in the CAPP (2005) and UOG studies (Environment Canada 2014) were revised and estimates were recalculated accordingly. Specific details of the changes are provided below.
    1. Revisions to refinery energy consumption and refined petroleum product production resulted in changes to fugitive, venting and flaring emission estimates from petroleum refineries for the period 2005 to 2015.
    2. Revisions to natural gas transmission, storage and distribution activity data resulted in minor changes to fugitive, flaring and venting estimates for these industrial segments in 2013 and 2014.
    3. Revisions to natural gas production volumes and volumes of fuel flared and vented in British Columbia caused minor changes to emission estimates in 2012.
    4. Revisions to crude oil production in Manitoba, Saskatchewan, British Columbia and Newfoundland and Labrador for the 2013 data year caused minor changes to venting emission estimates in 2014.

5. Changes to the number of spills in Newfoundland and Labrador, Saskatchewan, Alberta and British Columbia resulted in minor changes to emission estimates from accidents and equipment failures for the period 2012 to 2014.
6. Revisions to the number of capable wells in Manitoba for the 2014 data year caused minor changes to emission estimates from accidental venting from surface casing vents.

3.3.2.6. Planned Improvements

Oil Sands/Bitumen

A comprehensive study to update the bitumen study (CAPP 2006) is underway with the goal of improving emission estimates from oil sands mining, extraction and upgrading in Canada. The new study will also develop a robust method for updating emission estimates in the rapidly expanding oil sands industry, as prioritized in recent ERT reviews. The study is scheduled to be complete in late 2017.

Upstream Oil and Gas

As described above, emission estimates for the UOG industry are currently based on detailed studies that are conducted approximately every five years, with emissions for intervening years extrapolated based on the latest dataset. This approach does not facilitate the adoption of new scientific data (i.e. emission factors) as it becomes available, nor does it properly capture the emissions impact of technological improvements or regulations in a timely manner. Work is therefore 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. This data is being reviewed and a method for incorporating this new data 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.

While two CO_2 pipelines exist in Canada, they are associated with the use of carbon dioxide in an enhanced oil recovery (EOR) process. All CO_2 from this process is recovered for reuse and therefore no estimates are provided for emissions from storage. 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. Further discussion can be found in Section 3.5.2.

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

Carbon dioxide captured at Dakota Gasification Company's Great Plains Synfuels Plant in North Dakota (in the United States) and SaskPower's Boundary Dam Power Station near Estevan (starting in November 2014) is transported by pipeline to the Cenovus EOR facility at Weyburn, Saskatchewan.

3.4.1.1. Source Category Description

The source is fugitive emissions from the pipeline system used to transport the CO_2 to the injection site.

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. Emissions are calculated using the IPCC default medium EF of 0.0014 kt CO_2/km pipeline length/per 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

Environment and Climate Change Canada is monitoring the construction of additional CO_2 pipelines in Alberta and will incorporate these into emissions estimates as they come on-line.

3.5. Other Issues

3.5.1. CO_2 Emissions from Transport Biomass

As per the UNFCCC reporting guidelines, CO_2 emissions from the combustion of biomass used to produce energy are not included in the Energy Sector totals but are reported separately as memo items. They are accounted for in the Land Use, Land-use Change and Forestry (LULUCF) Sector and are recorded as a loss of biomass (forest) stocks. CH_4 and N_2O emissions from the combustion of biomass fuels for energy are reported in the fuel combustion section in the appropriate categories.

3.5.1.1. Fuel Ethanol

Quantities of fuel ethanol used in transportation are presented in Table 3-13. Ethanol properties were developed according to chemistry and resulted in a higher heating value (HHV)[6] of 24.12 TJ/ML, 52.14% carbon content and 789.2 kg/m3 density.

Based on feedback from Statistics Canada, 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 classes, 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 for 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.

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

Table 3–13 Ethanol Used for Transport in Canada

Year	1990	2005	2010	2011	2012	2013	2014	2015
Ethanol Consumed (ML)	7	252	1 727	2 324	2 330	2 429	2 385	2 408

Table 3–14 Biodiesel Used for Transport in Canada

Year	1990	2005	2010	2011	2012	2013	2014	2015
Biodiesel Consumed (ML)	0	1	164	569	578	646	626	628

3.5.1.2. Fuel Biodiesel

The quantities of biodiesel fuel used in transportation are presented in Table 3–14. The properties used for biodiesel were extracted from a biodiesel study conducted between 2004 and 2005 (BioMer 2005). The higher heating value (HHV)7 used is 35.18 TJ/ML, with a 76.5% carbon content and 882 kg/m^3 density.

Unlike fuel ethanol, biodiesel is not considered by Statistics Canada to be reported within the diesel fuel energy statistics, and therefore the volumes of biodiesel consumed are in addition to the volumes of diesel fuel reported in the RESD. 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 classes, 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.

3.5.2. Carbon Capture and Storage – Enhanced Oil Recovery (EOR)

In Canada, CO_2 captured during coal gasification in the US and at SaskPower's Boundary Dam coal-fired power station, is used as a flooding agent in EOR operations to increase crude oil production volume at two depleting oil reservoirs. Carbon dioxide is used as a flooding agent in EOR since it acts as a solvent while 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. This process is commonly known as 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 is transported via pipeline to the field. In addition, starting in late 2014, some CO_2 was transported to the Weyburn site from SaskPower's Boundary Dam coal-fired power station. As of January 1, 2016, 540 kt of CO_2 had been captured at the Boundary Dam facility and shipped to the Weyburn site (SaskPower 2016). This fresh supply and CO_2 recovered from previous flooding cycles are combined and injected into the reservoir. Currently about 2.8 Mt per year of CO_2 is injected at the Weyburn-Midale operations.[7] From 2000 to 2015, the Weyburn site injected over 30 Mt of new CO_2 purchased from the Dakota gasification plant, with an injection rate of 7000 t of CO_2 per day (PTRC 2011). Since 2005, the Midale site has injected more than 2 Mt of CO_2, with an injection rate of 1800 t of CO_2 per day (PTRC 2004).

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

7 *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.

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 (from 2000 to 2004) of the IEAGHG's CO_2 monitoring and storage project, managed by the Petroleum Technology Research Centre (PTRC), indicates that over 98% of CO_2 will remain trapped in the Weyburn reservoir after 5000 years and only 0.14% will be released to the atmosphere (Mourits 2008). Additional details on the findings of the first phase of the research project are available on the website of the Petroleum Technology Research Centre (PTRC).

The final phase (from 2005 to 2011) of the IEA Weyburn-Midale research project outlined on the PRTC website focused on developing a best practice manual for future projects on the geological storage of CO_2, drawing from 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 impacts 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.

3.5.3. Country-Specific Issues: Emissions Associated with the Export of Fossil Fuels

Canada exports a large proportion of its produced fossil fuel resources, mostly to the United States. In 2015, Canada exported approximately 66% (energy equivalent) of its gross natural gas and crude oil production. The emissions associated with the export of crude oil and natural gas are estimated using existing models for the development of inventory estimates, as well as annually updated activity data from a variety of sources. The emissions/sectors included within the two main fuel stream estimates are as follows:

- *Natural Gas*: This component accounts for GHG emissions specific to the production, gathering, processing and transmission of natural gas. Only those sources that exist for the primary purpose of producing natural gas for sale are considered, including stationary, fugitive and transmission emissions. Gas distribution systems and end-use emissions are specifically excluded, since they pertain to domestic gas consumption rather than gas imports and exports.
- *Crude Oil*: Similarly, this component considers stationary, fugitive and transport emissions related to the production, treatment, storage and movement of crude oils.

It must be noted that the absolute emission estimates provided here have a high level of uncertainty—up to 40% or more. On the other hand, the trend estimates are more accurate and can be considered to be representative.

The results demonstrate that, between 1990 and 2015, emissions associated with the production of oil and gas for exports have increased by approximately 240%, coinciding with an increase of approximately 232% in total exported oil and gas (Table 3–15). Over the same period, oil exports have increased at a rate 2.7 times greater than the growth in domestic production, while the emissions associated with those exports have grown by 300% (Table 3–16). This is due to increased exports of more GHG-intensive unconventional crude products (i.e. crude bitumen and synthetic crude oil) from Canada's oil sands (Table 3–19). Emissions associated with natural gas exports have more than doubled, coinciding with an increase of almost 100% in those exports (almost twice the rate of growth of natural gas production) (Table 3–17).[8]

8 The source for all export and energy production data is Statistics Canada's *Report on Energy Supply and Demand in Canada* (Statistics Canada 2003–). The 1990–2013 GHG emissions associated with net exports are from Smyth (2010).

Conventional crude oil production is generally on the decline in Canada, with peak production occurring around 2003. However, in recent years production has increased with the increased use of horizontal drilling and hydraulic fracturing, and exports of conventional crude oil and the emissions associated with their export have also increased (Table 3–18). In contrast to the trend in conventional crude oil, production of unconventional crude oil[9] from Canada's oil sands has been consistently increasing (Table 3–19). In 2015, production was seven times higher than in 1990, while exports were almost eleven times higher than in 1990. Whereas exports have grown eleven-fold, the emissions associated with these exports are only seven times larger, reflecting improved efficiencies in extracting oil sands products.

9 Unconventional crude oil includes crude bitumen from mining and in-situ sources as well as synthetic crude oil.

Table 3–15 Combined Crude Oil and Natural Gas: Production, Export and GHG Emission Trends, Select Years

Crude Oil & Natural Gas Trends	1990	2000	2005	2010	2011	2012	2013	2014	2015
Domestic Production (PJ)	7 969	12 101	13 027	12 708	13 298	13 802	14 350	15 197	15 505
Energy Exported (PJ)	3 071	7 091	7 820	8 140	8 514	8 886	9 281	9 737	10 191
Emissions Associated with Gross Exports (Mt CO_2 eq.)	34.8	80.5	82.2	86.8	88.4	98.2	108.7	112.1	118.1

Table 3–16 Crude Oil: Production, Export and GHG Emission Trends, Select Years

Crude Oil Trends	1990	2000	2005	2010	2011	2012	2013	2014	2015
Domestic Production (PJ)	3 786	5 041	5 835	6 687	7 216	7 747	8 233	8 797	9 032
Energy Exported (PJ)	1 534	3 227	3 822	4 601	5 028	5 524	6 139	6 761	7 210
Emissions Associated with Gross Exports (Mt CO_2 eq.)	22.0	46.8	49.2	58.4	60.8	66.9	76.4	83.1	87.9

Table 3–17 Natural Gas: Production, Export and GHG Emission Trends, Select Years

Natural Gas Trends	1990	2000	2005	2010	2011	2012	2013	2014	2015
Domestic Production (PJ)	4 184	7 060	7 192	6 021	6 082	6 054	6 117	6 400	6 473
Energy Exported (PJ)	1 537	3 864	3 998	3 539	3 486	3 363	3 143	2 975	2 981
Emissions Associated with Gross Exports (Mt CO_2 eq.)	12.8	33.7	33.0	28.4	27.6	31.3	32.3	29.0	30.2

Table 3–18 Conventional Crude Oil: Production, Export and GHG Emission Trends, Select Years

Crude Oil Trends	1990	2000	2005	2010	2011	2012	2013	2014	2015
Domestic Production (PJ)	2 973	3 590	3 459	3 184	3 378	3 451	3 583	3 607	3 337
Energy Exported (PJ)	1 112	2 433	2 293	2 027	2 172	2 238	2 638	2 822	2 682
Emissions Associated with Gross Exports (Mt CO_2 eq.)	14.1	34.2	28.0	21.1	21.6	23.2	30.5	34.1	33.6

Table 3–19 Unconventional Crude Oil: Production, Export and GHG Emission Trends, Select Years

Crude Oil Trends	1990	2000	2005	2010	2011	2012	2013	2014	2015
Domestic Production (PJ)	813	1 451	2 376	3 503	3 838	4 296	4 650	5 190	5 695
Energy Exported (PJ)	421	794	1 529	2 575	2 856	3 286	3 500	3 939	4 528
Emissions Associated with Gross Exports (Mt CO_2 eq.)	7.9	12.6	21.2	37.2	39.2	43.7	45.8	49.0	54.2

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: 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 51.1 Mt to the 2015 national GHG inventory (Table 4–1), compared with 55.9 Mt in 1990. The 2015 IPPU emissions represented 7.1% of total Canadian GHG emissions in 2015. The

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
INDUSTRIAL PROCESSES AND PRODUCT USE	55 900	56 900	54 400	48 500	52 100	56 500	53 500	50 900	51 100
Mineral Products	8 400	9 100	10 000	7 800	7 900	8 500	7 700	7 800	8 000
Cement Production	5 800	6 500	7 600	6 000	6 100	6 600	6 000	5 900	6 300
Lime Production	1 760	1 860	1 710	1 370	1 430	1 450	1 360	1 470	1 340
Mineral Product Use	910	750	910	410	450	440	380	380	430
Chemical Industry	17 300	18 000	9 470	5 470	6 090	6 410	6 400	5 990	6 510
Ammonia Production	2 770	2 940	2 710	2 490	2 880	3 000	2 950	2 540	2 850
Nitric Acid Production	970	960	1 200	1 100	1 100	1 100	990	1 000	1 100
Adipic Acid Production	10 000	10 000	2 500	-	-	-	-	-	-
Petrochemical and Carbon Black Production (includes Carbide Production)	3 300	3 800	3 000	1 900	2 100	2 300	2 500	2 400	2 500
Metal Production	23 800	23 500	20 200	16 200	17 100	16 900	14 800	15 000	14 200
Iron and Steel Production	10 500	11 500	10 300	9 170	10 100	10 200	8 040	8 930	7 990
Aluminium Production	10 300	10 000	8 680	6 870	6 810	6 470	6 530	5 830	6 020
SF_6 Used in Magnesium Smelters and Casters	2 960	2 010	1 230	183	183	248	213	229	221
Production and Consumption of Halocarbons, SF_6 and NF_3	980	500	5 100	7 800	8 600	9 100	9 400	10 000	11 000
Non-Energy Products from Fuels and Solvent Use	5 000	5 500	8 800	11 000	12 000	15 000	15 000	12 000	11 000
Other Product Manufacture and Use	370	410	530	430	400	490	500	400	480

Note: Totals may not add up due to rounding.

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 below.

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,

Table 4–2 Impact of Recalculations from Revisions and Improvements

Greenhouse Gas Categories	GHG Emissions or Change in Emissions[1] (Mt CO_2 eq), Selected Years							
	1990	1995	2005	2010	2011	2012	2013	2014
INDUSTRIAL PROCESSES AND PRODUCT USE								
Current (2017) submission	55.9	56.9	54.4	48.5	52.1	56.5	53.5	50.9
Previous (2016) submission	55.9	58.9	58.3	50.5	51.4	55.8	52.7	51.0
Net change in emissions	0.0	-1.9	-3.9	-2.0	+0.7	+0.7	+0.8	-0.1
Mineral Products								
Current (2017) submission	8.4	9.1	10.2	7.8	7.9	8.5	7.7	7.8
Previous (2016) submission	8.4	9.1	10.2	7.8	7.9	8.5	7.7	7.8
Net change in emissions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chemical Industry								
Current (2017) submission	17.3	18.0	9.5	5.5	6.1	6.4	6.4	6.0
Previous (2016) submission	17.3	19.7	9.5	5.5	6.1	6.4	6.4	6.0
Net change in emissions	0.0	-1.7	0.0	0.0	0.0	0.0	0.0	0.0
Metal Production								
Current (2017) submission	23.8	23.5	20.2	16.2	17.1	16.9	14.8	15.0
Previous (2016) submission	23.8	23.5	20.2	16.2	17.1	16.9	14.8	14.7
Net change in emissions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+0.3
Production and Consumption of Halocarbons, SF_6 and NF_3[2]								
Current (2017) submission	1.0	0.5	5.1	7.8	8.6	9.1	9.4	10.1
Previous (2016) submission	1.0	0.7	5.7	7.5	8.0	8.3	8.6	9.0
Net change in emissions	0.0	-0.2	-0.6	+0.3	+0.6	+0.8	+0.9	+1.0
Non-Energy Products from Fuels and Solvent Use[2]								
Current (2017) submission	5.0	5.5	8.8	10.8	12.0	15.2	14.7	11.7
Previous (2016) submission	5.0	5.5	12.1	13.1	11.9	15.2	14.7	13.1
Net change in emissions	0.0	0.0	-3.3	-2.3	+0.1	0.0	0.0	-1.4
Other Product Manufacture and Use								
Current (2017) submission	0.4	0.4	0.5	0.4	0.4	0.5	0.5	0.4
Previous (2016) submission	0.4	0.4	0.5	0.4	0.4	0.5	0.5	0.4
Net change in emissions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes:
1. Totals may not add up due to rounding.
2. IPPU source categories with the largest recalculations are Non-Energy Products from Fuels and Solvent Use, followed by Production and Consumption of Halocarbons (specifically consumption of HFCs).

Quebec and Nova Scotia.[1] Total clinker production capacity in Canada is approximately 16 Mt/year.

In 2015, the category accounted for 6 300 kt (or 0.9%) of Canada's total emissions, with about a 8.8%-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 are unavailable, the application of a Tier 3 method is not possible.

Equation 4–1:

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

where:

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 by-pass 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 by-pass dust and CKD for recent years 1990, 2000, and 2002–2014 (CAC 2014). These same quantities have been estimated for the remaining reporting years (1991–2001 and 2015). 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 years 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. The calcination emission factor for the year 2015 has not been provided by CAC to date, and as a result it has been assumed to be the same as that for the year 2014. The correction factor for CKD/by-pass 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 years 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 were obtained from the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC 2010). Clinker production data for 1997–2015 were

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

obtained from Statistics Canada (Statistics Canada 1990–2004; Statistics Canada no date (a)).

Provincial/territorial emissions are estimated on the basis of clinker capacity of cement plants across Canada. The source of 1990–2006 data had been 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 the years 2014 and 2015 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 Environment and Climate Change Canada, last email September 16, 2014).

4.2.4. Category-Specific QA/QC and Verification

This key category in the IPPU Sector has undergone Tier 1 quality control (QC) checks as outlined in Canada's Quality Manual, a document describing Canada's National Inventory Quality Management System (Environment Canada 2014). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

4.2.5. Category-Specific Recalculations

The correction factor for the loss of cement kiln dust and by-pass dust (CF_{ckd}) has been updated to include the 2014 data submitted by CAC, resulting in a minor downward recalculation of between 3 kt to 15 kt throughout the entire time series.

4.2.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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

4.3.1. Category Description

Dolomitic lime and high-calcium lime are both produced in Canada, and emissions from their production are accounted for in this inventory submission. Table 4–3 indicates the proportion of

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 1340 kt (0.2%) to Canada's total emissions in 2015, 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. 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 were obtained from the *Canadian Minerals Yearbook* (NRCan 1990–2006)[4] for the period up to and including the year 2006. In subsequent years, information was provided directly by Natural Resources Canada via personal communication.[5] The most recent lime production data are preliminary and subject to revision in subsequent publications.

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. 2007–2015. Canada, Production of Limestone – Stone. Unpublished data. Natural Resources Canada, Mineral & Mining Statistics Division

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.

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.

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] Starting in 2014, the calcining capacities were no longer being updated and have been assumed to be at 2013 levels.

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 Canada and Climate Change, dated November 6, 2013).

Table 4–3 Split between Dolomitic and High-Calcium Lime Production in Canada (1990–2015)

Year	% Split	
	Dolomitic Lime	High-Calcium Lime
1990–1992	14%	86%
1993–1999	16%	84%
2000–2002	8%	92%
2003–2008	9%	91%
2009–2015	7%	93%

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 decrease in calcining capacity of a plant in Ontario that produced only dolomitic lime.

4.3.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for the Lime Production category. It took into account the uncertainties associated with the production data, emission factors, correction factor for hydrated lime and percentage split between the two types of lime. The uncertainty associated with the category as a whole has been evaluated at ±8.2%, with lime production data and the percentage split being the largest contributors. 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 QA/QC and Verification

The Lime Production category has undergone Tier 1 QC checks as set out in Canada's Quality Manual (Environment Canada 2014). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

4.3.5. Category-Specific Recalculations

Updates to the activity data for 2014 resulted in a small (37 kt) upward recalculation of emissions for that year.

4.3.6. Category-Specific Planned Improvements

A potential improvement plan for this category will be the introduction of a lime kiln dust (LKD) correction factor to account for the losses of dust in the CO_2 emission estimates.

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 2015, the aggregate category accounted for 430 kt (or 0.06%) of Canada's total GHG emissions, with a decrease of approximately 52% in total emissions since 1990. Limestone and Dolomite Use

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

accounted for 47% of the Mineral Product Use emissions, whereas Non-metallurgical Magnesia Production, Other Uses of Soda Ash, and Glass Production contributed 26%, 14%, and 13% 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.

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]

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 have been estimated on the basis of soda ash production, import and export data.

Import and export data have been obtained from Global Trade Information Services (GTIS 1995–2006, 2007–2009) and Statistics Canada's Canadian International Merchandise Trade Database (Statistics Canada 2010–2015). The trade data for the years 1990–1994 were assumed to be the average of the 1995–2000 trade data, as GTIS commenced reporting trade data in 1995. The total

9 1990–2006 data are available in the Canadian Minerals Yearbook (NRCan 1990–2006). Subsequent data have been provided by Natural Resources Canada via personal communication.

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 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 were 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 have 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 were sourced from Environment Canada, Quebec Region, Environmental Protection Branch.[10] The activity data for 2006 and 2007 have been estimated from the average ratio of magnesite consumed to magnesia produced between 1990 and 2005.

The third plant has been operational for the full reporting period (1990–2015) and its annual activity data are sourced from British Columbia's Ministry of Energy and Mines (British Columbia Geological Survey 2016).

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

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

The emission factor used for Canadian limestone use is derived from the process stoichiometric ratio of 440 g of CO_2 per kilogram of pure limestone used, and is adjusted to consider a purity fraction of 95% (Derry Michener Booth and Wahl and Ontario Geological Survey 1989). The Canadian emission factor is therefore 418 g CO_2/kg of limestone used (AMEC 2006).

An overall emission factor of 468 g CO_2/kg of dolomite used was derived on the basis of the emission factors for pure limestone (440 kg CO_2/tonne) and magnesite (522 kg CO_2/tonne) and on the assumption that dolomite is composed of approximately 58% $CaCO_3$ and 41% $MgCO_3$ (AMEC 2006).

For the years 1990 through 2006, data on raw stone use in iron and steel furnaces, non-ferrous smelters, glass factories, pulp and paper mills, and other chemical uses have 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 are 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

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.

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	796	341	0	45	36	409

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. 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).

11 Cook S. 2013. Personal communication to Edalatmanesh M, Environment and Climate Change Canada, November 18, 2013. Canadian Electricity Association.

4.4.3. Uncertainties and Time-Series Consistency

Glass Production (CRF Category 2.A.3)

The Tier 1 uncertainty assessment of the Glass Production category considers uncertainties associated with the consumption data, emission factors, and assumptions for soda ash and limestone used in glass production. The overall uncertainty associated with the 2015 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.

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.

4.4.4. Category-Specific QA/QC and Verification

A Tier 1 QC checklist has been completed for the categories included in Mineral Product Use as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the 2006 IPCC Guidelines.

4.4.5. Category-Specific Recalculations

Updates to activity data for Other Uses of Soda Ash and Limestone and Dolomite Use resulted in a small upward recalculation (<0.5 kt) for 2014.

4.4.6. Category-Specific Planned Improvements

Organic carbon contained in raw materials used in the production of ceramics (CRF category 2.A.4.a) is a source of CO_2 emissions that is currently not estimated in Canada's inventory. It is therefore planned to assess the significance of this source in Canada for future inventory submissions.

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

4.5.1. Category Description

The Ammonia Production category accounted for 2900 kt (0.4%) of Canada's emissions in 2015, and its level of emissions has increased by 2.8% 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.

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 2008–2015 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. 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 and that 5 kg of CO_2 are emitted per tonne of urea produced. The resulting recovery factor (RF_{CO2}) is therefore 0.728 kg CO_2/kg urea.

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

Equation 4–2: CO_2 Emissions from Ammonia Production

$$E_{CO2} = \sum_i AP_i \cdot FF_i \cdot CC_j - RF_{CO2} \cdot UP_i$$

where:

E_{CO2}	=	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_{CO2}	=	factor for CO_2 recovered for urea production, 0.728 kg CO_2/ kg urea
UP_i	=	urea production of facility i, kt

Assuming a complete conversion of NH_3 and CO_2 to urea, the stoichiometric mass ratio of CO_2:urea (0.733 tonnes CO_2 per tonne urea) is used to convert urea production to CO_2, as recovered from ammonia process emission. Using a CO_2 release rate of 5 kg per tonne of urea production, the net emissions recovered (RF_{CO2}) is calculated at 0.728 tonnes CO_2/tonne urea.

Urea production data for years 2008 through 2015 were retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. For the years 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 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 9.2% in accordance with changes in natural gas volumes consumed for ammonia production and with changes in urea production.

4.5.4. Category-Specific QA/QC and Verification

Ammonia Production is a key category and has undergone a Tier 1 QC check as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the 2006 IPCC Guidelines (IPCC 2006).

4.5.5. Category-Specific Recalculations

No recalculations were performed for this category.

4.5.6. Category-Specific Planned Improvements

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

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

4.6.1. Category Description

The Nitric Production category accounted for 1100 kt (0.15%) of Canada's emissions in 2015, a 14% 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 2015, five out of six) operate with a high-pressure design and have NSCR abatement technology installed (Cheminfo Services 2006).

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 4–5 as "absorption Type 1." Alternatively, plants can have in place a second tower to allow "double absorption." This is referred to in Table 4–5 as "absorption Type 2" (Cheminfo Services 2006).

4.6.2. Methodological Issues

A mix of T_1, T_2 and T_3 methods were used in the estimation of N_2O from nitric acid production, the pre-dominance being with T_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 were available (only one plant).

Data supporting the estimation of N_2O emissions from nitric acid production for 1990–2004 were gathered through a study conducted for Environment Canada (Cheminfo Services

Table 4–5 Nitric Acid Industry-Typical Emission Factors

Type of Production Process Technology	Type of Emission Control Technology	Emission Factor (kg N_2O/t HNO_3)	Data Source
Dual Pressure	Extended Absorption "Type 1"	9.4	1992 letter from G. Collis[1]
Dual Pressure	Extended Absorption "Type 2"	12	1992 letter from G. Collis
High Pressure	NSCR	0.66	1992 letter from G. Collis
High Pressure	SCR	8.5	IPCC (2000)

1. Collis G. 1992. Personal communication (letter from Collis G. to Director, Greenhouse Gas Division, dated March 23, 1992). Canadian Fertilizer Institute.

2006), those for 2005–2009 were obtained by Environment Canada from industry through a voluntary data submission process, and those for 2008–2015 were obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. The collected data were used in the country-specific hybrid emission estimation methodology described above.

When facility-level production data are 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 were 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 2012-2015, production data were 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 CO_2 emissions from the category as a whole vary slightly over time from 2.1% 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 QA/QC and Verification

The Nitric Acid Production category has undergone Tier 1 QC checks as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

4.6.5. Category-Specific Recalculations

Updates to the activity data for 2012 and 2013 resulted in small downward recalculations of emissions (32 and 1 kt, respectively).

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 been indefinitely idled since the spring of 2009; hence for current years, 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:

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

where:

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:

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

where:

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 QA/QC and Verification

Adipic Acid Production is a key category that has undergone Tier 1 QC checks as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the 2006 IPCC Guidelines.

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 QA/QC and Verification

The Soda Ash Production category has undergone QC checks with the Tier 1 General Inventory Level QC Procedures outlined in the 2006 IPCC Guidelines (IPCC 2006).

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, Petrochemical and Carbon Black Production, and Fluorochemical Production (CRF Categories 2.B.5, 2.B.8 and 2.B.9.a)

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.

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).

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

There were five ethylene facilities in operation in Canada between 1990 and 2015, 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.

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).

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

Four facilities produced carbon black in Canada between 1990 and 2015, three of which are currently operating.

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

Three styrene facilities produced styrene in Canada between 1990 and 2015, one of which closed in 1998.

These categories combined, Carbide Production (CRF category 2.B.5) and Petrochemical and Carbon Black Production (CRF category 2.B.8), contributed 2500 kt (0.4%) to Canada's total emissions in 2015, a 22% decrease from 1990.

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 980 kt, 1100 kt and 840 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.

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 were identified in the study. The following equation was therefore used to estimate total CH_4 emissions from carbide production:

Equation 4–6:

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

where:

y	=	companies
SiC or CaC_2 capacity	=	data collected from the industry, kt
Capacity utilization	=	based on Cheminfo Services' knowledge of the industry, %
Emission Factor_SiC	=	11.6 kg CH_4/t SiC (IPCC 2006)
Emission Factor_CaC_2	=	4.8 kg CH_4/t CaC_2, derived from CH_4 emission factor for silicon carbide and the ratio of IPCC default Calcium Carbide CO_2 emission factor to IPCC default Silicon Carbide CO_2 emission factor (i.e. 11.6 (kg CH_4/t SiC) * (1.09 $tCO_2/tCaC_2$ / 2.62 tCO_2/tSiC))

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

When available, CO_2, CH_4, and N_2O, facility-reported emissions data were 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 2012–2015, production data are 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 and Climate Change Canada to the four companies that have had ethylene production operations in Canada. Three of the four operating plants responded. Together, the plants represented 90% of Canadian ethylene production capacity in 2009. The data provided included emissions and production values for the years 2007 to 2009 and were 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 are taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. For 2008–2015, production data are 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 were used in the inventory. When reported emission data are 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.

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

CH_4 emissions from EDC production for the years 1990 to 2009 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 come from the Canadian C2+ 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/

13 Cheminfo Services 2010

14 Cheminfo Services 2015

OECD/IEA 1997), under the name dichloroethylene. The Canadian C2+ 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).

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

CH_4 emissions from carbon black production were also 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 CH_4 emissions. From the received responses, two facility-level Tier 3 emission factors were derived as weighted averages of the reported 2007–2009 data.

Emission factors of 1.3 kg/t for CH_4 and 0.032 kg/t for N_2O were derived as weighted averages of the reported 2007–2009 data. One sector-wide process CH_4 emission factor was also calculated as a weighted average using the same set of data reported by the two facilities (1.29 kg CH_4/t product).

The sector-wide 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.

The above EF is applied when facility-level emission factors cannot be used. When process emissions are reported directly by a facility, the reported data are used in the inventory. When reported emission data are not available, estimates are calculated on the basis of an estimated carbon black production (allocated to each non-reporting facility by its share of capacity) and the Tier 3 sector average emission factor (either facility-level or sector-wide). The estimated carbon black production is calculated from total national carbon black production less the sum of all reported carbon black production. National carbon black production data are taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. Interpolations were made for years in between (i.e. 1996–2006) on the basis of a sector average growth rate for 1990–1994. The total sector production for each year from 1996 to 2006 is calculated by multiplying the sector average growth rate by the total sector production of the preceding year (starting from 1995). Production data for the years 2010 to 2015 are 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 was any venting of these process or recycle streams. Fugitive emissions from these streams would also contain methane (Cheminfo Services 2010).

In the absence of data from operating facilities, a Tier 1 approach was taken to develop process CH_4 emission estimates. Annual styrene production data were retrieved from the Canadian C2+ Petrochemical Report. For the purpose of emission estimation at the provincial level, the annual

styrene production is allocated to each plant on the basis of capacity share. 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. Due to the unavailability of 2010 and 2011 production data, these data years are assumed equal to 2009 production. However, production data that are included in Statistics Canada's Industrial Chemicals and Synthetic Resins Survey for the years 2012 to 2015 are used for emission estimations of these data years.

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/OECD/IEA 1997). It was assumed that destruction (through thermal oxidation) or transformation of HFC-23 was not practiced in Canada. The 1990–1992 production data were collected by Environment Canada from HCFC producers.[15]

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).

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), the following set of default uncertainties (based on expert knowledge of the industry) was used in the analysis:

- national methanol production: 5%;
- reported methanol production: 2%;
- facility methanol capacities: 5%;
- facility fraction of total sector unreported production: 10%;
- reported process CH_4 emissions: 20%;
- reported process N_2O emissions: 30%; and
- reported process CO_2 emissions: 10%.

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 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

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.

estimates for their data. As such, the following set of default uncertainties (based on expert knowledge of the industry) was used in the analysis:

- capacity data: ±5%;
- reported production data: ±2%;
- capacity share fractions used for allocation of national production data: ±10%;
- reported process CH_4 emissions: ±20%; and
- reported process N_2O emissions: ±30%.

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), a set of default uncertainties (based on expert knowledge of the industry) was used in the analysis. The uncertainty associated with the category as a whole for the time series is estimated at ±21% (Cheminfo Services 2010).

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, the following set of default uncertainties (based on expert knowledge of the industry) was used in the analysis:

- capacity data: ± 5%;
- reported production data: ±2%;
- capacity share fractions used for allocation of national production data: ±10%;
- reported process CH_4 emissions: ±20%; and
- reported process N_2O emissions: ±30%.

Uncertainties associated with this category the range from ±6% to ±11% for CH_4 emissions, ±11% to ±13% for N_2O emissions, and ±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, a set of default uncertainties (based on expert knowledge of the industry) was used in the analysis. The Tier 1 uncertainty associated with CH_4 emissions from the category ranges from ±20% to ±22%.

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

Uncertainty in the HFC-23 emission estimates has not been assessed. However, it is believed that the production data reported by HCFC-22 producers were 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.

4.9.4. Category-Specific QA/QC and Verification

These categories have undergone Tier 1 QC checks as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedure outlined in the 2006 IPCC Guidelines (IPCC 2006).

4.9.5. Category-Specific Recalculations

There were no changes to the methodology used to estimate emissions in this category. However, corrections to emissions estimates for Methanol Production for 1995 and 1999–2001 resulted in downward recalculations ranging from 250 kt to 1700 kt.

4.9.6. Category-Specific Planned Improvements

Production of ethylene oxide is a source of CO_2 and CH_4 emissions that is currently not estimated in Canada's inventory. It is therefore planned to develop a method/model in order to estimate and report these emissions for CRF category 2.B.8.d, Ethylene Oxide in future inventory submissions.

There are no other 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 7990 kt (1.1%) to Canada's total emissions in 2015, a 24% 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 4–7:

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

where:

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 1990–2015). 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 2013–2015. 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 2010–2015; as a result, the 2009 coke carbon content is assumed for 2010–2015 (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[16] provided an industry-average content value, which is considered confidential.

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

Equation 4–8:

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

where:

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 4–8, 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

16 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 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 4–8) is not equal to the amount of total pig iron production (used in Equation 4–7). 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 were obtained from Statistics Canada for 1990–2003 and 2004–2012 (Cat. No. 41-001 and 41-019, respectively) and from CSPA for 2013–2015. The values of the carbon contents and emission factors presented in Equation 4–8 were provided by the CSPA.[17]

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 information on process material, 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 3.3.

CH_4 emissions were estimated on the basis of the mass of metallurgical coke used (Statistics Canada 1990-2015) 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 1990-2015) were used to distribute national level emissions to the applicable provinces.

It should be noted that RESD data published for any given year are 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 ±5.75% and ±405%, respectively, resulting in an overall uncertainty of ±5% for the category as a whole.

17 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.

4.10.4. Category-Specific QA/QC and Verification

Iron and Steel Production is a key category that has undergone Tier 1 QC checks as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the 2006 IPCC Guidelines (IPCC 2006).

4.10.5. Category-Specific Recalculations

There were no changes to the methodology used to estimate emissions in this category. However, revisions to activity data for 2014 (revised coke consumption and limestone and dolomite use) resulted in an overall upward recalculation of approximately 300 kt of CO_2.

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. These fuel data are 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 6020 kt (0.8%) of Canada's emissions in 2015, representing an overall decrease in emissions of 42% 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.[18] The consumption of SF_6 is highly variable depending on whether either or both of these operations (SF_6

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

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).[19]

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.[20] Under a memorandum of understanding signed in 2006 between Environment Canada and the Aluminum 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 of 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 were not available, companies have used Quebec's Framework Agreement or International Aluminium Institute (IAI) EFs as the default (Alcan 2010). Since 2010, most facility-reported process-related estimates of CO_2, PFCs and SF_6 are Tier 3 plant-level estimates using plant-specific parameters.[21]

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.

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

20 http://www.westernclimateinitiative.org/.

21 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.

4.11.4. Category-Specific QA/QC and Verification

CO_2 and PFC emissions from Aluminium Production are key categories that have undergone Tier 1 QC checks as elaborated in Canada's Quality Manual (Environment Canada 2014). The checks performed are consistent with the Tier 1 General

Inventory Level QC Procedures outlined in the 2006 IPCC Guidelines (IPCC 2006).

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 cover gas at its plant.[22] This research, as well as the use of substitute gas mixtures, produced significant reductions in SF_6 emissions in the mid- to late 1990s. For the years 2005 to 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 200 kt CO_2 eq (<0.1% of Canada's emissions in 2015).

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

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

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 were provided voluntarily by the producers to Environment Canada through personal communication. Since there were 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 used the IPCC default method (emissions of SF_6 = consumption of SF_6), as recommended in the IPCC Good Practice Guidance (IPCC 2000). However, they used different methods for estimating their SF_6 consumption. Norsk Hydro confirmed the use of the weight difference method,[23] 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.[24] In this method, accounting of delivered purchases and inventory changes of SF_6 used are recorded. The purchases must be the actual volumes received in the calendar period; therefore, beginning-of-year and end-of-year inventories are taken into account.

The technique applied to estimate emissions from magnesium production is considered to be a Tier 3 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 were 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 were provided by all seven operating casting facilities through a voluntary data submission process. They were used for the calculation of emissions. For 2008, data were 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 were provided by the other five facilities. 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 2015 are 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 a modified Tier 3 type method, as it is based on the reporting of facility-specific emission data and some assumptions. For 2005–2007, the method used is considered a Tier 3 type.

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

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

4.12.3. 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 ±4%. It should be noted that the uncertainty assessment was done for only one year of the time series (2007). As such, it is expected that emission estimates of more recent years (2005 onwards) would have a similar uncertainty value, while older estimates would have a slightly higher uncertainty.

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 (±4%) 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 QA/QC and Verification

Magnesium Production and Magnesium Casting have both undergone Tier 1 QC checks as set out in Canada's Quality Manual (Environment Canada 2014). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the 2006 IPCC Guidelines (IPCC 2006).

4.12.5. Category-Specific Recalculations

There were no recalculations for this category.

4.12.6. Category-Specific Planned Improvements

Efforts will be made to obtain up-to-date SF_6 use data from magnesium casting.

4.13. Non-energy Products from Fuels and Solvent Use

(CRF Category 2.D)

4.13.1. Category Description

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 10 800 kt (1.5%) to Canada's total emissions in 2015, a 115% increase from 1990.

4.13.2. Methodological Issues

Emission factors for non-energy use of fuels were developed on the basis of the total potential CO_2 emission rates and the IPCC 1996 Energy Sector's default percentages of carbon stored in products (IPCC/OECD/IEA 1997). 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 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 4–6.

Fuel quantity data for non-energy fuel usage were reported by the RESD (Statistics Canada 1990–2015). It should be noted that RESD data for any given year are preliminary and subject to revisions in subsequent publications. These data were multiplied by the emission rates shown in Annex 3.3 to estimate CO_2 emissions for this category.

This technique 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. Methodological issues for calculating CO_2 emissions from the non-energy use of fossil fuels are not addressed specifically in the IPCC Good Practice Guidance (IPCC 2000). However, and as noted previously, the 1996 IPCC Guidelines provide a method of estimating non energy use of fuels on the basis of the amount of carbon stored in the products resulting from the process. The CO_2 emissions are derived from the amount of residual carbon that is released during the production process (residual carbon = total carbon minus amounts stored in product).

Table 4–6 Non-energy Fuel Types Used in the Canadian GHG Inventory

GASEOUS Fuels	SOLID Fuels	LIQUID Fuels
Natural gas	Canadian bituminous	Refined petroleum products
	Sub-bituminous	Petroleum feedstocks
	Lignite	Natural gas liquids
	Anthracite	Propane
	Foreign bituminous	Butane
	Petroleum coke	Ethane

4.13.3. 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).

4.13.4. Category-Specific QA/QC and Verification

Non-energy Products from Fuels and Solvent Use is a key category that has undergone Tier 1 QC checks as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the 2006 IPCC Guidelines (IPCC 2006).

4.13.5. Category-Specific Recalculations

Revised RESD data in this category resulted in downward recalculations for 2005–2010 and 2014 (ranging from 1.4 Mt to 3.4 Mt) and in a small upward recalculation for 2011 of 99 kt.

4.13.6. Category-Specific Planned Improvements

There are no specific improvements planned for this category. However, 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.

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

4.14.1. 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 the electronics industry in Canada released about 3 kt CO_2 eq in 2015.

4.14.2. 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 2b methodology, as shown in Equation 4–9, was used to estimate PFC emissions from the semiconductor manufacturing industry:

Equation 4–9:

$$E_{SC} = E_{FC} + E_{CF4}$$

where:

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_{CF4}	=	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 were used from Table 3.15 of the IPCC (2000).

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 IPCC (2000).

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, whereas 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.

The process relied on the current user and is therefore considered to be an IPCC 2006 Tier 2b estimate using Equation 6.7 (IPCC 2006) for an etching process. As the process used by the 2010 purchaser is unknown, a Tier 2a IPCC 2006 method was applied. The midpoint of the 1986 activity data range obtained from Environment Canada's DSL was selected and treated as a Tier 2a estimate.

In all cases, NF_3 usage, as opposed to NF_3 remote usage, was assumed, as were default IPCC 2006 emission factors, a default heel value of 10% and an assumption that no emission control technologies were employed. Default by-product CF_4 emission factors were also used to estimate CF_4 emissions from NF_3 usage with Tier 2a methods.

The identified user for 2013 was assumed to have utilized an equal amount from 2010 to 2015. The (unidentified) 2010 purchaser was assumed to have consumed its supply on an equal basis from 2010 to 2015. The 1986 data point was therefore linearly interpolated with the 2010 value, with emissions assumed constant since.

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 that used to calculate PFC and NF_3 emissions. However, there is no by-product CF_4 created during the use of SF_6 in the process. 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%.[25] The IPCC 2006 default emission factor (1-U) of 0.2 was used. It was assumed that there has been no emission control technology applied by this industry.

Since sales data were 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 SF_6 sales to semiconductor manufacturers in 2004–2009 were estimated by multiplying the total SF_6 import data (from Statistics Canada) by

25 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.

the sales distribution data (in %) received from SF_6 distributors (Cheminfo Services 2005a). No SF_6 sales data were collected for the 2010–2015 data years. The average proportion of SF_6 sold to the semiconductor manufacturing industry from 2004 to 2009 was therefore used to determine the fraction of the total import quantities which were sold to the semiconductor manufacturing industry for the 2010 and 2011 data years. For the 2012–2015 data years, the gross output (GO) economic data for NAICS 334 (Computer and Electronic Products Manufacturing) were used to extrapolate the estimated 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).

Note that attempts were made to collect SF_6 use data directly from manufacturers, but the response rate for the data-gathering exercise was low and the small amount of collected data would not bring in any improvement to the current estimation method.

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

Minor amounts of PFC emissions have been identified as related to PFC use in the electronics industry for emissive applications. Emissive sources in Canada include electrical environmental testing, gross leak testing and thermal shock testing. Unidentified and miscellaneous PFC uses reported in the PFC survey were also considered as part of emissive sources. According to the IPCC Tier 2 methodology, 50% of PFCs used in these applications would be released during the first year and the remaining 50% released in the following year.

4.14.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was also 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 ±23%.

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%).

4.14.4. Category-Specific QA/QC and Verification

PFC, NF_3, and SF_6 emissions from semiconductor manufacturing are not key categories. However, they have undergone Tier 1 QC checks as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

4.14.5. Category-Specific Recalculations

There were no recalculations for this category.

4.14.6. Category-Specific Planned Improvements

There are currently no improvements planned for these source categories.

4.15. Product Uses as Substitutes for ODS (CRF Category 2.F, HFCs)

4.15.1. Category Description

In order to provide a clear representation of the Canadian category of Product Uses as Substitutes for ODS, it has been divided into two separate sections of this report for hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (sections 4.15 and 4.16, 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. Canadian emissions from HFC consumption were therefore considered negligible for the 1990–1994 period (IPCC/OECD/IEA 1997). 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. Hence, HFC consumption in Canada began in 1995 (Table 4-7). HFCs are used in a variety of applications, including refrigeration and air conditioning (AC), 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 11 000 kt CO_2 eq (1.5%) to Canada's total emissions in 2015, a 2300% increase from 1995.

4.15.2. Methodological Issues

For this submission, Canada has implemented the IPCC Tier 2a approach to estimating HFC emissions by type of sub-application.

Activity Data

Canadian HFC use data are derived from bulk imports, imports and exports of manufactured items. Canada occasionally exports small quantities of HFCs in bulk. Up to the year 2005, activity data were gathered via periodic, mandatory surveys for the data years 1995 through 2004; additional mandatory activity data collection took place in 2014 and 2016, covering activities in the years 2008–2015. 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 were therefore estimated on the basis of the 1996 to 1999 survey data.

Voluntary surveys for bulk sales and imports and exports of manufactured items data by market

Table 4–7 HFCs Used in Canada and Their Timeframe

HFC Type	Timeframe	HFC Type	Timeframe
HFC-125	1995 onwards	HFC-236fa	1996 onwards
HFC-134	2015	HFC-245fa	2001 onwards
HFC-134a	1995 onwards	HFC-32	1995 onwards
HFC-143a	1995 onwards	HFC-365mfc	2008 onwards
HFC-152a	1995 onwards	HFC-41	1999 and 2000
HFC-227ea	1995 onwards	HFC-4310mee	1998 onwards
HFC-23	1995 onwards		

segment were performed from 2006 to 2011 for activity data for the years 2005 through 2010. The surveys were performed by Environment Canada and others (additional information is provided in Annex 3.3) and had varying response rates and aggregation levels of subcategories.

The 2014 and 2016 mandatory surveys of HFC bulk imports, exports and sales by HFC type and market segment forms the foundation for the 2008 through 2015 bulk portion of the HFC inventory. In the case of overlap between the voluntary and the mandatory surveys, the mandatory survey takes precedence. Some additional imports and exports of manufactured items activity data were reported to the 2014 and 2016 surveys and are included in the inventory. Reporting of HFC to the mandatory survey was done on the basis of use categories so that the quantities for manufacture and servicing could be broken out.

There are two facilities in Canada that can destroy HFC and other substances, but no data are available on the amount of HFC destroyed.

Emission Factors

Canada uses country-specific emission factors that reflect the impact of provincial and federal HFC regulations and improvements achieved by industry in the design and manufacture of HFC-containing equipment.

Surveys were performed in 2012 to document current practices in HFC use and disposal and to support the development of country-specific emission factors that are representative of Canada's circumstances (EHS 2013, Environment Canada 2015). The country-specific emission factors were applied for the entire time period. Emission factors are presented with references in Annex 6.

For aerosols, foam blowing, fire extinguishing solvents and miscellaneous subcategories, default emission factors from the 2006 IPCC guidelines (IPCC 2006) were used.

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 category and subcategory, 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 consumption of a chemical in a specific subcategory, a modified version of IPCC equation 7.1 (IPCC 2006, Volume 3) is used to suit the Canadian data as shown in Equation 4–10.

Equation 4–10:

$$C_{net,i} = IM_{bulk,i} + IM_{manufacture,i} - EX_{manufacture,i}$$

where:

$C_{net,i}$	=	Net consumption of HFC i, kg
$IM_{Bulk,i}$	=	Imports of bulk of HFC i, kg
$IM_{manufacture,i}$	=	Imports of manufactured items of HFC i, kg
$EX_{manufacture,i}$	=	Exports of manufactured items of HFC i, kg

The approach/model tracks the lifecycle of each HFC by subcategory and year, then estimates annual emissions for each applicable lifecycle stage (assembly of the product, 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, operational 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 stage are estimated for each subcategory by multiplying the HFC quantity in that stage by its corresponding emission factor. It is assumed that once an item is manufactured, the technology and its inherent operational emissions rate will remain constant throughout its lifetime. The operational emission estimate takes into consideration the quantity of HFC that has already

been emitted during the assembly stage. Likewise, the emission estimate from the end-of-life of the product is based on the quantity of HFC available after the assembly and operational emissions have taken place and on the corresponding emission factor for the subcategory. The end-of-life emission factor used also considers regulations in place at the time of decommissioning.

For solvents, a similar approach is applied to estimate emissions and track changes in stock of solvents. However, only the emission factors for operational emissions are used (IPCC 2006, Volume 3, Equation 7.5) as there is no information available on used HFC solvent destruction.

The annual total emissions are calculated using IPCC 2006, Volume 3, Equation 7.4. Refer to Annex 3.3 for additional detail on methodology.

4.15.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was performed for HFC consumption. It took into account the uncertainties associated with all subcategories, such as residential/commercial refrigeration, stationary/mobile air conditioning, etc. To determine the uncertainty for a subcategory, the uncertainties related to activity data (Cheminfo Services 2005c) and emission factors (Japan Ministry of the Environment 2009) were used. It should be noted that the category uncertainty can vary throughout the time series because it is dependent on the magnitude of each of the subcategory 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.

4.15.4. Category-Specific QA/QC and Verification

Consumption of halocarbons resulting in HFC emissions is a key category that has undergone Tier 1 QC checks as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the 2006 IPCC Guidelines (IPCC 2006).

4.15.5. Category-Specific Recalculations

The emissions from all of the subcategories have been recalculated as a result of updated activity data, emission factors, changes in methodology to meet 2006 IPCC Guidelines, and updated growth model surrogate variables. Specifically, the activity data were updated for HFC bulk sales and imports for 2013 to 2015 for all subcategories. Regarding emission factors, the country-specific emission factors derived from the 2012 survey for refrigeration and air conditioning were used for the entire time period. The Fire Protection emission factor values presented in Annexes 3 and 6 were corrected to the IPCC 2006 default values. Also, corrections were made to CRF export formulae for all subcategories for the HFC quantity used in manufacturing. As a result, the 1995 to 2014 estimates for HFC consumption were revised. The magnitude of revisions ranges from -34% to +12%.

4.15.6. Category-Specific Planned Improvements

Old survey data will be mined for additional HFC 245fa information. Research into the commercial and industrial 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, statistics and import/export data will be examined to determine a method to arrive at HFC quantities.

4.16. Product Uses as Substitutes for ODS (CRF Category 2.F, PFCs)

4.16.1. Category Description

Perfluorocarbon (PFC) consumption began in Canada in 1995. PFCs are used as substitutes for ozone-depleting substances (ODS) in the following subcategories: Refrigeration and Air Conditioning, Foam Blowing Agents, Aerosols and Solvents.

PFC releases were about 1.7 kt CO_2 eq in 2015, an 81% decrease from 1995.

4.16.2. Methodological Issues

The IPCC Tier 2 methodology was used to estimate emissions from the consumption of PFCs for the years 1995 to 2015. Details of the method are found in the following subsections. The 1995–2000 activity data were obtained through the 1998 and 2001 PFC surveys conducted by Environment Canada. As 2001–2004 data were 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 were then integrated with existing PFC use data. The 2008 and 2009 PFC use data from major distributors were collected in 2009 and 2010. No collection of 2010 to 2015 PFC use data occurred. The 2010 PFC use data were extrapolated from the 2009 PFC use data using 2009 and 2010 economic gross output data of applicable economic sectors. The 2011–2015 PFC use data were then extrapolated from the 2008, 2009 and 2010 estimates by least squares linear regression.

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

Equations 1 and 2 from Volume 3, Chapter 2, of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) were used to estimate the emissions from the assembly of residential refrigeration, commercial refrigeration, stationary air conditioning systems, and mobile air conditioning systems, as well as leakage emissions for the same applications.

Table 4–8 Percentage of PFC Losses (k) During Assembly and Leakage Rates (x) for Various Applications

Application Type	k Values (%)	x Values (%)
Refrigeration (including ultra low temperature refrigeration)	3.5	17
Stationary AC	3.5	17
Mobile	4.5	30

The assembly losses (k values) and leakage rates (x values) used were chosen from a range of values that were provided for each equipment category in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) (see Table 4–8).
The refrigerant "bank" used for this calculation includes the amount of PFCs contained in equipment manufactured in Canada and in imported equipment and excludes the amount of PFCs in exported equipment. It was assumed that no leakage occurred in the year of manufacturing. The Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) give a range of values for the annual leakage rate (x) for each of the different equipment categories. The annual leakage rate chosen for each category is shown in Table 4–8.

It is assumed that there were no PFC emissions from the disposal of refrigeration and stationary air conditioning systems between 1995 and 2009, since these systems have a lifetime of 15 years (IPCC default value) and PFC use began only in 1995. For the disposal of mobile air conditioning systems with a slightly shorter lifetime of 12 years (the IPCC default average value), it is assumed that there were no recovery or recycling technologies in place and, therefore, that 100% of the quantities remaining in systems built in 1995 would be emitted in 2008. This is likely an over-estimation because various regulatory requirements currently existing in Canada would prohibit the release of PFCs.

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

During the production of closed-cell foam, approximately 10% of the PFCs used are emitted (IPCC/OECD/IEA 1997). The remaining quantity of PFCs is trapped in the foam and is slowly emitted over a period of approximately 20 years. The Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), Volume 3, Chapter 2, Section 2.17.4.3, was used to calculate the IPCC Tier 2 emission estimate from closed-cell foam.

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

Since no data on PFCs used in aerosols were gathered from Environment Canada's PFC surveys, it was assumed that PFC emissions coming from the use of PFCs in aerosols were negligible.

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

The IPCC Tier 2 methodology presented in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) was used to estimate PFC emissions from solvents. The emission estimate for the current year is equal to half of the PFCs used as solvents in the current 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. PFCs used as solvents include the following categories:

- electronics industries;
- laboratory solvents; and
- general cleaning.

4.16.3. 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 ±23%.

4.16.4. Category-Specific QA/QC and Verification

Consumption of halocarbons resulting in PFC emissions is not a key category. However, it has undergone Tier 1 QC checks as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

4.16.5. Category-Specific Recalculations

There have been no recalculations for these categories.

4.16.6. Category-Specific Planned Improvements

There are currently no improvements planned for these categories.

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

4.17.1. 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), emissions of N_2O from medical applications (CRF category 2.G.3.a), emissions of N_2O from use as a propellant (CRF category 2.G.3.b), PFC emissions from other contained product uses which are not ODS substitutes or electronics industry-related (CRF category 2.G.4), and CO_2 emissions from the use of urea in selective catalytic reduction (SCR) vehicles (CRF category 2.G.4).

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 recent 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 480 kt (<0.1%) to Canada's total emissions in 2015, a 29% increase from 1990.

4.17.2. 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. 2006–2015) 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 2006–2015 were provided by the Canadian Electricity Association (CEA) and Hydro Quebec, which collectively represent electricity companies across Canada. The emission data submitted by the CEA and Hydro Quebec were prepared following the *SF_6 Emission Estimation and Reporting Protocol for Electric Utilities* ("the Protocol") (Environment Canada and Canadian Electricity Association). Note that CEA and Hydro Quebec 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 of 2006–2015 was the sum of all provincial estimates. The Protocol is the result of a collaborative effort between Environment Canada, the CEA, and Hydro Quebec.

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 Quebec 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. Because 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. NOC was unable to provide sales and import data for 2015, and an average of 2010 to 2014 data was therefore applied.

The producer and distributors were surveyed to obtain sales data by market segment and qualitative information in order to establish the

2005 Canadian N_2O sales pattern by application (Cheminfo Services 2006). The sales patterns for 2006–2015 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)

'Contained' sources consist of PFCs used as an electronic insulator and a dielectric coolant for heat transfer in the electronics industry. The IPCC Tier 2 emission factors (IPCC 2000) are applied to the PFC use data obtained from the PFC survey to estimate PFC emissions from contained sources, as per Equation 3.54 of the IPCC 2000 Guidance.

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles (CRF Category 2.G.4)

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.

Catalytic converters that employ urea to help reduce NO_x emissions are referred to as selective catalytic reduction (SCR) catalysts. To determine the activity for calculating 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.

In order 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 their testing program.[26]

4.17.3. 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

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

associated with the category as a whole for the time series ranged from ±10% to ±23%.

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. 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%.

4.17.4. Category-Specific QA/QC 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 Tier 1 QC checks as developed in Canada's Quality Manual (Environment Canada 2014). The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

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 modelling process.

4.17.5. Category-Specific Recalculations

Minor recalculations (due to corrections and revised activity data) were made to the CO_2 emission estimate from the use of urea in SCR vehicles, resulting in a downward recalculation of 43 kt.

4.17.6. Category-Specific Planned Improvements

There are currently no planned improvements for these categories.

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 22% between 1990 and 2015. 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 now reported in the Agriculture Sector; however, CO_2 emissions from and removals by agricultural lands are still 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 semi -arid 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, but have since decreased to 12 and 13 million head, respectively. Since 1990, poultry populations have increased to 140 million. Dairy cattle populations have decreased steadily since 1990 to less than 1 million head in 2015.

Since 1990, cropping practices have changed in Canada, with canola production increasing from 3 Mt to 17 Mt, corn production from 7 Mt to 14 Mt, soybean production from 1.3 Mt to 6.2 Mt, and wheat production decreasing slightly from 32 Mt to 28 Mt. Inorganic nitrogen consumption increased from 1.2 Mt N in 1990 to 2.6 Mt N in 2015, the area under summerfallow decreased by 7.1 million hectares (Mha) and the area using conservation tillage increased by 15 Mha.

As a result of those changes, Canada's total greenhouse gas (GHG) emissions from the Agriculture Sector increased from 49 Mt CO_2 eq in 1990 to 59 Mt CO_2 eq in 2015 (Table 5–1). This difference represents an increase of 22% from 1990, mainly due to higher populations of beef cattle and

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.

swine (10% and 30% increases, respectively), as well as an increase in the use of inorganic nitrogen fertilizers (117%).

Emissions of CH_4 from livestock accounted for 26 Mt CO_2 eq in 1990 and 29 Mt CO_2 eq in 2015, and mean estimates lie within an uncertainty range of -16% to +20%. Over the time series of 1990 to 2015, mean CH_4 emissions are estimated to have increased by 2.5 Mt CO_2 eq, a 9% increase. The observed increase in emissions falls within an uncertainty range of 5% to 13%. Emissions of N_2O from agricultural soils and livestock accounted for 21 Mt CO_2 eq in 1990 and 27 Mt CO_2 eq in 2015; mean estimates lie within an uncertainty range of -27% to +29%. Over the time series, mean N_2O emissions increased by 6.6 Mt CO_2 eq, an increase of 32%.

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 major livestock populations decreased (see Enteric Fermentation and Manure

Table 5–1 Short-and Long-Term Changes in GHG Emissions from the Agriculture Sector[1]

GHG Source Category		GHG Emissions (kt CO_2 eq)								
		1990	2000	2005	2010	2011	2012	2013	2014	2015
Agriculture TOTAL[1]		**49 000**	**58 000**	**61 000**	**56 000**	**55 000**	**57 000**	**60 000**	**58 000**	**59 000**
Enteric Fermentation (CH_4)		23 000	28 000	31 000	26 000	25 000	25 000	25 000	25 000	25 000
Dairy Cattle		4 400	3 900	3 700	3 600	3 600	3 600	3 700	3 700	3 700
Beef Cattle[2]		18 000	23 000	26 000	21 000	20 000	20 000	20 000	20 000	20 000
Others[3]		730	1 100	1 300	1 100	1 100	1 100	1 100	1 100	1 100
Manure Management		7 500	9 100	9 800	8 500	8 400	8 400	8 400	8 500	8 500
Dairy Cattle	CH_4	980	880	850	820	820	810	840	840	840
	N_2O	560	450	410	390	380	380	380	380	380
Beef Cattle[2]	CH_4	960	1 100	1 200	1 000	1 000	1 000	990	980	980
	N_2O	1 900	2 700	3 000	2 400	2 400	2 400	2 400	2 400	2 400
Swine	CH_4	1 300	1 700	2 000	1 600	1 600	1 600	1 600	1 700	1 700
	N_2O	90	110	130	110	110	110	110	110	120
Poultry	CH_4	160	190	190	190	190	190	190	190	190
	N_2O	430	530	540	560	560	560	560	560	560
Others[4]	CH_4	40	50	60	60	60	60	60	60	60
	N_2O	90	150	170	160	160	160	160	160	160
Indirect Source of N_2O		1 000	1 200	1 300	1 100	1 100	1 100	1 100	1 100	1 100
Agricultural Soils (N_2O)		17 000	19 000	18 000	20 000	20 000	21 000	23 000	22 000	23 000
Direct N_2O Emissions from Managed Soils		14 000	15 000	15 000	17 000	16 000	18 000	19 000	18 000	19 000
Inorganic Nitrogen Fertilizers		5 700	7 400	6 800	8 400	8 800	10 000	11 000	11 000	11 000
Animal Manure Applied to Soils		1 700	2 000	2 100	1 800	1 800	1 800	1 800	1 800	1 800
Urine and Dung Deposited by Grazing Animals		220	240	250	220	210	210	210	200	210
Crop Residues		4 500	4 600	5 000	5 600	5 100	5 300	6 400	5 500	5 700
Mineralization Associated with Loss of Soil Organic Matter		490	540	510	590	610	640	680	720	750
Cultivation of Organic Soils		60	60	60	60	60	60	60	60	60
Conservation Tillage[5]		-300	-750	-880	-990	-1 100	-1 300	-1 500	-1 400	-1 500
Summerfallow		1 300	1 000	780	520	480	470	460	350	280
Irrigation		300	360	360	360	370	390	420	390	390
Indirect Sources		2 700	3 300	3 300	3 500	3 500	3 700	4 000	3 900	4 000
Field Burning of Agricultural Residues (CH_4 & N_2O)		230	130	50	30	30	40	50	50	50
Liming and Urea Application (CO_2)		1 200	1 600	1 400	1 800	2 000	2 300	2 700	2 500	2 700

Notes:
1. Totals may not add up due to rounding.
2. Beef Cattle includes dairy heifers.
3. Others, Enteric Fermentation, includes buffalo, goat, horse, lamb, llama/alpaca, sheep and swine, deer/elk, wild boars.
4. Others, Manure Management, includes bison, goat, horse, lamb, llama/alpaca, sheep, fox, mink, rabbits, deer/elk, wild boars.
5. The negative values reflect a reduced N_2O emission due to the adoption of conservation tillage.

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.

In this submission, emissions were calculated as being 491 kt CO_2 eq lower in 1990, 493 kt CO_2 eq lower in 2005 and 903 kt CO_2 eq lower in 2014 compared to the previous submission, for recalculations of -1.00%, -0.80% and -1.53%, respectively (Table 5-2). Some modifications were made to liming, the method for estimating ammonia emissions from inorganic N fertilizers, and the population of alternative livestock. Corrections were made to the spatial distributions of livestock, crop areas and tillage practices. These changes were due either to continuous inventory improvements (minor corrections) or to Expert Review Team (ERT) recommendations (Table 5-2).

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.

Table 5–2 Quantitative Summary of Recalculations for the Agriculture Sector in 2017 NIR

		Recalculations (kt CO_2 eq)							
		1990	2000	2005	2010	2011	2012	2013	2014
Previous submission (2016 NIR), kt CO_2 eq		**49 000**	**59 000**	**61 000**	**57 000**	**56 000**	**58 000**	**60 000**	**59 000**
Current submission (2017 NIR), kt CO_2 eq		**49 000**	**58 000**	**61 000**	**56 000**	**55 000**	**57 000**	**60 000**	**58 000**
Change due to ERT recommendation(s):									
Modifications to activity data for alternative livestock prior to 2001		1.1	1.6	0	0	0	0	0	0
Enteric Fermentation	kt CO_2 eq	0.2	0.3	0	0	0	0	0	0
	%	0.0004	0.0005	0	0	0	0	0	0
Manure Management	kt CO_2 eq	0.5	0.9	0	0	0	0	0	0
	%	0.001	0.002	0	0	0	0	0	0
Agricultural Soils	kt CO_2 eq	0.36	0.44	0	0	0	0	0	0
	%	0.0007	0.0008	0	0	0	0	0	0
Revision of data on lime application		0	0	0	0	0	0	52	-12
Liming, Urea Application and Other Carbon-containing Fertilizers	kt CO_2 eq	0	0	0	0	0	0	52	-12
	%	0	0	0	0	0	0	0.09	-0.02
Change due to continuous improvement or refinement:									
Change in the method for estimating ammonia emissions from inorganic N fertilizers		-260	-380	-340	-440	-460	-540	-580	-580
Agricultural Soils	kt CO_2 eq	-260	-380	-340	-440	-460	-540	-580	-580
	%	-0.54	-0.65	-0.55	-0.77	-0.82	-0.93	-0.97	-0.99
Corrections to livestock distribution, crop areas and tillage practices to align with the Census of Agriculture		-230	-180	-160	-180	-200	-210	-240	-320
Enteric Fermentation	kt CO_2 eq	-5	-7	-8	-7	-6	-6	-7	-6
	%	-0.010	-0.012	-0.013	-0.012	-0.012	-0.011	-0.011	-0.011
Manure Management	kt CO_2 eq	-0.2	-0.3	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2
	%	-0.0004	-0.0004	-0.0005	-0.0004	-0.0004	-0.0004	-0.0004	-0.0004
Agricultural Soils	kt CO_2 eq	-220	-160	-140	-170	-180	-200	-230	-300
	%	-0.45	-0.28	-0.23	-0.29	-0.33	-0.34	-0.38	-0.51
Field Burning of Agricultural Residues	kt CO_2 eq	-0.002	0.000	0.000	0.000	0.000	0.000	0.000	-0.040
	%	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00007

Table 5–3 Qualitative Summary of the Revisions to Methodologies, Corrections and Improvements Carried out for Canada's 2017 Submission

Correction or Improvement	Recalculation Category	Years Affected
1. Modifications to activity data for alternative livestock prior to 2001	CH_4 emissions from enteric fermentation, manure management, and N_2O emissions from direct and indirect emissions from manure management systems and agricultural soils	1990–2000
2. Change in the method for estimating ammonia emissions from inorganic N fertilizers	N_2O emissions from agricultural soils	1990–2014
3. Corrections to livestock distribution, crop areas and tillage practices to align with the Census of Agriculture	CH_4 emissions from enteric fermentation and manure management, and N_2O emissions from agricultural soils	1990–2014
4. Change in emission factor for lime application to take into account a portion of dolomite contained in ;lining material based on the ERT's recommendation	CO_2 emissions from agricultural use of limestone	1990-2014

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, ranch-style, pasturing systems for cow-calf operations. Most dairy production occurs in eastern Canada in high-production, high-density facilities. Eastern Canada has also traditionally produced swine in high-density, intensive production facilities. Over the past 20 years, some swine production has shifted to western Canada. Other animals that produce CH_4 by enteric fermentation, such as bison, goats, horses, llamas/alpacas, deer and elk, wild 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 by IPCC Good Practice Guidance (IPCC 2000). 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.

Increased milk production in dairy cattle herds over the 1990–2015 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 7.5% 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 22%. 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

An uncertainty analysis using the Monte Carlo technique was carried out on the methodology used to estimate emissions of methane 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 the year 2015, uncertainty ranges from the 2012 analysis are applied to new emission estimates.

The uncertainty range for CH_4 emissions from enteric fermentation was similar in 1990 and 2015, and mean estimates lie within a range of -17% to +22% (Table 5–4). Over the time series of 1990 to 2015, mean emissions are estimated to have increased by 2.2 Mt CO_2 eq, a 10% increase. The observed increase falls within an uncertainty range of 6% to 16%.

The uncertainty in emissions was mainly associated with the calculation of the emission factor. The range of uncertainty around the calculation of the Non-dairy Cattle Tier 2 emission factors was the highest (41%). Calculations of uncertainty in emissions and emission factors were the most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular

Table 5–4 Uncertainty in Estimates of Emissions of CH_4 from Enteric Fermentation

Animal Category	Uncertainty Source		Mean Value[1]	2.5% Prob[2]	97.5% Prob
Dairy Cattle	Population (1000 head)		943	894 (-5.2%)	993 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		156	131 (-16%)	189 (+21%)
	Emissions (Mt CO_2 eq)		3.7	3.1 (-17%)	4.5 (+22%)
	Population (1000 head)		11 522	11 314 (-1.8%)	11 740 (+1.9%)
Non-dairy Cattle	Tier 2 Emission Factor (kg/head/year)		70	57 (-19%)	86 (+22%)
	Emissions (Mt CO_2 eq)		20	16 (-19%)	25 (+25%)
Other Animals	Emissions (Mt CO_2 eq)		1.1	0.9 (-18%)	1.3 (+17%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	23	19 (-17%)	28 (+22%)
		2015	25	21 (-17%)	31 (+22%)
	Trend	1990–2015	2.2 (10%)	1.4 (+6%)	3.7 (+16%)

Notes:
1. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2015.
2. 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 2015.

the methane conversion rate (Y_m) and the factor associated with the estimation of the net energy of maintenance (Cf_i) (Karimi-Zindashty et al. 2012).

The methodology and parameter data used in the calculation of emission factors are consistent throughout the entire time series (1990–2015), 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 both paper and 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, 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 review of literature, 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. Details of this review can be found in Annex 3.4.

5.2.5. Recalculations

Recalculations were minor in this submission (under 0.1%, Table 5–5). Modifications to activity data for alternative livestock prior to 2001 resulted in an increase in estimates of emissions from Enteric Fermentation of 0.2 kt CO_2 eq in 1990, but had no impact on emissions in 2005 or 2014. A very minor adjustment to the distribution of livestock resulted in a decrease in emissions of 5 kt CO_2 eq in 1990, 8 kt CO_2 eq in 2005, and 6 kt CO_2 eq in 2014. The recalculations did not alter the short-term or long-term emission trends (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.

At present, data have been collected to develop a time series that accounts for changes in feed ration digestibility in dairy cattle. The methodology is currently being refined and documented. Implementation of new data and methodologies will occur over the short term.

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, is nearing completion. 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.

Table 5–5 Recalculations of Estimates of Emissions and Their Impact on Emission Trend and Total Agricultural Emissions from Enteric Fermentation, Manure Management CH_4 and Manure Management N_2O

Emission Source	Year	Submission Year	Category Emissions (kt CO_2 eq)	Change in Emissions (kt CO_2 eq)	Relative Change Category Emissions (%)	Old Trend (%)	New Trend (%)
Enteric Fermentation	1990	2016	22820	-5	-0.02	Long term (1990 - 2014)	
		2017	22815			10	10
	2005	2016	31355	-8	-0.03		
		2017	31347			Short term (2005 - 2014)	
	2014	2016	25086	-6	-0.03	-20	-20
		2017	25080				
Manure Management CH_4	1990	2016	3491	-0.2	-0.005	Long term (1990 - 2014)	
		2017	3491			5.5	6.0
	2005	2016	4287	-0.3	-0.01		
		2017	4286			Short term (2005 - 2014)	
	2014	2016	3742	-0.2	-0.01	-14	-14
		2017	3742				
Manure Management - Direct N_2O	1990	2016	3075	0.5	0.02	Long term (1990 - 2014)	
		2017	3075			15	17
	2005	2016	4228	0.001	0.000		
		2017	4228			Short term (2005 - 2014)	
	2014	2016	3590	0.000	0.000	-16	-15
		2017	3590				
Manure Management - Indirect N_2O	1990	2016	985	0.035	0.004	Long term (1990 - 2014)	
		2017	985			14	14
	2005	2016	1314	0.000	0.000		
		2017	1314			Short term (2005 - 2014)	
	2014	2016	1132	0.000	0.000	-14	-14
		2017	1132				

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 and by animal category. Dairy, poultry and swine production occur in modern high-density production facilities. Dairy and swine produce large volumes of liquid manure, while poultry produces solid manure, both of which 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. Production systems for other animals, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boar, sheep, and mules and asses are generally in pastured or medium-density production facilities producing mainly solid manure. Furbearing 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).

All 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) from which 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. For the Swine, Sheep and Poultry categories, different parameters were used for animal subcategories based on size class for swine and sheep as well as for turkeys, broilers and layers in the poultry category.

Emission factors were derived using the CH_4 producing potential (B_0) and CH_4 conversion factors (MCF) taken from the 2006 IPCC Guidelines. AWMS for each animal category were taken from Marinier et al. (2005) for each province, taking into account regional differences in production practices and manure storage systems. For minor animals recently added, 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 A3.4.3.4.

An increase in emission factors over the period of 1990 to 2015 (see Table A3-14 in Annex 3.4) reflects higher gross energy intake for dairy cattle due to increased milk productivity and for non-dairy cattle due to changes in live body weights (see Section 5.2.2). A decrease in emission factors for swine is related to the shift in swine production from eastern to western Canada.

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 3.7 Mt CO_2 eq from manure management CH_4 emissions from Canadian livestock in 2015 lies within an uncertainty range of -32% to +27% (Table 5–6). The emission estimate from manure management in 1990, 3.5 Mt CO_2 eq, has

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

Animal Category	Uncertainty Source		Mean Value[1]	2.5% Prob.[2]	97.5% Prob
Dairy Cattle	Population (1000 head)		943	894 (-5.2%)	993 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		35.5	14 (-60%)	53 (+50%)
	Emissions (Mt CO_2 eq)		0.84	0.33 (-61%)	1.3 (+50%)
Non-dairy Cattle	Population (1000 head)		11 522	11 314 (-1.8%)	11 740 (+1.9%)
	Tier 2 Emission Factor (kg/head/year)		3.4	2.2 (-34%)	5.5 (+62%)
	Emissions (Mt CO_2 eq)		0.98	0.64 (-34%)	1.6 (+65%)
Swine	Population (1000 head)		13 243	12 885 (-2.7%)	13 600 (+2.7%)
	Tier 2 Emission Factor (kg/head/year)		5.1	2.5 (-51%)	7.3 (+43%)
	Emissions (Mt CO_2 eq)		1.7	0.83 (-51%)	2.4 (+44%)
Other Animals	Emissions (Mt CO_2 eq)		0.25	0.16 (-35%)	0.28 (+15%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	3.5	2.3 (-33%)	4.8 (+38%)
		2015	3.8	2.6 (-32%)	4.8 (+27%)
	Trend	1990–2015	0.26 (7.5%)	-0.34 (-9.6%)	0.28 (+8%)

Notes:
1. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2015.
2. 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 2015.

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 7.5% increase in mean emissions between 1990 and 2015 lies within an uncertainty range of a possible decrease of -10% to a maximum increase of +8%.

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).

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2015), 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.

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 both paper and 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 both paper and electronic form.

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

5.3.1.5. Recalculations

Recalculations for CH_4 emissions from manure management were minor (under 0.1%, Table 5-5). Modifications to activity data for alternative livestock prior to 2001 increased emissions by 0.02 kt CO_2 eq in 1990, but did not impact emissions in 2005 or 2014. Additionally, minor adjustments to the distribution of livestock resulted in a decrease in emissions of 0.2 kt CO_2 eq in 1990, 0.3 kt CO_2 eq in 2005, and 0.2 kt CO_2 eq in 2014. The recalculations did not alter the short-term or long-term emission trends (Table 5–5).

5.3.1.6. Planned Improvements

Analysis of the manure management model suggested that improvements could be made to the values used for the distribution of AWMS based on Statistics Canada's farm environmental management surveys (FEMS). Those data, combined with recent publications on livestock management (Sheppard et al. 2009a, 2009b, 2010, 2011a, 2011b; Sheppard and Bittman 2011, 2012) may provide the basis for new manure management time series over the medium term.

As noted in Section 5.2.6, data have been collected to develop a time series that accounts for changes in feed ration digestibility. Methodology will be developed to incorporate a time series for digestible energy used in the calculation of volatile solids for certain animal categories and will be incorporated over 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

Emissions of N_2O from manure management are estimated using the IPCC Tier 1 methodology. Emissions are calculated 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.

The animal characterization data are the same as those used for Enteric Fermentation category estimates (Section 5.2) and for CH_4 Emissions from Manure Management (Section 5.3.1). The average annual nitrogen excretion rates for domestic animals are taken from the 2006 IPCC Guidelines. The amount of manure nitrogen subject to losses because of leaching and volatilization of NH_3 and NO_x during storage is adjusted by animal type and manure management system according to the default values provided in the 2006 IPCC Guidelines.

The fraction of nitrogen available for conversion into N_2O is estimated by applying system-specific emission factors to the manure nitrogen handled by each management system. 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 3.6 Mt CO_2 eq from manure management in 2015 lies within an uncertainty range of 2.1 Mt CO_2 eq (-43%) to 5.5 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.

The same methodology, emission factors and data sources are used for the entire time series (1990–2015).

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

Recalculations for N_2O emissions from manure management were minor (under 0.1%, Table 5–5). Modifications to activity data for alternative livestock prior to 2001 resulted in an increase of 0.5 kt CO_2 eq in emissions in 1990, but did not impact emissions in 2005 or 2014. Minor adjustments were also made to the distribution of livestock leading to a decrease in emissions of less than 0.001 kt CO_2 eq in 1990, 2005, and 2014. The recalculations did not alter the short-term or long-term emission trends (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, plans are in place to analyze whether improvements could be made to the values used for the distribution of AWMS based on Statistics Canada farm environmental management surveys.

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 will be calculated and incorporated over the medium term.

Further uncertainty work will be carried out to establish trend uncertainty 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 site of manure storage 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 separately for NH_3 volatilization and N leaching using the IPCC Tier 1 methodology. The fractions of manure nitrogen subject to losses because of leaching and volatilization of NH_3 and NO_x during storage are adjusted by animal type and manure management system according to the default values provided in the 2006 IPCC Guidelines. 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.

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 (1990–2015).

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

Recalculations for indirect N_2O emissions from manure management occurred because of the inclusion of updated activity data for alternative livestock, and modifications to the distribution of livestock as discussed in sections 5.3.1.5 and 5.3.2.5. These changes affected the amount of manure N that is subject to leaching and NH_3 volatilization. The net impact of the recalculations resulted in a small decrease in emissions of 0.04 kt CO_2 eq in 1990, and less than 0.001 kt CO_2 eq in 2005 and 2014, with a relative change of less than 0.005%. The recalculations did not affect the long- or short-term emission trend.

5.3.3.6. Planned Improvements

As noted in Section 5.3.1.6, plans are in place to analyze whether improvements could be made to the values used for the distribution of AWMS based on Statistics Canada farm environmental management surveys. Efforts have also been made to develop country-specific fractions of NH_3 volatilization and N leaching by livestock categories and AWMS for dairy, beef cattle and swine, for implementation over the medium term.

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 through two pathways: i) volatilization of nitrogen from inorganic fertilizer and manure as NH_3 and NO_x and its subsequent deposition off-site; and ii) leaching and runoff of inorganic fertilizer, manure and crop residue N. Changes in crop rotations and management practices, such as summerfallow, tillage and irrigation, can also affect direct N_2O emissions by altering mineralization of organic nitrogen, nitrification and denitrification.

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 inorganic nitrogen fertilizers and animal manure, 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 inorganic nitrogen fertilizers and animal manure 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 by ecodistrict and are scaled up at provincial and national levels. The amount of nitrogen applied is obtained 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

Table 5–7 Uncertainty Estimates for Emissions of N_2O from Manure Management and Agricultural Soils

Emission Source		Mean Value[1]	2.5% Prob.[2]	97.5% Prob
			Mt CO_2 eq	
Manure Management	Direct Emissions	3.6	2.1 (-43%)	5.5 (+51%)
	Indirect Emissions	1.1	0.46 (-60%)	1.9 (+70%)
Agricultural Soils (N_2O)		23	15 (-36%)	35 (+52%)
Direct N_2O Emissions from Managed Soils		19	13 (-28%)	25 (+34%)
	Inorganic Nitrogen Fertilizers	11	7.1 (-35%)	16 (+43%)
	Animal Manure Applied to Soils	1.8	1.2 (-33%)	2.6 (+41%)
	Urine and Dung Deposited by Grazing Animals	0.21	0.083 (-60%)	0.36 (+75%)
	Crop Residues	5.7	3.7 (-35%)	8.3 (+45%)
	Mineralization Associated with Loss of Soil Organic Matter	0.76	0.49 (-35%)	1.1 (+45%)
	Cultivation of Organic Soils	0.06	0.013 (-79%)	0.12 (+96%)
	Soil N Mineralization/Immobilization	-0.85	-0.48 (-44%)	-1.3 (+55%)
Indirect N_2O Emissions from Managed Soils		4.0	1.6 (-60%)	6.8 (+70%)
	Atmospheric Deposition	1.2	0.3 (-75%)	2.5 (+110%)
	Nitrogen Leaching and Runoff	2.8	0.56 (-80%)	5.6 (+100%)

Notes:
1. Mean value reported from database.
2. Values in parentheses represent the uncertain percentage of the mean.

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 application of fertilizers on agricultural soils in 2015 lies within an uncertainty range of 7.1 Mt CO_2 eq (-35%) to 16 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 (1990–2015).

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).

5.4.1.1.5. Recalculations

There were revisions to field crop areas due mainly to the re-adjustment of EO data to align with the census-based provincial cropland area. Crop area recalculations modified the distribution of fertilizer N among ecodistricts.

Table 5–8 Recalculations of Estimates of N_2O Emissions and Their Impact on Emission Trend 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	2016	5656	3.1	0.1	Long term (1990 - 2014)	
		2017	5659			87	87
	2005	2016	6767	7.0	0.1		
		2017	6774			Short term (2005 - 2014)	
	2014	2016	10576	3.7	0.03	56	56
		2017	10580				
Animal Manure Applied to Soils	1990	2016	1719	-0.8	-0.05	Long term (1990 - 2014)	
		2017	1718			5.1	5.2
	2005	2016	2103	-2.2	-0.1		
		2017	2101			Short term (2005 - 2014)	
	2014	2016	1807	1.0	0.1	-14	-14
		2017	1808				
Crop Residues	1990	2016	4524	10.0	0.2	Long term (1990 - 2014)	
		2017	4534			23	22
	2005	2016	4979	6.7	0.1		
		2017	4986			Short term (2005 - 2014)	
	2014	2016	5573	-24.9	-0.4	12	11
		2017	5549				
Urine and Dung Deposited by Grazing Animals	1990	2016	216	0.001	0.001	Long term (1990 - 2014)	
		2017	216			-4.7	-4.6
	2005	2016	251	0.04	0.02		
		2017	251			Short term (2005 - 2014)	
	2014	2016	206	0.1	0.1	-18	-18
		2017	206				
Mineralization Associated with Loss of Soil Organic Matter	1990	2016	662	-172	-26	Long term (1990 - 2014)	
		2017	491			44	46
	2005	2016	615	-104	-17		
		2017	510			Short term (2005 - 2014)	
	2014	2016	957	-239	-25	56	41
		2017	718				

These recalculations resulted in a small increase in emissions of 3.1 kt CO_2 eq in 1990, 7.0 kt CO_2 eq in 2005 and 3.7 kt CO_2 eq in 2014, with a relative change of less than 0.2% (Table 5–8). The recalculation did not affect the long- or short-term emission trend.

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. Animal Manure Applied to Soils

5.4.1.2.1. Source Category Description

The application of animal manure 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

all manure managed by drylot, liquid and other animal waste management systems.

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 animal 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 manure 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.

5.4.1.2.3. Uncertainties and Time-Series Consistency

In the case of N_2O emissions from manure 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 1.8 Mt CO_2 eq from manure spreading of Canadian livestock wastes in 2015 lies within an uncertainty range of 1.2 Mt CO_2 eq (-33%) to 2.6 Mt CO_2 eq (+41%) (Table 5–7). The main source of uncertainty in the calculation of emissions from manure includes the slope of the P/PE regression equation for estimating N_2O emission factors, animal N excretion rates, 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 (1990–2015).

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

Corrections to the livestock distribution due to the re-adjustment of EO data to align with the census-based provincial cropland area resulted in the re-distribution of manure N among ecodistricts. Modifications to alternative livestock prior to 2001 also occurred as noted in sections 5.3.1.5 and 5.3.2.5.

Total recalculations resulted in a small decrease of 0.8 kt CO_2 eq in 1990, 2.2 kt CO_2 eq in 2005 and an increase of 1.0 kt CO_2 eq in 2014, with a relative change of less than 0.2% (Table 5–8). These recalculations increased the long-term emission trend from 5.1% to 5.2% and had no impact on the short-term emission trend.

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 5.7 Mt CO_2 eq from crop residue decomposition in 2015 lies within an uncertainty range of 3.7 Mt CO_2 eq (-35%) to 8.3 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 (1990–2015).

5.4.1.3.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see Section 1.3, Chapter 1) in a manner consistent with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

5.4.1.3.5. Recalculations

In this year's submission, changes to calculations of N_2O emissions from decomposition of crop residues were mainly due to the re-adjustment of EO data to align with the census-based provincial cropland area, resulting in the re-distribution of N in crop residue among ecodistricts.

Total recalculations consisted of an increase of 10 kt CO_2 eq in 1990, 6.7 kt CO_2 eq in 2005 and -24.9 kt CO_2 eq in 2014, with a relative change of less than 0.5%. These small recalculations lowered the long- or short-term emission trend by 1%.

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 to establish trend uncertainty over the medium term.

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 is deposited by 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 A_3.4.5. 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 0.21 Mt CO_2 eq from pasturing Canadian livestock in 2015 lies within an uncertainty range of 0.1 Mt CO_2 eq (-60%) to 0.4 Mt CO_2 eq (+75%) (Table 5–1).

The same methodology and emission factors are used for the entire time series (1990–2015).

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

The re-adjustment of EO data to align with the census-based provincial cropland area resulted in the re-distribution of livestock population in Eastern Canada among ecodistricts with different soil textures.

Total recalculations resulted in a small increase in emissions of 0.001 kt CO_2 eq in 1990, 0.04 kt CO_2 eq in 2005 and 0.1 kt CO_2 eq in 2014, with a relative change of less than 0.2%. These recalculations increased the long-term emission trend from -4.7% to -4.6% and had no impact on the short-term emission trend.

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, N mineralization associated with the loss of soil organic carbon contributes to the overall N balance of agricultural lands. This nitrogen, once in an inorganic form, is prone to loss in the form of N_2O during either nitrification or denitrification. As a result, this N 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 2015 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 database containing soil organic carbon and N 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, animal 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

There were significant changes in the areas of conservation tillage and summerfallow in this year's submission, as noted in Sections 5.4.1.7.5 and 5.4.1.8.5. These changes are due to the re-adjustment of EO data to align with the census-based provincial cropland area. The area of annual crops increased 2 Mha in 1990, 0.5 Mha in 2005, and decreased 2.2 Mha in 2014. Likewise,

the area of perennial crops decreased 1.1 Mha in 1990, 1.5 Mha in 2005, and 2.5 Mha in 2014. The changes in these cropland management practices affected the losses of soil organic carbon at the ecodistrict levels.

These changes resulted in a reduction of emissions by 172 kt CO_2 eq or 26% in 1990, 104 kt CO_2 eq or 17% in 2005 and 239 kt CO_2 eq or 25% in 2014. These recalculations changed the long-term trend from 44% to 46% and the short-term emission trend from 56% to 41%.

5.4.1.5.6. 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. 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 1990–2015 (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 organic soil areas and the uncertainty in the default emission factor.

The estimate of N_2O emissions of 0.06 Mt CO_2 eq from organic soils in 2015 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 (1990–2015).

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 and no-tillage.

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_2OIT), represents the effect of NT or RT on N_2O emissions (see Annex 3.4).

5.4.1.7.3. Uncertainties and Time-Series Consistency

For N_2O emissions from 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 -1.5 Mt CO_2 eq from conservation tillage practices in 2015 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 (1990–2015).

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

There were significant changes in the areas of intensive tillage (IT), reduced tillage (RT) and no tillage (NT) in this year's submission. These changes are also due to the re-adjustment of EO data to align with the census-based provincial cropland area. As a result, conservation tillage, including no-till and reduced tillage, increased 0.7 Mha for 1990, and 0.4 Mha for 2005, and decreased 1.9 Mha for 2014.

These changes resulted in a decrease in removals of 0.9 kt CO_2 eq in 1990 and 0.7 kt CO_2 eq in 2005 and 5.8 kt CO_2 eq in 2014, with a relative change of less than 0.5%. These recalculations had no or little impact on the long-term or short-term emission reduction trend due to conservation tillage (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

Table 5–9 Recalculations of Estimates of N_2O Emissions and Their Impact on Emission Trend 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	2016	-305	0.9	-0.3	Long term (1990–2014)	
		2017	-304			370	370
	2005	2016	-885	0.7	-0.1		
		2017	-884			Short term (2005–2014)	
	2014	2016	-1433	5.8	-0.4	62	61
		2017	-1428				
Summerfallow	1990	2016	1362	-26.3	-1.9	Long term (1990–2014)	
		2017	1336			-73	-74
	2005	2016	793	-15.3	-1.9		
		2017	778			Short term (2005–2014)	
	2014	2016	367	-20.4	-5.6	-54	-55
		2017	346				
Irrigation	1990	2016	338	-37.0	-10.9	Long term (1990–2014)	
		2017	301			22	31
	2005	2016	398	-35.8	-9.0		
		2017	363			Short term (2005–2014)	
	2014	2016	413	-20.0	-4.8	4	9
		2017	393				

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 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 0.28 Mt CO_2 eq from summerfallow land in 2015 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 (1990–2015).

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

The re-adjustment of EO data to align with the census-based provincial cropland area also had an impact on summerfallow emissions in this year's submission also due to. The area of summerfallow increased 0.5 Mha for 1990, and 0.1 Mha for 2005, and decreased 0.2 Mha for 2014.

These changes resulted in a decrease in emissions of 26.3 kt CO_2 eq or 1.9% in 1990, 15.3 kt CO_2 eq or 1.9% in 2005, and 20.4 kt CO_2 eq or 5.6% in 2014, and changed the long- or short-term trend slightly. (Table 5–9).

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 the 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 0.39 Mt CO_2 eq from irrigated land in 2015 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 (1990–2015).

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. Recalculations are a function of all factors discussed in previous sections, including changes in tillage practices and summerfallow noted in Sections 5.4.1.7.5 and 5.4.1.8.5. The readjustment of EO data to align with the census-based provincial cropland area decreased the area of irrigation by 1.4 kha in 2012, 4.7 kha in 2013, and 9.6 kha in 2014, respectively.

These changes resulted in a decrease in emissions of 37 kt CO_2 eq in 1990, 35.8 kt CO_2 eq in 2005 and 20 kt CO_2 eq in 2014, with a relative change of -11%, -9% and -5%, respectively. These recalculations increased the long-term emission trend from 22% to 31% and the short-term emission trend from 4% to 9% (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 redeposition 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 inorganic fertilizer or manure 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 inorganic fertilizer application. The method for deriving ammonia emission factors closely follows the model used by Sheppard et al. (2010) to derive specific emission factors for various ecoregions in Canada (see Annex 3.4). That model derives ammonia emission factors on the basis of 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).

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 2015 lies within an uncertainty range of 0.3 Mt CO_2 eq (75%) to 2.5 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 (1990–2015).

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

The change in the method for estimating ammonia emissions from inorganic N fertilizers resulted in a large reduction in N_2O emissions from this indirect source of 265 kt CO_2 eq or 25% in 1990, 341 kt CO_2 eq or 24% in 2005, and 584 kt CO_2 eq or 33% in 2014, respectively (Table 5-10). These recalculations resulted in a significant reduction in the long-term emission trend from 64% to 46%, and in the short-term emission trend from 22% to 6% (Table 5–10).

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, and crop residue nitrogen from agricultural soils. Indirect N_2O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using $FRAC_{LEACH}$ 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 Estimates of N_2O Emissions and Their Impact on Emission Trend from Indirect Emissions of Agricultural Soils, Atmospheric Dposition 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	2016	1064	-265	-25	Long term (1990–2014)	
		2017	799			64	46
	2005	2016	1436	-341	-24		
		2017	1095			Short term (2005–2014)	
	2014	2016	1749	-584	-33	22	6
		2017	1164				
Nitrogen Leaching and Runoff	1990	2016	1919	-0.03	-0.001	Long term (1990–2014)	
		2017	1919			41	41
	2005	2016	2228	-0.4	-0.02		
		2017	2228			Short term (2005–2014)	
	2014	2016	2712	-6.6	-0.24	22	21
		2017	2705				

The default value for the fraction of nitrogen that is lost through leaching and runoff ($FRAC_{LEACH}$) 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 2.8 Mt CO_2 eq from nitrogen leaching and runoff in 2015 lies within an uncertainty range of 0.6 Mt CO_2 eq (-80%) to 5.6 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 (1990–2015).

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

The re-adjustment of EO data to align with the Census-based provincial cropland area resulted in the re-distribution of livestock population and manure N among ecodistricts. Total recalculations consisted of a decrease of 0.03 kt CO_2 eq in 1990, 0.4 kt CO_2 eq in 2005 and 6.6 kt CO_2 eq in 2014 (Table 5-10). These recalculations had little impact on the short- or long-term emission trend.

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 **F***arm 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 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, there are no recalculations from this emission source.

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

2 http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5044&lang=en&db=imdb&adm=8&dis=2#a4

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 0.32 ± 0.21 Mt CO_2 eq for the level uncertainty.

The same methodology is used for the entire time series of emission estimates (1990–2015).

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

Natural Resources Canada provided an update on agricultural use of lime for 2013 and 2014. This resulted in a decrease in emissions of 11.7 kt CO_2 eq for 2014.

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 and composition of the 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 (1990–2015).

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 was no recalculation 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) due to controlled burning, CH_4 and N_2O emissions from wetland drainage and rewetting due to peat extraction, and N_2O released following Land conversion to Cropland.

In 2015, the estimated net GHG flux in the LULUCF Sector, calculated as the sum of CO_2[1] and non-CO_2 emissions and CO_2 removals, amounted

1 Unless otherwise indicated, all emissions and removals are in CO_2 equivalents.

Table 6–1 LULUCF Sector Net GHG Flux Estimates, Selected Years

Sectoral Category	Net GHG Flux (kt CO_2 eq)[2]							
	1990	2005	2010	2011	2012	2013	2014	2015
Land Use, Land-Use Change and Forestry TOTAL[1]	**-99 000**	**-37 000**	**-28 000**	**-26 000**	**-30 000**	**-29 000**	**-33 000**	**-34 000**
a. Forest Land	-250 000	-180 000	-160 000	-160 000	-160 000	-160 000	-170 000	-160 000
Forest Land remaining Forest Land	-250 000	-180 000	-160 000	-160 000	-160 000	-160 000	-170 000	-160 000
Land converted to Forest Land	-1 100	- 960	- 750	- 710	- 650	- 600	- 550	- 510
b. Cropland	8 900	-10 000	-12 000	-12 000	-12 000	-11 000	-11 000	-11 000
Cropland remaining Cropland	- 890	-14 000	-15 000	-15 000	-14 000	-14 000	-14 000	-14 000
Land converted to Cropland	9 800	4 200	3 000	2 900	2 800	2 700	2 700	2 700
c. Grassland	640	850	320	630	1 600	680	680	680
Grassland remaining Grassland	640	850	320	630	1 600	680	680	680
Land converted to Grassland	NO	NO	NO	NO	NO	NO	NO	NO
d. Wetlands	4 900	3 000	2 800	2 700	3 100	2 800	2 600	2 700
Wetlands remaining Wetlands	1 400	2 200	2 200	2 100	2 200	2 100	2 100	2 100
Land converted to Wetlands	3 500	730	600	650	870	730	550	610
e. Settlements	4 000	3 700	3 800	3 800	3 900	3 700	3 700	3 600
Settlements remaining Settlements	-2 400	-2 400	-2 400	-2 400	-2 400	-2 400	-2 400	-2 400
Land converted to Settlements	6 400	6 200	6 200	6 200	6 300	6 100	6 100	6 000
f. Other Land	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO
g. Harvested Wood Products	130 000	150 000	140 000	140 000	140 000	140 000	140 000	130 000
Forest Conversion[3]	22 000	16 000	15 000	15 000	15 000	15 000	14 000	14 000

Notes:
1. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.
2. Negative sign indicates net removals of CO_2 from the atmosphere.
3. Not a reporting category, it overlaps with the subcategories of Land converted to Cropland, Land converted to Wetland, Land converted to Settlements and Harvested Wood Products.

NE = Not estimated, NO=Not Occuring

to a net removal of 34 Mt. When applied to the national totals, they decrease the total Canadian GHG emissions by 16.2%, 5.0% and 4.6%, in 1990, 2005 and 2015 respectively. Table 6-1 provides the net flux estimates for 1990, 2000, 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. Net removals have decreased in the latter part of the time series, reflecting the influence of forest harvest and the ongoing impact of insect disturbances in western Canada. When interannual variations and trends in the net flux from the managed forest associated with wildfires are removed from reporting, net removals from Forest Land decrease from 250 Mt in 1990 to 160 Mt in 2008.

Emissions from the Harvested Wood Products[2] category, which is closely linked to Forest Land, vary over the 1990–2015 period. 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 fluctuate between 125 Mt in 2009 (lowest harvest year) and 156 Mt in 1995 and 2000.

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 33 Mt in 2015, which includes net removals of 164 Mt from Forest Land and net emissions of 132 Mt from HWP.

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 period 1990–2006, from emissions of 8.9 Mt in 1990 to net removals of 11.5 Mt in 2006. A decline in emissions from Forest Land converted to Cropland also contributes to this trend. From 2006 to 2015, net removals decreased to 10.9 Mt, 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 carbon in lands previously converted to conservation tillage is approaching equilibrium.

Over the period 1990–2015, net fluxes in the Wetlands category (peat extraction and flooded lands) fluctuated between 2.6 Mt (2014) and 4.9 Mt (1990 and 1993). Emissions from flooded lands in 2015 accounted for 43% of all emissions in the Wetlands category, compared to 81% in 1990. Emissions from Land converted to Wetlands decreased over the reporting period from 3.5 Mt to 0.6 Mt.

Net emissions reported in the Settlements category fluctuated between 3.3 Mt (1997) and 4.2 Mt (2007), mainly driven by rates of conversion from forested land, estimated to be 5.8 Mt in 2015. Steady removals of 2.4 Mt per year from the growth of urban trees offset these emissions by an average of 40% 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 22 Mt in 1990 to 14.3 Mt in 2015, including the emissions from HWP resulting from forest conversion activities since 1990. This decline in emissions includes decreases of 5.3 Mt, 1.3 Mt and 0.5 Mt in immediate and residual emissions from Forest Land con-

2 Includes harvested wood products from Forest Land conversion.

verted to Cropland, Settlements and Wetlands, 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 carbon emissions emitted as CO_2, CH_4 and CO due to biomass burning, which are reported in CRF Table 4(V). CO emissions are reported as CO_2 in Table 4(V) and as indirect CO_2 emissions in the cross-cutting Table 6. Emissions and removals are automatically tallied in CRF Table 4.

This year's submission includes significant recalculations in the Forest Land category (Table 6–2) due mainly to the implementation of an improved approach for estimating anthropogenic emissions and removals. To a lesser extent, recalculations also occurred as a result of the introduction of new British Columbia forest inventory and yield tables as well as changes to model parameters and input data including refinement of insect disturbance constraints, updated volume-to-biomass conversion parameters, and corrections of model coding errors in the application of yield tables.

Other less significant recalculations occurred in the other sectoral categories including: revisions of area rates of forest conversion since 2005, alignment of EO-based cropland areas to provincial

Table 6–2 Summary of Recalculations in the LULUCF Sector

Sectoral Category		1990	2005	2010	2011	2012	2013	2014
Land Use, Land-use Change and Forestry TOTAL[1]	**kt**	**-12 000**	**-37 000**	**-83 000**	**-95 000**	**-70 000**	**230**	**-100 000**
	%	14%	-7340%	-152%	-138%	-173%	-0.8%	-146%
a. Forest Land	kt	-5 500	-31 000	-76 000	-89 000	-64 000	7 200	-100 000
	%	2.2%	20%	92%	125%	64%	-4.2%	159%
Forest Land remaining Forest Land	kt	-5 400	-31 000	-76 000	-89 000	-64 000	7 200	-100 000
	%	2.2%	20%	92%	127%	64%	-4.2%	161%
Land converted to Forest Land	kt	- 63	- 41	- 15	- 8.1	-2.9	- 2.7	0.0
	%	6.3%	4.4%	2.1%	1.2%	0.4	0.5%	0.0%
b. Cropland	kt	-1 600	-1 700	-2 300	-2 200	-2 400	-2 500	-2 900
	%	-15%	20%	25%	24%	26%	28%	34%
Cropland remaining Cropland	kt	-1 500	-1 600	-2 000	-2 100	-2 200	-2 300	-2 600
	%	-241%	13%	16%	17%	18%	20%	23%
Land converted to Cropland	kt	- 38	- 89	- 320	- 120	- 210	- 150	- 310
	%	-0.4%	-2.1%	-9.7%	-3.9%	-7.2%	-5.2%	-11%
c. Grassland	kt	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Grassland remaining Grassland	kt	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
d. Wetlands	kt	- 990	-1 300	-1 100	- 990	- 670	- 750	- 720
	%	-17%	-31%	-28%	-27%	-18%	-21%	-21%
Wetlands remaining Wetlands	kt	150	73	- 63	- 170	- 96	- 210	- 170
	%	13%	3.3%	-2.8%	-7.7%	-4.2%	-9.3%	-7.3%
Land converted to Wetlands	kt	-1 100	-1 400	-1 000	- 820	- 570	- 540	- 550
	%	-24%	-66%	-63%	-56%	-40%	-42%	-50%
e. Settlements	kt	- 260	- 240	- 18	- 150	- 71	- 210	- 64
	%	-6.0%	-6.0%	-0.5%	-3.7%	-1.8%	-5.3%	-1.7%
Settlements remaining Settlements	kt	140	130	130	130	130	130	130
	%	-5.4%	-5.3%	-5.2%	-5.2%	-5.2%	-5.2%	-5.2%
Land converted to Settlements	kt	- 390	- 370	- 150	- 280	- 200	- 340	- 200
	%	-5.8%	-5.7%	-2.4%	-4.3%	-3.1%	-5.3%	-3.1%
g. Harvested Wood Products	kt	-3 800	-3 200	-3 400	-3 300	-3 400	-3 500	940
	%	-2.8%	-2.1%	-2.4%	-2.3%	-2.4%	-2.5%	0.7%
Forest Conversion[2]	kt	-1 000	-1 200	-1 200	- 920	- 670	- 860	- 910
	%	-4.4%	-6.8%	-7.4%	-5.9%	-4.3%	-5.6%	-6.0%

Notes:
1. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.
2. Not a reporting category.

areas reported by Statistics Canada, implementation of a new modelling approach and activity data for peat extraction, corrections of appliance factors and moisture content assumptions used in residential firewood estimates, and updates to HWP commodity and export parameters from the Food and Agriculture Organization of the United Nations (FAO) (Table 6-3). The cumulative impact of all these recalculations resulted in decreases in the calculated sink of 12 Mt, 37 Mt and 105 Mt for 1990, 2005 and 2014, respectively.

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 carbon transfers to HWP.

Environment and Climate Change Canada has established formal and explicit governance mechanisms for LULUCF Sector reporting through memoranda of understanding (MOUs) with Agriculture and Agri-Food Canada and the Canadian Forest Service of Natural Resources Canada (NRCan/CFS) for coordinating, planning 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 improvement to the new approach for improving reporting of anthropogenic emissions and removals in Forest Land; continued work on the HWP model structure, in particular including improvements to the integration of residential firewood harvest from forest lands and other land-use categories; completion of uncertainty estimates in all

Table 6–3 Summary of Changes in the LULUCF Sector

List of Changes	Change Category	Years Affected
Forest Land		
Implementation of new reporting approach to exclude emissions and removals from impact of natural disturbances	Changes to model parameters and algorithms	Complete time series
Refinement of aspen defoliator disturbance constraints	Changes to model parameters and algorithms	Complete time series
Updated volume-to-biomass conversion parameters	Changes to model parameters and algorithms	Complete time series
Correction of handling of yield tables	Changes to model parameters and algorithms	Complete time series
Introduction of new British Columbia forest inventory and yield tables	Activity data updates	Complete time series
Forest conversion activity data updates for 2005–2014	Activity data updates	2005–2014
Cropland		
Realignment of EO-based cropland areas to Statistics Canada provincial totals	Activity data updates	Complete time series
Impact of updated volume-to-biomass conversion parameters in carbon budget model (CBM)	Changes to model parameters and algorithms	Complete time series
Forest conversion activity data updates for 2005–2014	Activity data updates	2005–2014
Wetlands		
Implementation of geospatial activity data and a new modelling approach for peat extraction	Method changes	Complete time series
Impact of updated volume-to-biomass conversion parameters in CBM	Changes to model parameters and algorithms	Complete time series
Reservoirs - Deforestation recalculations largely in Wetlands remaining Wetlands in reporting zone 4 throughout time series and recent Romaine reservoir construction	Activity data updates	2011–2014
Settlements		
Downward revisions of areas of urban trees by an average of -23 kha/year, due to revision of urban boundaries for 1990	Activity data updates	Complete time series
Impact of updated volume-to-biomass conversion parameters in CBM.	Changes to model parameters and algorithms	Complete time series
Forest conversion activity data updates for 2005–2014	Activity data updates	2005–2014
Harvested Wood Products		
Corrections in appliance factors, moisture contents assumptions and EF unit conversion for residential firewood; updates of commodity and export FAO parameters; minor corrections in legacy emissions	Changes to model parameters and algorithms	Complete time series
Updates on harvest activity data and deforestation based on new geomatics analysis	Activity data updates	Complete time series

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, a common definitional framework was 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 1 ha or more where tree formations can reach 25% crown cover and 5 m in height *in-situ*. Not all Canadian forests are under the direct influence of human activities, prompting the non-trivial question of what areas properly embody "managed forests." For the purpose of the GHG inventory, managed forests are those managed for timber and non-timber resources (including parks) or subject to fire protection. Annex 3.5 provides more detail on the implementation of the "managed forests" definition.

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 Grasslands 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 2015. 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 comprised of 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. 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 semiarid 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.

Table 6–4 Land Use and Land-use Change Matrix for the 2015 Inventory Year (Areas in kha)[1]

		Final Land Use					
		Forest Land[2]	Cropland	Grassland[3]	Wetlands[4]	Settlements	Other
Initial Land Use	Forest Land	225 863	12	NO	2	22	NO
	Cropland	NE	45 138	NO	NE	11	NO
	Grassland	NO	0.01	6 608	NE	1	NO
	Wetlands	NO	NE	NO	539	NE	NO
	Settlements[4]	NO	NE	NO	NO	896	NO
	Other	NO	NO	NO	1	NO	NE

Notes:
1. Non-diagonal cells refer to annual rates of land-use change, i.e., total land converted during the latest inventory year.
2. Includes all managed forest areas comprised of: areas reported (as in CRF table 4.A) and areas excluded from reporting due to the application of the new natural disturbance approach.
3. Only includes areas of agricultural grassland.
4. Only includes areas for which estimates are reported in the CRF.

NE = Not estimated.
NO = Not occurring.

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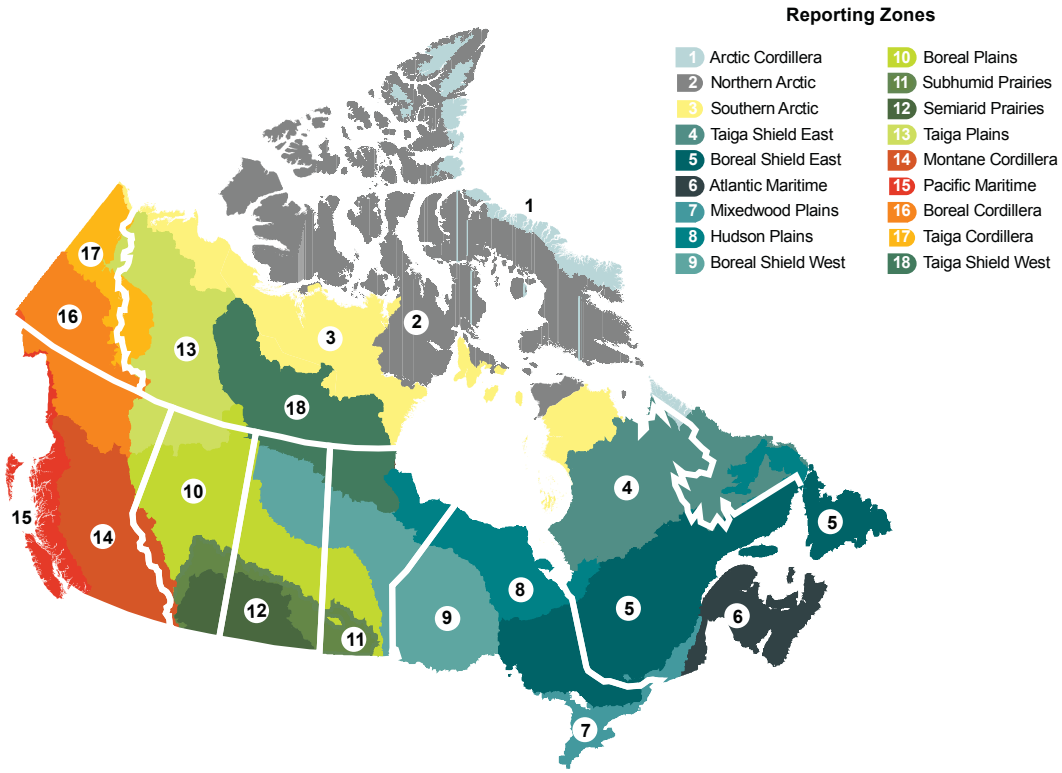
Figure 6–1 Reporting Zones for LULUCF Estimates



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.

6.3. Forest Land (CRF Category 4.A)

Forest and other wooded lands cover 388 million hectares (Mha) of Canadian territory; forest lands alone occupy 347 Mha (NRCan 2016a). Managed forests, those under direct human influence, account for 226 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 2015, the net GHG balance of managed Forest Land amounted to removals of 164 Mt (Table 6–1 and CRF Table 4), while emissions from wood products originating from Canada's managed forests amounted to 132 Mt.

The Forest Land estimate includes net emissions and removals of CO_2, as well as N_2O, CO 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 (226 Mha, net removals of 164 Mt in 2015) and Land converted to Forest Land (0.05 Mha, net removals of 0.51 Mt in 2015).

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 carbon is stored in vegetation (biomass), dead organic matter (DOM) and soils. Carbon dioxide and other GHGs are returned to the atmosphere by vegetation 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.

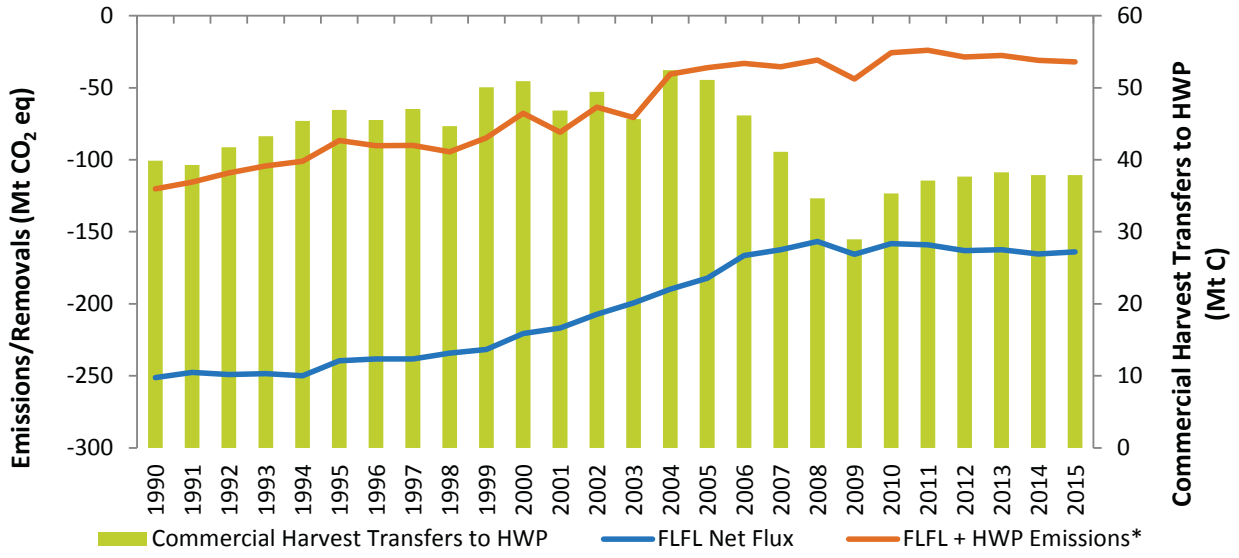
Forest planning, harvest operations and subsequent forest regeneration are the primary direct human influences on emissions and removals in forests. Forest harvest transfers carbon to Harvested Wood Products (HWP) (Section 6.4), and produces harvest residues (branches, foliage and non-commercial species) which are left to decay or are burned. Clear-cut harvesting re-sets stand age to 0; this changes the rate of carbon accumulation in 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 carbon harvested from the forest represent the net flux between managed forests and the atmosphere (Figure 6–2).

Estimates for the net removals from Forest Land exclude the impacts of non-anthropogenic natural disturbances (wildfires, insect infestations and wind throw).[3] Net removals from Forest Land decreased from 250 Mt in 1990 to 160 in 2008, increased slightly in 2009 and then remained relatively constant thereafter (Figure 6–2). The large decrease in removals that occurred between 2000 and 2008 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 carbon accumulation in biomass[4] in the reporting zone. At the same time, low-level insect infestations resulted in small increases in tree mortality over large areas, increasing emissions

3 Impacts of natural disturbances with greater than 20% tree mortality.

4 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

Table 6–5 Forest Land Remaining Forest Land Areas, GHG Fluxes and C Transfers, Selected Years

Subcategories	1990	2005	2010	2011	2012	2013	2014	2015
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	190 000	180 000	190 000	190 000	190 000	190 000	190 000	190 000
Areas with Natural Disturbance Impacts	42 000	42 000	40 000	39 000	39 000	38 000	38 000	38 000
Net Flux (kt CO_2)[1,2]	**-240 000**	**-110 000**	**-39 000**	**-20 000**	**-53 000**	**-120 000**	**-4 500**	**83 000**
Reported Estimates	-250 000	-180 000	-160 000	-160 000	-160 000	-160 000	-170 000	-160 000
Emissions from Natural Disturbances	14 000	75 000	120 000	140 000	110 000	41 000	160 000	250 000
Carbon Transferred to HWP (Mt C)[3]	**47**	**56**	**41**	**43**	**43**	**44**	**43**	**43**

Notes
1. Negative sign indicates removal of CO2 from the atmosphere.
2. Net flux corresponds to the sum of net GHG balance due to forest management activities and emissions due to natural disturbances, not reported in the CRF tables.
3. The current design of the CRF tables for the LULUCF Sector does not enable representation of C transfer to the HWP in-use pool. This transfer between LULUCF categories is presented here for information purposes.

from decomposition. In the Boreal Plain, insect infestation and harvest rates also resulted in a shift in the average age of forests of that reporting zone, but also a reduction in the number of commercially mature forest stands and consequently a reduction in the rate of carbon uptake for the region. Reduced carbon uptake and increased emissions from decomposition in these regions resulted in a large enough decrease in removals to impact the national trend.

6.3.1.2. Methodological Issues

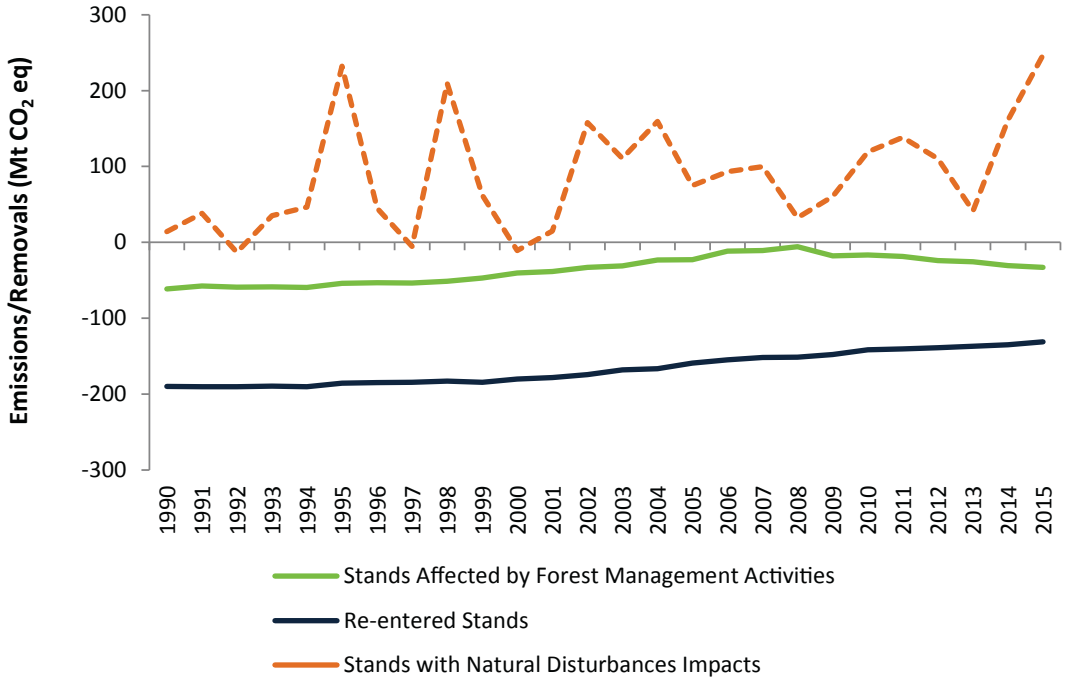
Canada applies a Tier 3 methodology for estimating GHG emissions and removals in managed forests. Canada's National Forest Carbon Monitoring, Accounting and Reporting System (NFCMARS) includes a model-based approach (Carbon Budget Model of the Canadian Forest Sector, or CBM-CFS3) (Kull et al. 2014; Kurz 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 stocks, stock changes and CO_2 emissions and removals. The model uses regional ecological and climate parameters to simulate carbon transfers among pools, to harvested wood products and to the atmosphere. More detailed description of forest carbon modelling can be found in Annex 3.5.2.1.

In previous inventory editions, emissions and removals in Forest Land displayed large inter-annual 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). For this submission, an improved approach for estimating anthropogenic emissions and removals in managed forests was developed by separating forest stands impacted by anthropogenic and natural drivers (Figure 6–3). Emissions and removals from stands dominated by the impacts of natural disturbances are now temporarily excluded until stands attain commercial maturity and re-enter as they are actively considered within forest management planning or are directly affected by forest management activities. Direct forest management activities include commercial clearcut and partial harvest, commercial and pre-commercial thinning, and salvage logging. Additional information on the estimation approach is provided in Annex 3.5.2.3.

Carbon stock changes in managed forests are reported in CRF Table 4.A, by reporting zone. For any given pool, carbon stock changes include not only exchanges of GHG with the atmosphere, but also the carbon transfers to and from pools, for example its transfer from living biomass to dead organic matter upon stand mortality. Therefore,

Figure 6–3 Emissions and Removals in Forest Land Remaining Forest Land by Stand Component



individual carbon stock changes give no indication of the net fluxes between carbon pools in managed forests and the atmosphere.

Harvesting wood from managed forests results in both a transfer of carbon 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 carbon embedded in wood material taken off-site is tracked in the HWP pool and reported in the Harvested Wood Products category, and the emissions from the carbon that decompose on site are reported in Forest Land. Due to limitations in the current design of the CRF tables, the carbon 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 carbon transfer is reported as carbon 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 carbon stock change in the forest biomass and DOM pools as shown in the current design of CRF Table 4.A since the losses of carbon 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.

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 2017 submission (covering the entire 1990–2015 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.

Throughout the entire time series, the uncertainties associated with annual estimates are expressed as a 95% confidence interval, bound by 2.5th and 97.5th percentiles of the Monte Carlo run outputs. The uncertainty range of the CO_2 estimates is 101 Mt in 1990, 115 Mt in 2005 and 112 Mt in 2015 (Table 6–6). On average, uncertainty was ±56 Mt of the median result from the Monte Carlo runs over the entire time series. Non-CO_2 emissions contribute little to total uncertainty.

Table 6–6 Estimates of 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 (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
CO_2	1990	- 252	- 337	34	- 237	-6
	2005	- 183	- 267	46	- 152	-17
	2015	- 164	- 237	44	- 125	-24
CH_4	1990	0.31	0.25	-21	0.57	82
	2005	0.34	0.24	-30	0.89	165
	2015	0.26	0.18	-30	0.57	119
N_2O	1990	0.14	0.11	-21	0.28	94
	2005	0.17	0.12	-30	0.47	177
	2015	0.13	0.09	-30	0.29	129

While the relative uncertainty is presented, these values can be misleading, as the relative uncertainty may be increased when the net CO_2 balance approaches neutrality. This does not represent varying uncertainty levels; it is an artefact of the combination of large fluxes cancelling each other while their respective uncertainties do not.

Probability distributions are asymmetrical around the net flux estimate. Therefore, uncertainty ranges may be considered representative of the uncertainty in the model parameters and activity data; however caution should be taken when considering the distribution of the uncertainty around the net flux estimate. More information on the general approach used to conduct this analysis is provided in Annex A3.5.2.4.

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 period 1990 to 2003 were derived from the Canadian National Fire Database (CNFDB),[5] which comprises information from provincial resource management agencies, compiled and updated by the Canadian Forest Service. Estimates of area burned for the period 2004–2015 were obtained from the National Burned Area Composite (NBAC).[6] 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 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. QA/QC and Verification

Systematic and documented quality assurance/quality control (QA/QC) procedures are performed in four areas: workflow checks (manual), model checks (automated), benchmark checks (manual) and external reviews. Check results are systematically documented; an issue logging system identifies each issue and facilitates tracking and managing its resolution. Tier 2 quality control (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 carbon stocks predicted by the CBM-CFS3 with ground plot-based estimates of ecosystem carbon stocks from Canada's new National Forest Inventory (NFI). Datasets from the NFI of carbon stocks were entirely independent of the input data used for

5 http://www.nrcan.gc.ca/node/13159.

6 http://www.nrcan.gc.ca/node/13159.

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 improved 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 re-entry criterion for stands impacted by insect infestations was justifiable. However, it recommended that re-entry criterion for stand-replacing natural disturbances should be improved with regional differentiation. The details of the approach and corresponding estimates have also been presented to provincial forest experts in Canada and a consultation is underway to inform the refinement of re-entry criteria to further improve the representation of forest management practices.

6.3.1.5. Recalculations

There were significant recalculations in this category primarily due to the implementation of an improved approach for estimating anthropogenic emissions and removals in managed forests and, to a lesser extent, to modifications to the modelling system and activity data updates. Total recalculations, resulting from a combination of all changes, range from -250 Mt (1995) to +27 Mt (2000). The largest recalculations occur in large fire years 1995 (-250 Mt), 1998 (-211 Mt), and 2002 (-146 Mt), as significant immediate emissions and subsequent removals from stands disturbed by wildfires are now removed until the affected stands have re-attained commercial maturity. Details on these changes are presented in the three categories below.

Improved Estimation of Anthropogenic Emissions and Removals

In this submission, an improved approach was implemented for estimating anthropogenic emissions and removals in managed forests. The CBM-CFS$_3$ model tracks forest stands dominated by the impacts of anthropogenic activities separately from stands dominated by the impacts of uncontrollable natural disturbances. As a result, the large interannual variations in the net flux due to wildfires reported in previous submissions have been removed, resulting in estimates that better represent human-controlled emissions and removals in managed forests (Figure 6–2).

Modelling System Modifications

There were a number of modifications to the CBM-CFS3 model in this submission. Volume-to-biomass conversion parameters were updated on the basis of data from a larger collection of permanent and temporary sample plots. The collection of stands available for simulation of aspen defoliation by insects in Alberta was expanded. Errors were also corrected in commercial thinning disturbance matrices and in the coding for the selection and application of yield tables.

Activity Data Updates

The British Columbia provincial forest inventory and associated growth and yield information

were updated on the basis of information provided by the provincial government. As a result of the inventory update, the managed forest area for British Columbia was revised downwards by on average 6 Mha (9%). Model re-configurations were applied to incorporate new slash burning activity data for Manitoba from the National Forestry Database Program. Updates to official harvest data replaced preliminary harvest estimates for 2014.

Model modifications and activity data updates (excluding the improvement representing anthropogenic emissions and removals) largely resulted in a decrease in net removals, most notably in the 2000–2014 period (see Figure 6–4, represented as the 2017 Submission – Previous Estimation Approach compared to 2016 Submission). The changes that had the largest impact were the incorporation of a new British Columbia inventory, a reduction in unrealized insect disturbances by aspen defoliators and the correction in handling of yield tables.

6.3.1.6. Planned Improvements

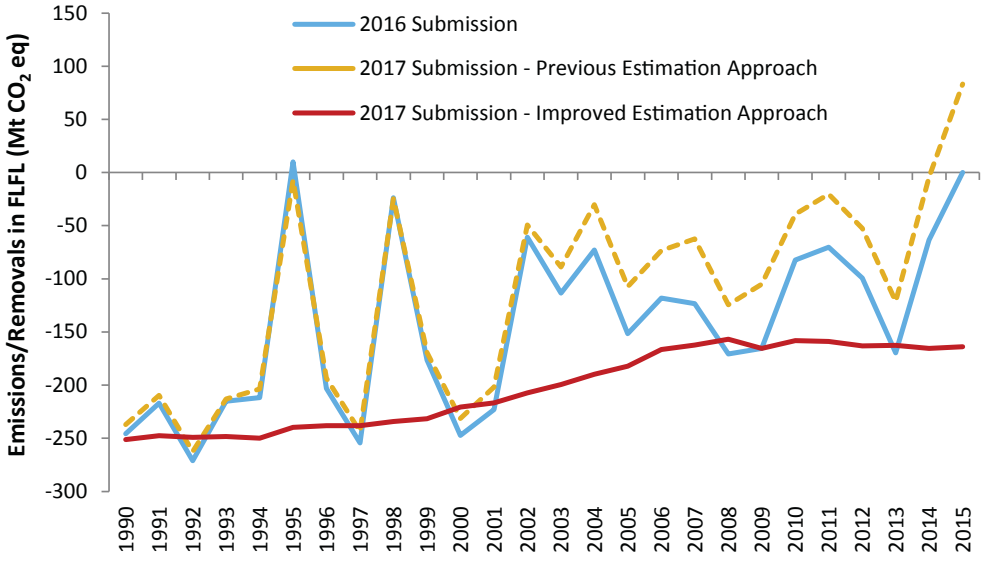
Planned improvements include further work to improve the representation of the impacts of forest management on estimates of anthropogenic emissions and removals in managed forests. This includes developing regionally specific re-entry criteria based on forest management practices or stand dynamics through consultation with provincial experts. A detailed trend uncertainty and sensitivity analysis and an examination of how various components contribute to the asymmetrical distribution of uncertainty estimates around net flux are also planned.

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-

Figure 6–4 Recalculations in Forest Land Remaining Forest Land



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 174 kha in 1990 to 49 kha in 2015. 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. Eighty two 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 13% in the Prairie provinces (Boreal Shield West, Boreal Plains and Subhumid Prairies reporting zones) and the remaining 5% in western Canada (Pacific Maritime and Montane Cordillera).

Net removals declined throughout the period, from 1.1 Mt in 1990 to 0.5 Mt in 2015. Net carbon accumulation largely occurs in biomass (117 Gg C in 2015 – CRF Table 4.A); soil carbon 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 2009–2015 inventory years.

GHG emissions and removals on lands newly converted to Forest Land were estimated using CBM-CFS_3, as described in Annex 3.5. Changes in soil carbon stocks are highly uncertain because of difficulties in locating data about the carbon stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil carbon 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. QA/QC and Verification

Tier 2 QC checks (Dymond 2008) specifically address estimate development in the Forest Land category. Environment and Climate Change Canada, while maintaining its own QA/QC proce-

dures 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 in the estimates for this 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 production approach described in the Annex to Volume 4, Chapter 12, of the 2006 IPCC Guidelines (IPCC 2006). 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 carbon begins to be stored in a pool of HWP that are in use. As a result, emissions fluctuated between 125 Mt in 2009 (lowest harvest year) and peaks of 156 Mt in 1995 and 2000. In 2015, HWP amounted to total emissions of 134.9 Mt, slightly higher than the 134.5 Mt emitted in 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.

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 carbon off-site from the point of forest harvest or forest conversion. The model tracks HWP sub-pools and carbon 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 carbon output from harvested wood from the ecosystem model, exports a portion as roundwood, converts all the rest of the 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 carbon from conventional contemporary harvest and residential firewood collection in Forest Land and a relatively small amount from forest conversion activities (around 2.5% of all inputs

Table 6–7 Carbon Stocks in HWP Pool and Emissions Resulting from Their Use and Disposal

Source Subcategories / Commodities	1990	2005	2010	2011	2012	2013	2014	2015
Carbon Stocks (Mt C)[1]								
Inputs	49	57	42	44	44	45	44	44
Conventional Harvest[2]	40	51	35	37	38	38	38	38
Forest Conversion[2]	1.8	1.2	1.0	1.0	1.0	1.0	1.0	1.0
Residential Firewood[3]	6.9	5.2	5.4	5.4	5.5	5.4	5.4	5.4
Exports	19	30	18	19	19	20	21	21
Net Stocks[4]	300	500	530	540	540	550	550	560
Emissions (Mt CO_2)[1]	**135**	**149**	**136**	**138**	**137**	**138**	**137**	**135**
Domestic Harvest	93	78	71	74	73	74	75	73
Solid Wood - Sawnwood	4.8	5.2	5.8	5.8	5.9	6.0	6.1	6.2
Solid Wood - Wood Panels	2.5	3.2	3.6	3.7	3.8	3.9	4.0	4.0
Other Solid Wood Products	0.8	1.8	2.0	2.0	2.1	2.1	2.1	2.1
Paper and Market Pulp	8.3	0.7	0.9	1.2	1.7	2.3	2.6	2.5
Firewood - Residential and Industrial	46	55	47	47	47	48	48	47
Mill Residue	31	13	11	14	13	12	12	11
Worldwide from Canadian Harvest	41	71	65	64	64	63	63	62
Solid Wood - Sawnwood	8.8	15	16	16	17	17	17	17
Solid Wood - Wood Panels	0.7	4.0	4.8	4.9	4.9	5.0	5.1	5.2
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	49	42	41	40	39	39	38
Mill Residue	0.5	2.1	1.3	1.8	1.9	2.1	2.0	1.5

Notes:
1. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.
2. Carbon estimated by the CBM-CFS3 model in form of wood biomass that results from forest harvest 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.E under subcategories related to Forest Conversion, if using instant oxidation approach for HWP. Includes a small proportion of carbon used for residential firewood.
3. Includes only carbon collected for residential firewood from the managed forest, as estimated by the CBM-CFS3. This C would be reported as C losses in CRF table 4.A under FLFL, if using instant oxidation approach for HWP.
4. Because inputs to the model consider harvest since 1941, net stocks over the reporting period may include C harvested before 1990.

in any year) transferred from the CBM-CFS3 model (see Section 6.3.1.2). For historical harvest, the input comes from historical commodity production from Statistics Canada at a national level of spatial resolution, covering the period 1941–1989.

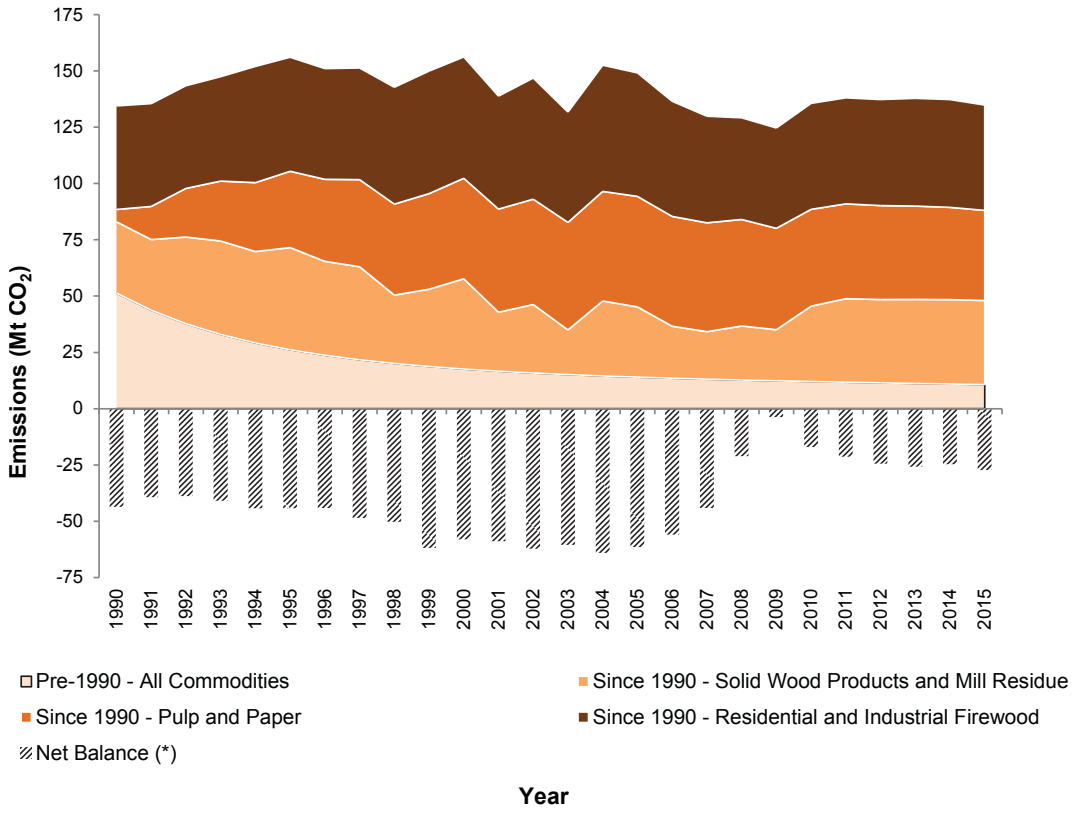
Data on the annual volume of residential firewood and industrial wood waste are provided by the Energy Sector. Residential firewood data come from 1996, 2006 and 2012 TNS Global/Canadian Facts Surveys, while data on industrial consumption of firewood come from the annual Report on Energy Supply and Demand in Canada (RESD). More information on the estimation methodology, data sources and parameters used in the model are available in Annex 3.1 (data sources) and Annex 3.5.

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 carbon inputs, stock changes in the HWP pool and resulting net emissions for each commodity are reported in CRF Table 4.G.

For the period 1990–2007, emissions resulting from the inclusion of the HWP pool are considerably lower than the emissions that would result from using an instant oxidation approach, as used in

Figure 6–5 Emissions from HWP Pool Using the Production Approach



* This time series represents the net CO_2 balance in the HWP pool based on the difference between annual emissions from HWP and carbon annually transferred from the forest in units of CO_2, and is presented here only for reference puposes.

submissions prior to 2015 with differences fluctuating between -39 Mt in 1991 and 1992 and -64 Mt in 2004 (highest harvest year) (bars in Figure 6–5). These large differences occur because carbon in wood removed from the forests in the reporting year was much higher than the carbon in the HWP pool that had come from lower harvest levels in past years and was disposed of in the reporting year. Conversely, after 2007, though harvest rates are lower, HWP emissions remain elevated relative to the instant oxidation estimate due to greater quantities of carbon in wood transferred out of the in-use pool coming from harvests in past years than carbon in wood removed by harvest in the reporting year.

6.4.3. Uncertainties and Time-Series Consistency

In the assessment of the uncertainty of HWP presented in the last year's submission, model parameters were varied for Monte Carlo simulations while the carbon inputs were held constant based on the output from the CBM-CFS3 forest ecosystem model. The results of this analysis therefore represented the uncertainty of the fate of harvested carbon, not the uncertainty in the rate of C inputs, which is determined in the uncertainty analysis of forest estimates (as described in Section 6.3.1.3).

Table 6–8 Estimates of CO_2 Emissions from Harvested Wood Products, with 2.5th and 97.5th Percentiles, for Selected Years

Inventory Year	Source of C inputs	Emissions (Mt CO_2)	2.5th Percentile (Mt)	% Uncertainty (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
1990	Conventional Harvest - since 1990	58.5	37.2	-36	80.1	37
	Forest Conversion - since 1990	3.4	1.1	-67	5.4	61
	Residential Firewood Collection	21.3	19.8	-7.1	22.8	7.2
	Historical Harvest - before 1990	51.3	46.8	-5	46.2	3
2005	Conventional Harvest - since 1990	116.0	92.1	-21	138.8	20
	Forest Conversion - since 1990	3.2	1.7	-47	5.1	61
	Residential Firewood Collection	16.0	14.7	-7.8	17.2	7.3
	Historical Harvest - before 1990	14.0	13.2	-9	14.6	10
2015	Conventional Harvest - since 1990	104.7	80.0	-24	118.8	13
	Forest Conversion - since 1990	2.9	1.5	-49	4.3	47
	Residential Firewood Collection	16.5	14.6	-11.6	17.7	6.9
	Historical Harvest - before 1990	10.7	10.2	-6	11.1	4

This year's uncertainty analysis includes, for the first time, 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 carbon harvested since 1990 (Table 6–8). More details are provided in Annex 3.5.

6.4.4. Recalculations

Recalculations in the HWP category are due to the combined effects of: i) corrections in appliance factors, moisture contents assumptions, and EF unit conversion for residential firewood (see Section 3.2.7 for more details); ii) updates of commodity and export parameters from FAO statistics; iii) a minor correction in legacy emissions; and vi) activity data updates for forest harvest, forest conversion and firewood. As a result, total emissions from HWP were recalculated downward by 3.8 Mt in 1990, 3.2 Mt in 2005 and 0.9 Mt in 2014.

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. Further improvements will therefore be required to better distribute firewood harvest to their appropriate land use.

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 50 Mha of the Canadian territory. In 2015, the net GHG balance in the Cropland category amounted to removals of 11 Mt (Table 6–1). For the purpose of reporting under the UNFCCC, Cropland is divided into Cropland remaining Cropland (net removals of 14 Mt in 2015) and Land (either forest or grassland) converted to Cropland (net emissions of 2.7 Mt and 0.007 Mt, respectively, in 2015). The estimates in Land converted to Cropland include net emis-

sions and removals of CO_2, as well as N_2O and CH_4 emissions.

6.5.1. Cropland Remaining Cropland
(CRF Category 4.B.1)

Cultivated agricultural land in Canada includes areas of field crops, summerfallow, hay fields and tame or seeded pasture. Cropland is found mainly in the nine southernmost reporting zones. About 83% of Canada's cropland is in the interior plains of western Canada, made up of the Semiarid Prairies, Subhumid Prairies and Boreal Plains reporting zones. Another 12% of cropland is found in the Mixedwood Plains reporting zone.

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. 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 carbon retained in these soils is a function of crop production and the rate of decomposition of soil organic carbon (SOC). Cultivation and management practices can lead to an increase or decrease in the organic carbon 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 0.89 Mt (Table 6–9). The soil C sink steadily increased to 15 Mt in 2006 and subsequently gradually decreased to 14 Mt in 2015. The increasing trend in removals in the first 17 years partly reflects the 88% reduction in summerfallow area from 1990 to 2015 and increased conservation tillage (from 1.3 Mt in 1990 to 5.9 Mt in 2015) (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

Table 6–9 Base and Recent Year Emissions and Removals Associated with Various Land Management Changes on Cropland Remaining Cropland

Categories	Land Management Change (LMC)	Emissions/Removals (Gg CO_2)[1]							
		1990	2005	2010	2011	2012	2013	2014	2015
Total Cropland remaining Cropland		- 890	-14 000	-15 000	-15 000	-14 000	-14 000	-14 000	-14 000
Cultivation of histosols		300	300	300	300	300	300	300	300
Perennial woody crops		31	- 7	-19	- 12	- 19	- 16	- 15	- 7
Total mineral soils		-1 200	-15 000	-15 000	-15 000	-15 000	-14 000	-14 000	-14 000
Change in crop mixture	Increase in perennial	-4 300	-12 000	-12 000	-12 000	-12 000	-12 000	-12 000	-11 000
	Increase in annual	6 500	7 500	8 600	8 800	9 100	9 400	9 700	10 000
Change in tillage	Conventional to reduced	- 890	-1 100	- 930	- 910	- 880	- 850	- 830	- 810
	Conventional to no-till	- 440	-3 600	-3 900	-3 900	-3 900	-4 000	-3 900	-3 900
	Other	- 0.4	- 860	-1 100	-1 100	-1 100	-1 200	-1 200	-1 200
Change in summerfallow (SF)	Increase in SF	2 500	2 000	1 800	1 700	1 700	1 600	1 600	1 600
	Decrease in SF	-4 800	-8 500	-9 200	-9 300	-9 500	-9 600	-9 700	-9 900
Land conversion—Residual emissions[2]		180	1 700	1 800	1 800	1 800	1 800	1 800	1 800

Notes:

1. Negative sign indicates removal of CO_2 from the atmosphere.
2. Net residual CO_2 emissions from the conversion of Forest Land and Grassland to Ccropland that occurred more than 20 years prior to the inventory year, including emissions from the decay of woody biomass and DOM.

mixture resulting in an emission of 2.2 Mt in 1990 and removal of 1.5 Mt in 2015.

Since 2006, however, there has been an increase in the proportion of annual crops in the crop mixture, decreased rates of adoption of conservation tillage and a slower rate of decrease in summerfallow areas than in the years prior to 2006. 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. Since 2006, net removals have decreased by roughly 1 Mt.

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 carbon.

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 carbon stocks for which activity data (time series of management practices) from the *Census of Agriculture* was 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 carbon 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 carbon 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 carbon 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) 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 carbon 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 carbon effects of an LMC in one direction (e.g. converting annual crops to perennial crops) is the opposite of the

carbon effects of the LMC in the opposite direction (e.g. converting perennial crops to annual crops).

The various carbon 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 carbon 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 carbon 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.[7]

The uncertainties associated with carbon change factors for fallow, tillage and annual/perennial crops were partitioned in two main sources: 1) process uncertainty in carbon change due to inaccuracies in predicting carbon change even if the situation of management practice was defined perfectly; and 2) situational uncertainty in carbon 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. With the major changes in agricultural activity data from the incorporation of EO data, uncertainty estimates for Cropland remaining Cropland need to be updated.

Consistency in the CO_2 estimates is ensured through the use of the same methodology for the entire time series of estimates (1990–2015).

QA/QC 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

7 T. Huffman, Agriculture and Agri-Food Canada, personal communication to Brian McConkey, 2007.

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 carbon 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 assessments of the literature. This difference led to the decision to use empirically based factors for changes in summer-fallow 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 carbon 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

In this submission there were significant changes in the area of tillage practices, summerfallow and perennial/annual crops because of the re-adjustment of EO data to align with the census-based provincial cropland area. This decision is based on the fact that the *Census of Agriculture* represents Canada's authoritative data on cropland activity. The EO data was used to supplement and improve the spatial accuracy of the census area data. As a result of these changes, there were changes to all area data throughout the time series, For example, the area of conservation tillage increased 0.7 Mha in 1990 and 0.4 Mha in 2005, and decreased 1.9 Mha in 2014. The area of annual crops increased 2 Mha in 1990 and 0.5 Mha in 2005, and decreased 2.2 Mha in 2014. Other cropland land management categories changed similarly.

These changes in cropland attributes for the Cropland remaining Cropland subcategory resulted in recalculations, with an increase in removals of 1.5 Mt in 1990, 1.6 Mt in 2005, and 2.6 Mt in 2014, respectively.

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 1990–2015) 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 (1990–2015).

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.

Recalculations

There was no recalculation involved in emission estimates 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

Perennial woody biomass currently includes vineyards, fruit orchards and Christmas tree farms. It also accumulates on abandoned cropland allowed to revert to natural vegetation. 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 recultivation. Owing to these data limitations, only vineyards, fruit orchards and Christmas trees are considered; for the time being changes in woody biomass from "abandoned cropland" on Cropland remaining Cropland are excluded.

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 carbon within existing farms, as carbon 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 carbon stock changes in total biomass. More information on assumptions and parameters can be found in Annex 3.5.

Uncertainties and Time-Series Consistency

Upon a loss of area with perennial woody crops, all carbon in woody biomass is assumed to be immediately released. It is assumed that the uncertainty for carbon loss equals the uncertainty associated with mass of woody biomass carbon. The default uncertainty of ±75% (i.e. 95% confidence limits) for woody biomass on Cropland from the 2006 IPCC Guidelines was used.

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 carbon change uncertainty. For area of gain in fruit trees, vineyards or Christmas trees, the uncertainty in annual carbon 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 woody specialty crops were estimated to be -7 ± 0.7 kt for the level uncertainty and -38 ± 55 kt for the trend uncertainty (McConkey et al. 2007).

The same methodology was used for the entire time series of emission estimates (1990–2015).

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.

Recalculations

The re-adjustment of EO data to align with the provincial census-based cropland area, as noted above, also resulted in a downward adjustment for the specialty crops by 22 kha in 1990, 12 kha in 2005, and 43 kha in 2014, respectively. As a result, there was a small decrease in emissions of 0.4 kt in 1990 and of 6.5 kt in 2005, and an increase in emissions of 57 kt in 2014.

Planned Improvements

Work has been done to attempt to better quantify woody biomass on cropland in Canada, and improvements will be made to the model over the short to 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 nearly 100% of the total emissions in this category, which have decreased from 9.5 Mt in 1990 to 2.7 Mt in 2015. Emissions from the conversion of Grassland are relatively insignificant

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 34% of forest area conversion in 2015). The cumulative area of Forest Land converted to Cropland as reported in CRF Table 4.B was 1286 kha over the 20 years prior to 1990 and 337 kha over the 20 years prior to 2015. 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 2015, immediate emissions from this year's Forest conversion to Cropland accounted for 1.0 Mt, while residual emissions from events that occurred in the last 20 years accounted for 1.6 Mt.

Methodological Issues – Dead Organic Matter and Biomass Pools

More than 92% 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). As explained below, 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 of forest that lies 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 2015 Inventory Year

Emission Components	Emissions (kt CO_2 eq)	Uncertainty (kt CO_2 eq)
Immediate CO_2 emissions	906	±311
Residual CO_2 emissions from the DOM pool	1 405	±423
Residual CO_2 emissions from the soil pool	212	±131
CH_4 emissions	84	±27
N_2O emissions	51	±14

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. 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

The area of deforestation has been updated since 2005, and this resulted in a small increase of the annual conversion of FLCL (39 ha in 2005 and 230 ha in 2014) (see Section 6.9). The re-adjustment of

EO data to align with the census-based provincial cropland area, as noted above, also resulted in changes in management practices within the FLCL. Estimates were also impacted by updates in volume-to-biomass conversion parameters in the CBM (see Section 6.9). As a result, there was a decrease in emissions of 53 kt in 1990, 77 kt in 2005, and 304 kt in 2014, respectively.

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, who 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 2015 from soils amounted to 7 kt, down from 264 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 carbon 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 7 ± 8.5 kt for the level uncertainty, and -260 ± 180 kt for the trend uncertainty.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2015).

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.

Recalculations

The re-adjustment of EO data to align with the provincial census-based cropland area resulted in changes in the area of Grassland converted to Cropland, namely decreases of 190 ha in 1990 and 350 ha in 2014, but an increase of 30 ha in 2005. The recalculations resulted in increased emissions of 15 kt in 1990, but in decreased emissions of 12 kt in 2005 and 10 kt in 2014.

Planned Improvements

Canada plans to validate the modelled soil carbon change factors with measured and published soil carbon 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: Semiarid Prairies (7029 kha), Montane Cordillera (108 kha) and Pacific Maritime (63 ha).

As with Cropland, the change in management triggers a change in carbon 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

Managed grassland is sometimes burned in Canada naturally by lightning, by accidental ignition, as a management tool to control invasive plants and stimulate the growth of native species, or as part of 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

The 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 on area, fuel load and combustion efficiency for each burning event for managed agricultural grassland were collected through consultations (Bailey and Liang 2013).

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 (1990–2015).

6.6.1.4. 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 and methodologies are documented and archived in both paper and electronic form.

6.6.1.5. Recalculations

There was no change in activity data or in the method for emission estimates.

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 11 700 kha of peatlands in Canada,[8] approximately 33 kha are, or were at some point in the past, drained for peat extraction. Some 18 kha are currently being actively managed. The other 15 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.

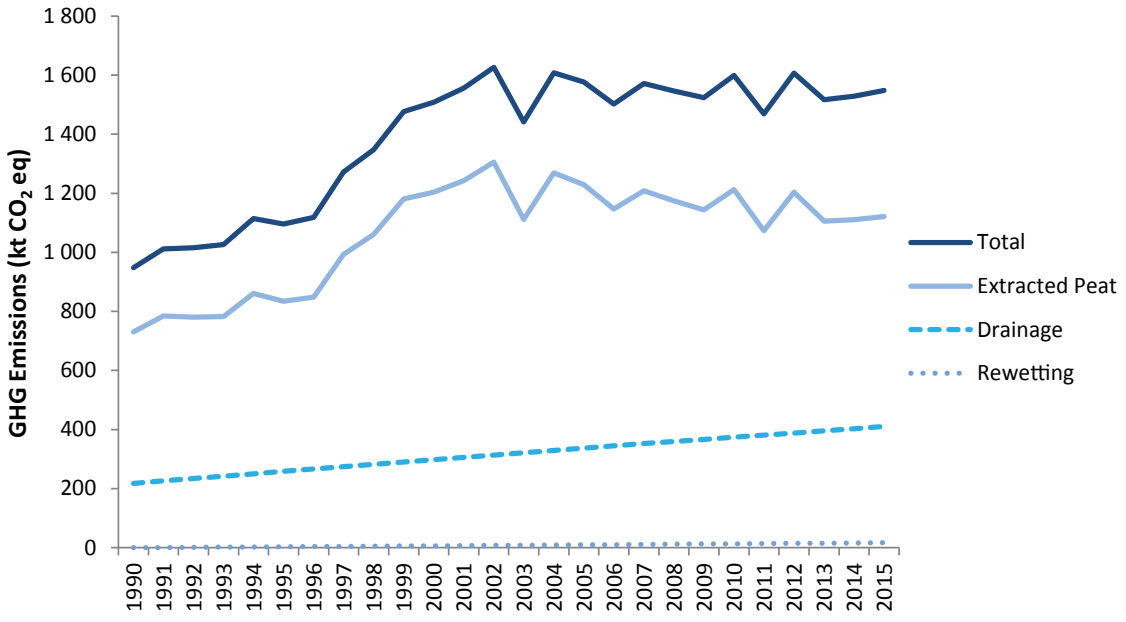
8 Natural Resources Canada - Peatlands of Canada area estimate. Note, this area includes peatlands that would be classified as Forest, Cropland and Grassland in the IPCC land classification.

Emissions from peat extraction increased from 0.9 Mt in 1990 to 1.5 Mt in 2015 (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 decommissioned, 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 and 2014 IPCC Wetlands Supplement. The approach is based on domestic science and land management practices specific to peat extraction in

Figure 6–6 Emissions from Peatlands Converted for Peat Extraction



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 carbon losses and from the decay of extracted peat. Domestic emission factors were derived from flux measurements reported by multiple research studies. 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 sub-categories: 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. 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.

6.7.1.4. QA/QC 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 are due to the development of a new estimation approach that incorporates guidance from the 2014 IPCC Wetlands Supplement, domestic GHG flux measurements and activity data from mapping. The implementation of the new approach has resulted in recalculations of -0.6 Mt in 1990, -1 Mt in 2005 and -0.6 Mt in 2014. This submission now includes on-site CH_4 and N_2O estimates and off-site CO_2 emissions from waterborne carbon losses for drained and rewetted sites. The development of activity data from remote sensing has improved the confidence in land-use change area estimates, now showing a steady increase in extraction area and subsequent increase in de-commissioned areas. The combination of new domestic emission factors and activity data for various land management sub-categories has improved the representation of rehabilitation (e.g. tree plantation), rewetting and restoration activities.

6.7.1.6. Planned Improvements

Refinements in the approach for estimating emissions and removals from 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, this submission includes only large hydroelectric reservoirs created by land flooding. 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 962 kha in 1993 to 39 kha in 2003 as new lands were flooded. In 2015, 54% of the 103 kha of reservoirs flooded for 10 years or less were previously forested (mostly unmanaged forests). Total emissions from reservoirs declined from 4.0 Mt in 1990 to 1.2 Mt in 2015.

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 carbon 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 below 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 carbon 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, 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 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 2015.

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 dissolved organic carbon (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. QA/QC 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 carbon on flooded forests is immediately emitted. Canada's method is more refined in that it distinguishes forest clearing and flooding; emissions from the former are estimated as in all forest clearing associated with land-use change. Further, in Canada's approach, emissions from the surface of reservoirs are derived from measurements, rather than from an assumption (immediate decay of all submerged biomass) that clearly is not verified.

6.7.2.5. Recalculations

Recalculations are due to updated volume-to-biomass conversion parameters in the CBM-CFS3 model (see Section 6.3.1.5) and to new activity data for land conversion and flooding for the Romaine hydroelectric complex. Average recalculations of -0.3 Mt for the period 1990–2011 are mainly due to updated volume-to-biomass conversion parameters. Recalculations of 72 kt in 2012, 64 kt in 2013 and -75 kt in 2014 are due to the combination of activity data for the Romaine complex as well as updated volume-to-biomass conversion parameters.

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 carbon from watersheds to reservoir systems. The monitoring of dissolved organic carbon 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 conversion to Settlements and non-forest land conversion to Settlements in the Canadian north. In 2015, 512 kha of Lands converted to Settlements accounted for emissions of 6 Mt. Forest Land converted to Settlements accounts for 97% of these emissions.

6.8.1. Settlements Remaining Settlements (CRF Category 4.E.1)

6.8.1.1. Sink Category Description

This category includes estimates of carbon 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 removals from urban tress were relatively stable throughout the time series at 2.4 Mt. Estimates are reported for nine of the southernmost reporting zones, where major urban centres are situated. The largest removals were in the Mixedwood Plains (1.2 Mt) and Pacific Maritime (0.4 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 a 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 net sequestration factor adjusted gross estimates to account for decomposition; the result was an estimate of the net annual carbon sequestration by urban trees. A Canadian-specific CRW value based on field data did not exist. A domestic CRW value (2.12 t C/ha) was therefore derived from data sets from the United States (Nowak et al. 2013), adjusting for Canada's shorter average growing season. The net carbon sequestration factor was estimated as 74% of the gross sequestration based on the United States analysis (Nowak 2013). 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 carbon sequestration (16%) was estimated from uncertainty estimates associated with data for the United States. The total uncertainty associated with the estimates of the net CO_2 sequestration of urban trees is 21% 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 (1990–2015).

6.8.1.4. QA/QC 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%) percent.

6.8.1.5. Recalculations

There has been a small change in the data used to derive removal estimates for this category since last year. Urban area delineation was revised on the basis of air photos from 1990, and more sample points were collected for reporting zones 5,7, 10 and 12 (i.e. Boreal Shield East, Mixedwood Plains, Boreal Plains and Semiarid Prairies) using methods described in Annex 3.5. This resulted in an average reduction of 135 kt in the estimated removals over the entire time series.

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 2015, emissions from Land converted to Settlements amounted to 6 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 is the leading forest conversion type since 1998. On average, during the 1990–2015 period, 24 kha of Forest Land were converted annually to Settlements, predominantly in the Boreal Plains, Boreal Shield East, Atlantic Maritime and Mixedwood Plains reporting zones. Forest land conversion accounts for 97% 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 have been the main drivers of land converted to Settlements in Canada. On average, during the 1990–2000 and 2000–2010 periods, 18 kha and 12 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. (2015) 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 from 2010 to 2015.

6.8.2.1.3. Uncertainties and Time-Series Consistency

The uncertainty in land-use change areas was quantified using 457 points over the five main Census Metropolitan Areas (i.e. Toronto, Hamilton, Oshawa, Montreal and Edmonton), which encompass over 45% of the total area changed. The overall accuracy in detecting areas of true change was above 80% and concurs with the values found by Huffman et al. (2015) on the accuracy of each individual land use map.

6.8.2.1.4. QA/QC and Verification

Polygons from the 2011 census were used to define the boundary of each Census Metropolitan Area, and Landsat imagery from the Global Land Surface products from ArcGIS online services[9] was obtained for each area for 1990, 2000 and 2010. 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

Land-use change areas for this category are reported for the first time this submission, and there were therefore no recalculations.

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 aboveground biomass during pre-conversion as well as soil carbon 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 Subarctic regions. In 2015, the conversion of Grassland to Settlements in the Canadian north accounted for emissions of 153 kt. The major source of emissions

9 http://imagery.arcgisonline.com/arcgis/rest/services

in this category is associated with conversion of Grassland to Settlements in reporting zone 13, the Taiga Plains.

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 557 Mha, intersecting with eight reporting zones (2, 3, 4, 8, 10, 13, 17 and 18). For all reporting zones except 4 and 8, various information sources and geographic data sets were used to identify areas of high land-use change potential and narrow down the geographical domain of interest. These areas were targeted for change detection analysis using 23 Landsat frames from circa 1985, 1990 and 2000. The scenes cover more than 8.7 Mha, or 56% of the area with high potential for land-use change.

For reporting zones 4 and 8 (i.e. Taiga Shield East and Hudson Plains), a change enhancement and manual delineation approach was implemented for the 1975–2000 time period for the entire area.

Emissions include only the carbon in pre-conversion above-ground biomass. In spite of the existing relevant literature, the estimation of actual or average biomass density over such a large area is challenging and remains fraught with uncertainty.

6.8.2.2.3. Uncertainties and Time-Series Consistency

The uncertainty about the area of non-forest land converted to Settlements in the Canadian north is estimated at 20%. The uncertainty estimate for the pre-conversion standing biomass varies between 33% and 53%. Annex 3.5 provides more information.

6.8.2.2.4. QA/QC 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 in the estimates for this category.

6.8.2.2.6. Planned Improvement

Future efforts to improve estimates for this category will focus on improving estimates of the pre-conversion above-ground biomass for land-use change events in the Arctic and Subarctic regions, by updating estimates of activity data for land-use change in these regions for the post 2000 time period

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 and Land converted to Settlements. 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 2015, Forest Land conversion to Cropland, Wetlands and Settlements amounted to total emissions of 11 Mt, down from 18 Mt in 1990. This decline includes a 5.3-Mt decrease in immediate and residual emissions from Forest Land conversion to Cropland and a 1.3-Mt decrease in emissions from Forest Land conversion to Wetlands

(reservoirs). There was also a small decrease of 0.5 Mt in immediate and residual emissions from Forest Land conversion to Settlements. Note that the above values include residual emissions more than 20 years after conversion (10 years for reservoirs and 1 year for peat extraction) that are reported under the "land remaining" categories, such as Cropland remaining Cropland or Wetlands remaining Wetlands.

Care should be taken to distinguish annual forest conversion rates (64 kha in 1990 and 36 kha in 2015) from the total area of Forest Land converted to other land uses as reported in the CRF tables for each inventory year. The CRF figures 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 2015, immediate emissions (2.4 Mt) represented only 21% of the total reported emissions due to forest conversion; 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 carbon stock changes in Cropland remaining Cropland and Wetlands remaining Wetlands.

Primary drivers of forest conversion include agricultural expansion, resource extraction and hydroelectric development. Forest conversion for agricultural expansion (i.e. Forest conversion to Cropland) accounted for 42% 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 conversion to Settlements, which comprises forestry roads, mining, oil and gas, hydro-infrastructure, transportation and built-up lands, increased from 21 kha in 1990 to 30 kha in 2006 and 2007, dropping to 22 kha in 2015 (Figure 6-7), based on results of the new mapping period. Since 1998, the Settlements category has become the main driver of forest conversion, accounting on average for 58% 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, especially in the Boreal Plains region, which reached 13 kha in 2006. Forest conversion for resource development in this region has decreased since, but still contributes to 28% of the total forest area lost nationally in 2015.

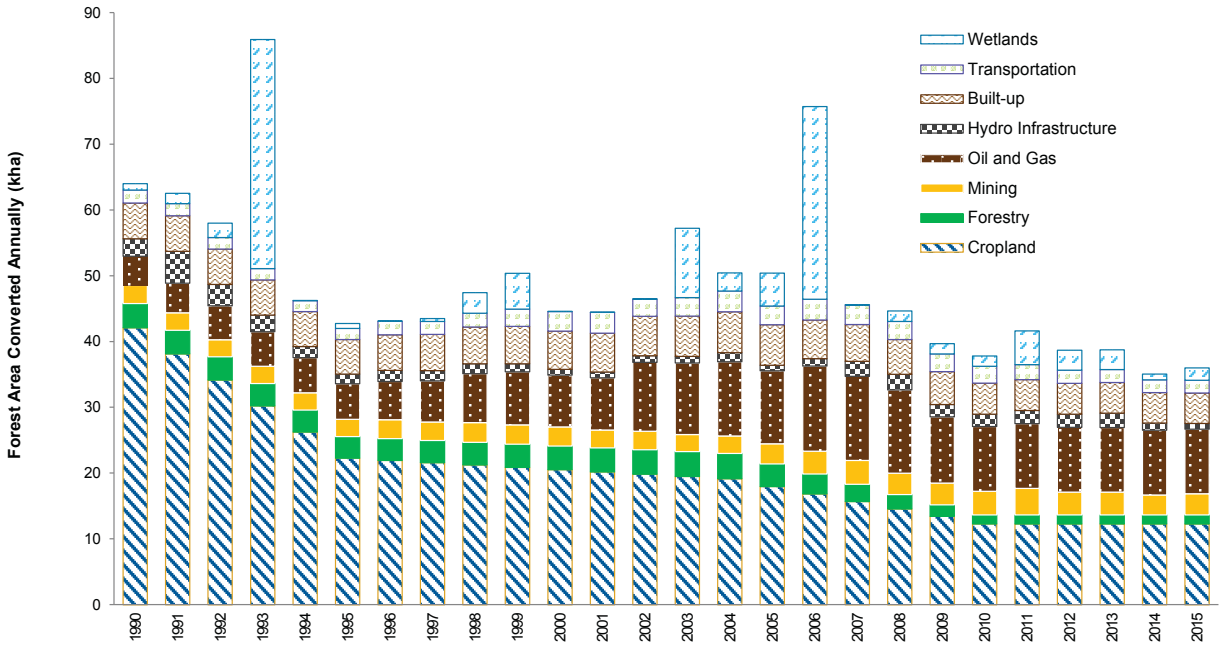
The occasional impoundment of large reservoirs (e.g. La Forge 1 in 1993 and Eastman 1 in 2006) may also convert large forest areas to Wetlands (Figure 6-7). However, because much of the pre-conversion C stocks are flooded, these episodic events may not release commensurate quantities of greenhouse gases.

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 9 (Boreal Shield West) and zone 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 activi-

Figure 6–7 Annual Forest Conversion Areas per End Land Use



ties 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. The core method involves mapping of forest conversion on samples from remotely sensed Landsat images dated circa 1975, 1990, 2000, 2008 and 2013. 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 and 2008–2013 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 2015 between 25 kha and 47 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. QA/QC 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). 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, mainly due to the use of updated activity data for the last mapping period (2005 to 2013), which involved a refinement of previous deforestation rates based on increased sampling (especially for areas with higher deforestation activity), the inclusion of new large events (i.e. hydro-reservoirs belonging to the Romaine complex) and revisions of the records of expertise. Recalculations are also due to updated values for volume-to-biomass conversion parameters in the CBM-CFS3 model.

The inclusion of new mapping improves forest conversion estimates in the later part of the time series, indicating that overall forest conversion rates have increased in recent years compared to previous estimates. From 2005 to 2014, there was an upward recalculation of forest conversion areas nationally of 13 kha.

The largest recalculations occurred in the area of forest land annually converted to Wetland, with a total increase of 7.6 kha over the period 2005–2014. Annual rates of forest conversion to Settlements and Cropland also saw cumulative increases of 3.8 and 1.7 kha, respectively, over the same period. Recalculations in land converted to Settlements were largely driven by lower rates of conversion than previously estimated for forestry roads and oil and gas sub-categories and upward recalculations in forest areas converted for hydro-reservoirs, hydroelectric infrastructure, mining and agriculture.

Upward recalculations were higher for the Boreal Shield East reporting zone than for the other reporting zones as a result of the impoundment of new hydro-reservoirs. Increased sampling also resulted in high recalculations in the Subhumid Prairies and Mixedwood Plains reporting zones. Downward recalculations occurred in the Boreal Plains reporting zone.

The increased sampling and adjusted volume-to-biomass factors led to annual downward recalculations ranging from -0.9 to -0.4 Mt for the 2005–2014 period. Recalculations for the years pre-2005 are below 8% and are inherent to the random selection of forest stands and updated values for volume-to-biomass conversion parameters in the CBM-CFS3 model (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 will be integrated into the forest conversion time series in five to eight years. Work has begun on compiling Landsat imagery over Canada for the next mapping period.

Chapter 7

WASTE (CRF SECTOR 5)

7.1. Overview

This sector includes emissions from the treatment and disposal of wastes. Sources and gases include methane (CH_4) from solid waste disposal (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.

When the waste treated or disposed of is derived from biomass, CO_2 emissions attributable to such wastes 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 inventory totals as part of the Waste Sector.

In 2015, the greenhouse gas (GHG) emissions from the Waste Sector contributed 25 Mt to total national emissions, compared to 24 Mt for 1990—an increase of 3.3% (Table 7–1). The emissions from this sector represented 3.9% and 3.4% of the overall Canadian GHG emissions in 1990 and 2015, respectively.

Emissions from the Solid Waste Disposal subsector, which consists of the combined emissions from municipal solid waste (MSW) landfills and wood waste landfills, accounted for 22 Mt or 90% of the emissions from this sector in 2015. The chief contributor to the Waste Sector emissions is the CH_4 released from MSW landfills, which for 2015 amounted to 19 Mt (0.74 Mt CH_4). This net emission value is determined by subtracting the amount of CH_4 captured from the total estimated CH_4 generated within the landfill, then adding any quantity of the captured CH_4 that was not combusted or flared. In 2012 and 2013, approximately 34% of the CH_4 generated in Canadian MSW landfills was captured and combusted (either for energy recovery or flared). Data for 2014 and 2015 are temporarily constant from 2013, until more recent information (collected in 2016) is incorporated.

Table 7–1 Waste Sector GHG Emission Summary, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)							
	1990	2005	2010	2011	2012	2013	2014	2015
Waste Sector	24	28	25	25	24	24	25	25
Solid Waste Disposal	22	25	22	22	22	22	22	22
Biological Treatment of Solid Waste	0.7	1	1	0.9	0.9	0.9	1	0.9
Wastewater Treatment and Discharge	0.87	1	1	1	1	1.1	1.1	1.1
Incineration and Open Burning of Waste	0.79	0.70	0.66	0.65	0.53	0.55	0.55	0.55

Note: Totals may not add up due to rounding.

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

	1990	2000	2005	2010	2011	2012	2013	2014
Waste Sector								
Current (2017) submission	26.0	28.7	30.6	29.0	28.8	28.4	28.4	28.5
Previous (2016) submission	23.9	25.8	27.6	24.8	24.8	24.3	24.4	24.6
Net change in emissions	-2.1	-3.0	-3.0	-4.2	-4.1	-4.1	-4.0	-4.0
Solid Waste Disposal								
Current (2017) submission	23.6	26.0	27.8	26.2	26.1	25.8	25.8	25.9
Previous (2016) submission	21.5	23.1	24.9	22.1	22.1	21.8	21.9	22.0
Net change in emissions	-2.1	-2.9	-2.9	-4.1	-4.0	-4.0	-3.9	-3.9
Biological Treatment of Solid Waste[2]								
Current (2017) submission	0.8	1.1	1.1	1.1	1.0	1.1	1.0	1.0
Previous (2016) submission	0.7	1.0	1.0	1.0	0.9	0.9	0.9	1.0
Net change in emissions	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Incineration and Open Burning of Waste								
Current (2017) submission	0.7	0.7	0.7	0.7	0.7	0.5	0.6	0.6
Previous (2016) submission	0.8	0.7	0.7	0.7	0.6	0.5	0.5	0.6
Net change in emissions	+0.1	+0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
Wastewater Treatment and Discharge								
Current (2017) submission	0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1
Previous (2016) submission	0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1
Net change in emissions	-0.0	-0.0	+0.0	+0.0	+0.0	+0.0	+0.0	-0.0

Notes:
1. Totals may not add up due to rounding.

The CH_4 generation rate from MSW landfills is directly dependent on the quantity and composition of landfilled waste, mitigated by landfill gas capture programs, provincial/municipal waste diversion projects and international exports of MSW. Nationally, in 2012, approximately 33 Mt of non hazardous waste (residential, institutional, commercial, industrial, construction and demolition) were generated. Waste diversion initiatives by municipal and provincial governments began in the early 1990s. In 2012, approximately 25% of the total waste generated was diverted from disposal (landfill or incineration) (Statistics Canada no date [a], no date [b]) compared to 21% in 2000. The percentage of diverted residential waste alone increased from 19% in 2000 to 33% in 2010. In contract, diversion of non-residential waste decreased from 22% to 19% over this period (Statistics Canada 2003, 2004, 2007a, 2008a, 2010a, 2013a).

The most significant estimation methodology changes were an upgrade to the waste model, including the incorporation of the 2006 IPCC Guidelines Tier 2 equations for first-order decay (Equations 3.1, 3.2 and 3.4 to 3.6 in Volume 5, Chapter 3). These updates resulted in recalculations of all estimates, particularly in MSW landfills (Table 7–2). A more detailed description of the recalculations due to new methods and activity data is provided in the recalculation section for each source in this chapter and in Chapter 8.

7.2. Solid Waste Disposal (CRF Category 5.A)

7.2.1. Source Category Description

Emissions are estimated from two types of landfills in Canada:

- municipal solid waste (MSW) landfills; and
- wood waste landfills.

In Canada, most waste disposal on land occurs in managed municipal or privately owned landfills. Very few, if any, unmanaged waste disposal sites exist.

Residential, institutional, commercial and industrial (ICI), and construction and demolition (C&D) wastes are disposed of in MSW landfills. Over the past 15 years, dedicated C&D landfills have been established. Typically, these landfills do not require CH_4 collection systems, as the CH_4 generation rate is very low because of the minimal organic content in the waste stream. However, for purposes of completeness of this emission source and accuracy of MSW landfill emissions estimates, the waste quantities now include C&D wastes.

Wood waste landfills are mostly privately owned and operated by forest industries, such as saw mills and pulp and paper mills. These industries use the 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 a 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 particle board. Wood waste landfills have been identified as a minor source of CH_4 emissions by comparison with MSW landfills.

7.2.2. Methodological Issues

The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) first-order decay methodology was used to estimate emissions from MSW and wood waste landfills and is implemented with a Scholl Canyon model. The model relates emissions to the cumulative biologically available waste landfilled over several years and has been validated independently through a study conducted by the University of Manitoba (Thompson et al. 2006).

Landfill gas, which is composed mainly of CH_4 and CO_2, is produced by the anaerobic decomposition of organic wastes. The decomposition process typically begins after waste has been in a landfill for 10 to 50 days. Although the majority of the CH_4 and CO_2 gases are generated within 20 years of landfilling, emissions can continue for 100 years or more (Levelton 1991).

A number of important site-specific factors contribute to the generation of gases within a landfill, including the following:

- Waste composition: Waste composition is probably the most important factor affecting landfill gas generation rates and quantities. The amount of landfill gas produced is dependent on the amount of organic matter landfilled, and the rate at which gas is generated is dependent on the distribution and type of organic matter in the landfill.
- Moisture content: Water is required for anaerobic degradation of organic matter; therefore, moisture content within a landfill significantly affects gas generation rates.
- Temperature: Anaerobic digestion is an exothermic process. The growth rates of bacteria tend to increase with temperature until an optimum is reached. Landfill temperatures may therefore be higher than ambient air temperatures. The extent to which ambient air temperatures influence the temperature of the landfill and gas generation rates depends mainly on the depth of the landfill. Temperature variations can affect microbial activity, subsequently affecting their ability to decompose matter (Maurice and Lagerkvist 2003).
- pH and buffer capacity: The generation of CH4 in landfills is greatest when neutral pH conditions exist. The activity of methanogenic bacteria is inhibited in acidic environments.

- Availability of nutrients: Certain nutrients are required for anaerobic digestion. These include carbon, hydrogen, nitrogen and phosphorus. In general, MSW contains the necessary nutrients to support the required bacterial populations.
- Waste density and particle size: The particle size and density of the waste also influences gas generation. Decreasing the particle size increases the surface area available for degradation and therefore increases the gas production rate. The waste density, which is largely controlled by compaction of the waste as it is placed in the landfill, affects the transport of moisture and nutrients through the landfill, which also affects the gas generation rate.

The Scholl Canyon model is used to estimate CH_4 generation from all landfills at a provincial level based on Volume 5 of the IPCC (2006). Canada assumes that no oxidation of methane takes place as it travels up through the landfills' final cover. This is due to the very large numbers and varying siting and design situations of abandoned, closed and active landfills that are accounted for by Canada from 1941 to the present. There are few historical documents on abandoned and older closed landfills. Therefore, in view of the uncertainty involved and the expected lack of natural or engineered final covers for most of the abandoned and older closed landfills, the oxidation factor was assumed to be zero.

7.2.2.1. CH_4 Generation

CH_4 emissions are determined by calculating the amount of CH_4 generated from landfill waste decomposition through the Scholl Canyon model, subtracting the CH_4 captured through landfill gas recovery systems, then adding the quantity of uncombusted CH_4 emitted by the flares for those locations where a portion or all of the recovered landfill gas is burned without energy recovery. The GHG emissions associated with the combustion of that portion of the landfill gas that is captured and utilized for energy generation purposes are accounted for in the Energy Sector.

The national CH_4 emission value is the summation of emissions from all regions. Detailed methodologies can be found in Annex 3.6.

Annual Waste Disposed

MSW Landfills

For the purposes of the inventory, MSW includes residential, ICI, and C&D wastes. Two primary sources were used in obtaining waste generation and landfill data for the GHG inventory (Table 7-3). The amounts of MSW landfilled from 1941 to 1990 were estimated by Levelton (1991). For the years 1998, 2000, 2002, 2004, 2006, 2008, and 2010, MSW disposal data were obtained from the *Waste Management Industry Survey* (WMIS) conducted by Statistics Canada on a biennial basis (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013a). In the absence of the formal publication of the WMIS, CANSIM Tables 153-0041 and 153-0043 (Statistics Canada no date [b], no date [c]) were used for 2012 disposal and diversion data, respectively. For the intervening years, the MSW disposal values were obtained by taking an average of the adjacent years. The amounts of waste disposed of from 2013 to 2015 were extrapolated by applying the Microsoft Excel Trend function to data from 2009 to 2012. Incinerated and exported waste quantities were subtracted from the disposal values in order to obtain the amounts of MSW landfilled for 1998–2015. For the years 1991–1997, with the exception of Prince Edward Island, the Northwest Territories, Nunavut and Yukon, the quantities of waste disposed of were estimated from an interpolation using a multiple linear regression approach applied to the Levelton (1991) and Statistics Canada (2000, 2003, 2004) MSW landfill values. MSW landfill values for Prince Edward Island, the Northwest Territories, Nunavut and Yukon for the period 1991–2015 were obtained by trending historical landfill data with the provincial populations for 1971–2015 (Statistics Canada 2006, 2015). Waste quantities imported into Canada are accounted for within the WMIS since the facilities

Table 7–3 Solid Waste Streams

Year	Waste Generated[1] (t)	Waste Diverted[2] (t)	Waste Disposed (t)	Waste Incinerated[3] (t)	Waste Exported[4] (t)	Waste Landfilled[5] (t)
1990	-	-	16 980 532	1 226 474	114 386	15 639 672
1991	-	-	17 822 265	1 172 762	114 386	16 535 116
1992	-	-	18 293 355	1 197 600	1 487 017	15 608 738
1993	-	-	18 788 510	1 135 575	1 487 017	16 165 919
1994	-	-	19 311 672	1 111 397	1 132 810	17 067 465
1995	-	-	19 860 524	1 083 862	1 150 660	17 626 002
1996	-	-	20 431 902	1 053 248	861 678	18 516 976
1997	-	-	21 022 594	1 019 842	836 611	19 166 142
1998	28 441 277	6 736 771	21 704 506	983 930	863 623	19 856 953
1999	-	-	22 436 688	887 995	891 347	20 657 347
2000	29 307 406	6 138 536	23 168 870	904 113	1 495 516	20 769 241
2001	-	-	23 625 121	904 545	1 851 119	20 869 456
2002	30 722 918	6 641 547	24 081 371	793 754	2 229 393	21 058 224
2003	-	-	24 654 069	810 286	3 097 743	20 746 039
2004	32 339 501	7 112 735	25 226 766	825 065	3 845 606	20 556 095
2005	-	-	25 821 889	833 386	3 958 265	21 030 238
2006	34 043 694	7 626 683	26 417 011	842 725	4 209 429	21 364 857
2007	-	-	26 171 744	846 121	4 773 475	20 552 148
2008	34 237 046	8 310 570	25 926 476	854 765	4 151 562	20 920 149
2009	-	-	25 439 446	865 497	3 632 711	20 941 238
2010	33 035 785	8 083 370	24 952 415	881 254	3 174 572	20 896 589
2011	-	-	24 816 945	896 843	3 689 930	20 230 171
2012	33 129 481	8 448 007	24 681 474	910 088	3 296 321	20 475 065
2013	-	-	24 892 254	920 268	3 394 204	20 577 783
2014	-	-	25 103 034	928 199	3 394 204	20 780 631
2015	-	-	24 778 359	935 191	3 394 204	20 448 964

Note:
1. Derived from addition of waste diverted and disposed.
2. Includes waste recycled and composted.
3. Data from Levelton (1991) and Environment Canada's Incineration Survey (1996, 2003a).
4. Data from Congressional Research Service (McCarthy 1993, 1995, 1996, 1997, 1998, 2000, 2001, 2004, 2007; McCarthy and Hardenbergh 2002; McCarthy et al. 1990), the Michigan Department of Environment (Michigan 1996-2011), and Environment Canada's Export Survey (2013a, 2014a).
5. Data for 1990 from Levelton (1991), otherwise derived from subtraction of waste incinerated and exported from waste disposed

report all wastes being disposed of on site, whether of domestic or international origin.

Wood Waste Landfills

British Columbia, Quebec, Alberta and Ontario together account for 93% of the wood waste landfilled in Canada (NRCan 1997). Data for wood waste generated and landfilled are presented in Table A3-3 of Annex 3.6.

CH_4 Generation Rate Constant (k)

The CH_4 kinetic rate constant (k) represents the first-order rate at which CH_4 is generated after waste has been landfilled. The value of k is affected by four major factors: moisture content, temperature, availability of nutrients and pH. It is assumed that in a typical MSW landfill the nutrient and pH conditions are not limiting It has been shown in Canadian field experiments that an insignificant amount of variation in landfill CH_4 production occurs between the winter and summer seasons (Bingemer and Crutzen 1987; Thompson and Tanapat 2005). Therefore, of all these factors, moisture content is the most influential parameter for Canadian landfills and is largely determined by the annual precipitation received at the landfills.

Annual provincial precipitation from ECCC's historical weather data were used to calculate k values for MSW landfills. A k value of 0.03/year was used for wood waste landfills (NCASI 2003). Detailed methodology and k values are presented in Annex 3.6.

7.2.2.2. Captured Landfill Gas

A portion of the landfill gas that is generated in MSW landfills is captured and combusted, either by flaring or by burning the gas for energy recovery. Gas capture does not occur at wood waste landfills. Data on MSW landfill gas capture was collected either from the Levelton report (1991) or from ongoing surveys of landfill facilities conducted by Environment Canada (1997, 1999a, 2001, 2003b, 2003c, 2007, 2009, 2011a, 2013b, 2014b). Data for 2014 and 2015 will be kept constant from 2013 until the most recent information collected by the 2016 survey is incorporated. Further details are available in Annex 3.6.

7.2.3. 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.

The estimates are calculated in a consistent manner over time.

7.2.4. QA/QC and Verification

The quality control process consisted of verifying that all activity data and methodological updates had been incorporated into the model. All links were valid and 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.

7.2.5. Recalculations

Emission estimations from MSW landfills were recalculated over the 1990–2014 time series to account for the following:

- Replacement of the first-order equation in the Scholl-Canyon model with the most recent IPCC default first-order decay (FOD) equation for municipal solid waste and wood waste emission estimates;
- Within the FOD method, adjustment of the k value to correspond with current year weather, as opposed to the year when the waste was deposited;
- Adjustment of provincial methane generation rates (k) for the years 2008-present due to updated precipitation data;
- Revision of the percentage of biogenic textile carbon and total carbon in municipal solid waste disposal from 65% to 60%;
- Adjustment of the fraction of degradable organic carbon (DOC) for the years 2008 to

present to account for recent changes in waste diversion initiatives.

These combined changes resulted in emission decreases in this subsector of -8.9% to -15.5% over the complete time series relative to the last submission.

7.2.6. Planned Improvements

Data for 2014 and 2015 will be kept constant from 2013 until the more recent information collected in 2016 is incorporated. Additionally, a third party review of Canada-specific DOC_f values will be conducted.

7.3. Biological Treatment of Solid Waste (CRF Category 5.B)

7.3.1. Source Category Description

This source category includes composting and anaerobic digestion at biogas facilities. Many municipalities in Canada utilize centralized composting and some are establishing centralized anaerobic digestion facilities to reduce the quantity of organics sent to landfill. GHG emissions from composting are affected by the moisture content and composition of the waste and the ability to maintain aerobic decomposition conditions. Over half of Canadian households (61%) participate in some form of composting. Of this proportion, 63% of those who composted yard waste and 60% of those who composted kitchen waste used curbside collection systems, whereas the remainder used a compost bin, pile or another composting method (Statistics Canada 2013b). As per the 2006 IPCC Guidelines, CO_2 emissions from biological treatment of solid waste are not included in inventory totals.

7.3.2. Methodological Issues

Statistics Canada produces composting data through its *Waste Management Industry Survey: Business and Government Sectors* (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013a, no date [b]) and its *Households and the Environment Survey* (Statistics Canada 2013b).

The *Waste Management Industry* Survey: *Business and Government Sectors* includes government-operated waste processing facilities and private companies involved in waste management and remediation services. However, some large private-sector industrial composting facilities who use composting feedstock other than MSW may have been excluded from the Statistics Canada data.

The *Households and the Environment Survey* provides percentages of households participating in centralized and backyard composting but not the quantity of organic waste used for backyard composting.

With the issues identified above, a Tier 1 method has been implemented using a default fraction of waste composted and disposed of based on IPCC 2006, Volume 5, Chapter 2, Table 2A.1. The quantity of waste composted was calculated as 19% of waste generated, whereas the waste generated was calculated from the default waste disposal fraction of 71% of waste generated.

Greenhouse gas emissions from anaerobic digestion related to the Waste Sector are currently not estimated. To our knowledge, emissions from anaerobic digestion in Canada are limited, although the number of anaerobic digesters under construction and in operation is growing, especially in farming operations and municipalities.

7.3.2.1. CH_4 Generation

Emissions of CH_4 from biological treatment of solid waste were estimated using a Tier 1 method using IPCC 2006 Volume 5, Chapter 4, Equation 4.1. A default CH_4 wet waste basis emission factor of 4 g CH_4/kg waste was used as per IPCC 2006 Volume 5, Chapter 4, Table 4.1. It was assumed that no CH_4 recovery was performed.

7.3.2.2. N_2O Generation

Emissions of N_2O from biological treatment of solid waste were estimated using a Tier 1 method using IPCC 2006 Volume 5, Chapter 4, Equation 4.2. A default CH_4 wet waste basis emission factor of 0.24 g N_2O/kg waste was used as per IPCC 2006 Volume 5, Chapter 4, Table 4.1.

7.3.3. 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 IPCC 2006 Volume 1, Chapter 3, Equation 3.3. Emission factor uncertainty is defined as the range of default values set out in IPCC 2006 Volume 5, Chapter 4, Table 4.1.

7.3.4. QA/QC and Verification

The quality control process consisted of verification in the model that all links were valid and that the cells addressed by those links were populated. The waste disposed data, from which the waste composted quantities were derived, were also subject to the QA/QC and verification process as outlined in section 7.2.4.

7.3.5. Recalculations

The emission factor for N_2O was revised from 0.3 kg N_2O /t waste to 0.24 kg N_2O/t waste to be consistent with the most recent value presented in the IPCC tier 1 guidelines. Along with the updates and corrections to activity data listed in section 7.2.5 of this chapter, these changes resulted in emission decreases between -7.3% to -10.9% over the complete time series relative to last year's submission.

7.3.6. Planned Improvements

Preliminary work has been conducted to collect composting activity data for commercial activities and estimations for residential composting activities. Further study is planned to confirm the commercial activity data and evaluate the validity and robustness of the estimation method for residential composting activities.

Further study is also planned with respect to obtaining activity data related to anaerobic digestion of solid waste in Canada.

7.4. Incineration and Open Burning of Waste (CRF Category 5.C)

7.4.1. Source Category Description

Emissions from the incineration of MSW, hazardous wastes, sewage sludge and clinical waste are included in the inventory. Some municipalities in Canada utilize incinerators to reduce the quantity of MSW sent to landfills and to reduce the amount of sewage sludge requiring land application.

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.

7.4.1.1. MSW Incineration

A combustion chamber of a typical mass-burn MSW incinerator is composed of a grate system on which waste is burned and is either water-walled (if the energy is recovered) or refractory-lined (if it is not). GHGs that are emitted from MSW incinerators include CO_2, CH_4 and N_2O.

As per 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.

According to the findings of a recent report commissioned by Environment Canada (CRA 2011), CH_4 emissions from Canadian MSW incinerators are considered insignificant. The study showed that CH_4 emissions calculated using the highest 2006 IPCC guidelines emission factor for MSW incineration (i.e. batch - fluidised bed), over the time period of 1990 – 2008, cumulatively yielded only approximately 93 kt CO_2 eq, or 0.03 percent (cumulatively) of the CH_4 emissions from MSW landfills.

7.4.1.2. Hazardous Waste Incineration

There are four hazardous waste incinerators in Canada located in Ontario and Alberta. Emissions of CO_2, N_2O and CH_4 are derived from the quantities of hazardous wastes incinerated that were provided directly by the facilities in a series of surveys conducted in 2006, 2008, 2010, 2012 and 2014 (Environment Canada 2014c). Data for 2014 and 2015 are temporarily constant from 2013, until the more recent information in the 2016 survey is incorporated.

7.4.1.3. Sewage Sludge Incineration

Two different types of sewage sludge incinerators are used in Canada: multiple hearth and fluidized bed. In both types of incinerators, the sewage sludge is partially de-watered prior to incineration. The de-watering is typically done in a centrifuge or using a filter press. Currently, municipalities in Ontario and Quebec operate sewage sludge incinerators. 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.

7.4.1.4. Clinical Waste Incineration

Three major centralized clinical waste incinerators in Canada—located in New Brunswick, Ontario and Alberta—accounted for 94.3% of the greenhouse gas emissions from this source in 2015. The remaining 5.7% 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 estimated from activity data provided directly by facilities in surveys from 2006, 2008, 2010 (Environment Canada 2010), 2012 (Environment Canada 2013b) and 2014 (Environment Canada 2014c); however, the waste quantities incinerated in 2014 and 2015 will be kept constant until the more recent information in the 2016 survey is incorporated.

As per 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 carbon waste, such as from plastics and rubber.

7.4.2. 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.

7.4.2.1. CO_2 Emissions

MSW Incineration

A Tier 1 method that uses Equation 5.2 (IPCC 2006) is employed to calculate CO_2 emissions from the incineration of fossil fuel-based waste (such as plastics and rubber). The three-step method was developed for MSW incineration:

- *Calculating the amount of waste incinerated:* The amount of waste incinerated each year was estimated based on a regression analysis using data from an Environment Canada (1996) study, which contains detailed provincial incineration data for the year 1992, and from a study performed by A.J. Chandler & Associates Ltd. for Environment Canada, which provides incineration data for 1999, 2000 and 2001 (Environment Canada 2003a).
- *Developing emission factors:* Provincial CO_2 emission factors are founded on the assumption that the carbon contained in waste undergoes complete oxidation to CO2. The amount of fossil fuel-based carbon available in the waste incinerated has been determined using typical percent weight carbon content values (Tchobanoglous et al. 1993). The amount of carbon per tonne of waste is estimated and converted to tonnes of CO_2 per tonne of waste by multiplying by the ratio of the molecular mass of CO_2 to that of carbon.
- *Calculating CO_2 emissions:* Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factor.

Hazardous Waste Incineration

CO_2 emissions were estimated from the quantities of hazardous wastes combusted over the 1990–2015 time series; however, the 2014 and 2015 waste quantities incinerated were kept constant from 2013, since the 2016 waste incineration survey results were not completed in time for the 2017 submission. 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 (Table 5.6, IPCC 2000).

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.

Clinical Waste Incineration

CO_2 emissions were estimated from the quantities of clinical waste combusted over the 1990–2015 time series; however, the 2014 and 2015 waste quantities incinerated were assumed constant from 2013, since the 2016 waste incineration survey results were not completed in time for the 2017 submission. 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 Volume 5 Chapter 5 Table 5.2).

7.4.2.2. N_2O and CH_4 Emissions

MSW Incineration

Emissions of N_2O from MSW incineration were estimated using the Tier 1 method (IPCC/OECD/IEA 1997). An average emission factor was calculated assuming that the IPCC five-stoker facility factors were most representative. To estimate emissions, the calculated emission factor was multiplied by the amount of waste incinerated by each province. CH_4 emissions from Canadian MSW incinerators are considered insignificant (CRA 2011). The

study showed that CH_4 emissions calculated using the highest 2006 IPCC guidelines emission factor for MSW incineration (i.e. batch - fluidised bed), over the time period of 1990 – 2008, cumulatively yielded only approximately 93 kt CO_2e, or 0.03 percent (cumulatively) of the CH_4 emissions from MSW landfills.

Hazardous Waste Incineration

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 2011b). The resulting emission factors were 3.16 x 10^{-3} kt N_2O/kt waste and 1.69 x 10^{-4} kt CH_4/kt of waste.

Sewage Sludge Incineration

Emissions generated by the incineration of sewage sludge are dependent on the amount of dried solids incinerated. Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994, as related in a personal communication with W. Fettes in February of 1994. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge. Data for the years 1997 and 1998 were obtained from a study prepared for Environment Canada (Environment Canada 1999b). Activity data for 1999, 2000 and 2001 were taken from another study conducted for Environment Canada (Environment Canada 2003a). To estimate the amount of sewage sludge incinerated in the years 2002–2015, a regression analysis was completed using the incineration values in the most recent study report.

CH_4 emissions are estimated based on emission factors obtained from the U.S. EPA publication *Compilation of Air Pollutant Emission Factors* (U.S. EPA 1995). 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, 0.8 kg N_2O/t of dried sewage sludge incinerated (IPCC 2000). 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.

Clinical Waste Incineration

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.

The default CH_4 emission factors from IPCC 2006, Volume 5, Chapter 5, Table 5.3, for stoker-type continuous and batch-type incineration of 0.2 kg/Gg waste and 60 kg/Gg waste, respectively, were

applied to individual incinerators as appropriate. Similarly, the default N_2O emission factors from IPCC 2006, Volume 5, Chapter 5, Table 5.6, for stoker-type continuous and batch-type incineration of 50 g N_2O/t waste and 60 g N_2O/t waste, respectively, were applied.

7.4.3. Uncertainties and Time-Series Consistency

The overall level 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 wastes (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 2015 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 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 as per IPCC 2006 Volume 1, Chapter 3, Equation 3.3.

7.4.4. 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.

7.4.5. Recalculations

- Error corrections resulting from QC.
- Additional improvements are provided in section 7.2.5.

The overall result of these changes ranged from a decrease of -1.0% to an increase of 8.1% in emissions from this subsector relative to the last submission.

7.4.6. Planned Improvements

The results of the next biennial incineration survey (2016) are planned to be incorporated in the 2018 submission. Facility-level incineration surveys had been conducted in 2008, 2010, 2012 and 2014.

Canada is planning to use the updated methodology and emission factors from the 2006 IPCC Guidelines for estimating CH_4 and N_2O emissions from this category (Table 5.3 in Volume 5, Section 5.4.2 and Table 5.4 in Volume 5, Section 5.4.3, respectively).

7.5. Wastewater Treatment and Discharge (CRF Category 5.D)

7.5.1. Source Category Description

In Canada, both municipal and industrial wastewater can be aerobically or anaerobically treated. Anaerobically treated wastewater produces CH_4, which is typically contained and combusted via anaerobic digestion systems. CH_4 emissions from aerobic systems are assumed to be negligible. Both types of treatment system generate N_2O through the nitrification and denitrification of sewage nitrogen.

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.

The emission estimation methodology for municipal wastewater handling is divided into two areas: CH_4 from anaerobic wastewater treatment and N_2O from human sewage.

7.5.2. Methodological Issues

Annex 3.6 provides additional information on the methodologies used for various categories covered by this subsector.

7.5.2.1. CH_4 Emissions

Municipal Wastewater Treatment

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 (AECOM Canada 2011). An estimated 1.97 kg CH_4/person per year is potentially emitted from anaerobically treated wastewater.

A maximum methane producing capacity B_o value was calculated based on the mass of methane produced per mass of COD degraded or COD_b (the COD that can be biologically degraded) as opposed to the COD_{total}:

$$B_o = 0.25\ g\ CH_4/g\ COD_b \times 1.47\ g\ COD_b/g\ BOD_5$$
$$= 0.36\ kg\ CH_4/kg\ BOD_5\ degraded$$

The typical range for BOD_5 is between 70% and 80% of the BOD_U (i.e.BOD ultimate), where the generally accepted standard in the industry is 68% of the BOD_U, which is converted to a typical ratio of BOD_U/BOD_5 (or COD_b/BOD_5) of 1.47:1.

This B_o value is lower than the default value of 0.6 kg CH_4/kg BOD (IPCC 2006 Volume 5, Section 6.2.2.2. Table 6.2) because the default value was calculated with the COD_{total} in the two terms of the equation above.

CH_4 emissions were calculated by multiplying the emission factor by the population of the respective province (Statistics Canada 2006, 2015, 2016) and by the fraction of wastewater that is treated anaerobically. Additional information on the methodology is provided in Annex 3.6.

Industrial Wastewater Treatment

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 last survey covered the 1990–2013 time series. Values for 2014 and 2015 were set at the latest (2013) available values; these values will be updated when the data from the 2016 survey are incorporated. 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.

7.5.2.2. N_2O Emissions

Municipal Wastewater Treatment

An N_2O emission factor is calculated as the product of the annual per capita protein consumption, the assumed protein nitrogen content (16%), the quantity of N_2O-N produced per unit of sewage nitrogen (0.01 kg N_2O-N/kg sewage nitrogen) and the N_2O/N_2O-N conversion factor (1.57).

Protein consumption estimates, in kg/person per year, were obtained from an annual Food Statistics report published by Statistics Canada (2007b, 2008b, 2010b). The protein consumption values used are those adjusted to account for retail, household, cooking and plate loss (AECOM Canada 2012).

Data are provided for the years 1991, 1996 and 2001 to 2009. Protein consumption data for intervening years are estimated by applying a linear regression to the Statistics Canada data. The Food Statistics publication was discontinued; therefore protein consumption values for 2010–2015 were extrapolated using a growth function. Emissions were calculated by multiplying the emission factor by the population of each province (Statistics Canada 2006, 2015, 2016). A summary of the values for these two parameters over the time series is given in Table 7–4.

Table 7–4 N_2O Emission Factors

Year	Annual Per Capita Protein Consumption (kg protein/person per year)	N_2O Emission Factor (kg N_2O/ person per year)
1990	23.82	0.060
1991	24.16	0.061
1992	24.29	0.061
1993	24.53	0.062
1994	24.77	0.062
1995[a]	25.01	0.063
1996[a]	25.04	0.063
1997[a]	25.50	0.064
1998[a]	25.75	0.065
1999[a]	26.01	0.065
2000[a]	26.26	0.066
2001[b]	26.63	0.067
2002[b]	26.57	0.067
2003[b]	26.19	0.066
2004[b]	26.35	0.066
2005[c]	25.96	0.065
2006[c]	25.93	0.065
2007[c]	26.20	0.066
2008[c]	25.64	0.064
2009[c]	25.50	0.064
2010[c]	25.47	0.064
2011[c]	25.34	0.064
2012[c]	25.22	0.063
2013[c]	25.09	0.063
2014[c]	24.97	0.063
2015[c]	24.85	0.062

Sources: [a]Statistics Canada (2007b), [b]Statistics Canada (2008b) and [c]Statistics Canada (2010b). The data have been adjusted to account for retail, household, cooking and plate loss.

7.5.3. Uncertainties and Time-Series Consistency

Municipal Wastewater Treatment

The overall level uncertainty associated with the wastewater treatment and discharge subsector was estimated to be in the range of -40% to +55% (ICF Consulting 2004). Based on 2001 data, the trend uncertainty associated with the total GHG emissions (comprising CH_4 and N_2O) from the wastewater treatment systems was estimated to be in the range of about +12% to +13%. The extrapolation of trend uncertainty in 2001 to the 2015inventory 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.

Since the methods and data sources have remained unchanged over the time series, the estimates for this category are consistent over time.

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 (data obtained from the latest industrial wastewater survey), 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.

7.5.5. Recalculations

Error corrections resulting from quality control and the incorporation of updated activity data for 2014 and 2015 resulted in changes that ranged from a 4.0% increase to a -0.39% decrease in emissions over the time series.

7.5.6. Planned Improvements

There are no planned improvements prioritized for the coming year.

Chapter 8

RECALCULATIONS AND IMPROVEMENTS

Canada's greenhouse gas (GHG) inventory undergoes a continuous process of updates, revisions and improvements in order to ensure that the most complete, consistent, comparable, accurate and transparent information possible is reported. Section 8.1 of this chapter provides an overview of the recalculations performed in this year's GHG inventory, including analysis by sector and by gas, in order 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

It is good inventory preparation practice for Annex I Parties to continually improve their national GHG inventories. Environment & Climate Change Canada consults and works closely with key federal and provincial 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 in the compilation of 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 (although this will only affect sub-totals);
iv) Refinements of methodologies and emission factors;
v) Inclusion of categories previously not estimated (which improves inventory completeness); and
vi) Recommendations from UNFCCC reviews.

8.1.1. Estimated Impacts on Emission Levels and Trends

In this year's GHG inventory, total emissions were revised for most years as shown in Figure 8–1. Recalculations occurred this year primarily due to updates in emission factors for coal, and implementation of an improved model and updated parameters for estimating emission for landfilled waste. In addition, there were updates in energy statistics provided by Statistics Canada, reallocations of emissions in Transport (from off-road to on-road) and other minor incremental enhancements. These improvements resulted in a downward revision of 5.3 Mt for 2014 in comparison to last year's NIR. The trend between 1990 and 2014

Figure 8–1 Comparison of Emission Trends (2016 NIR vs 2017 NIR)

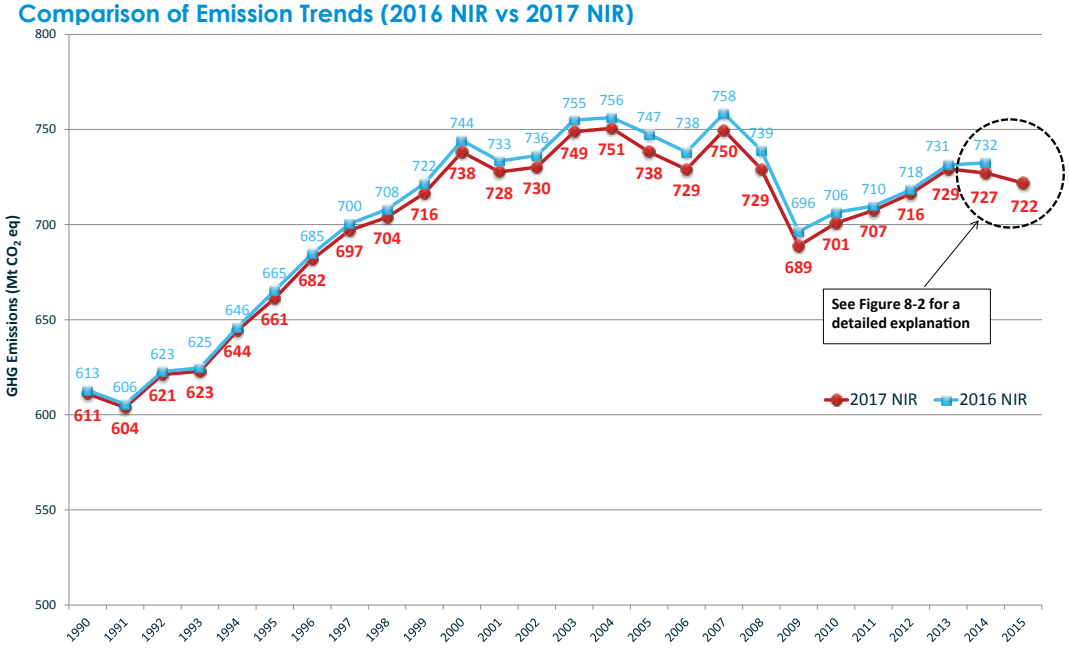
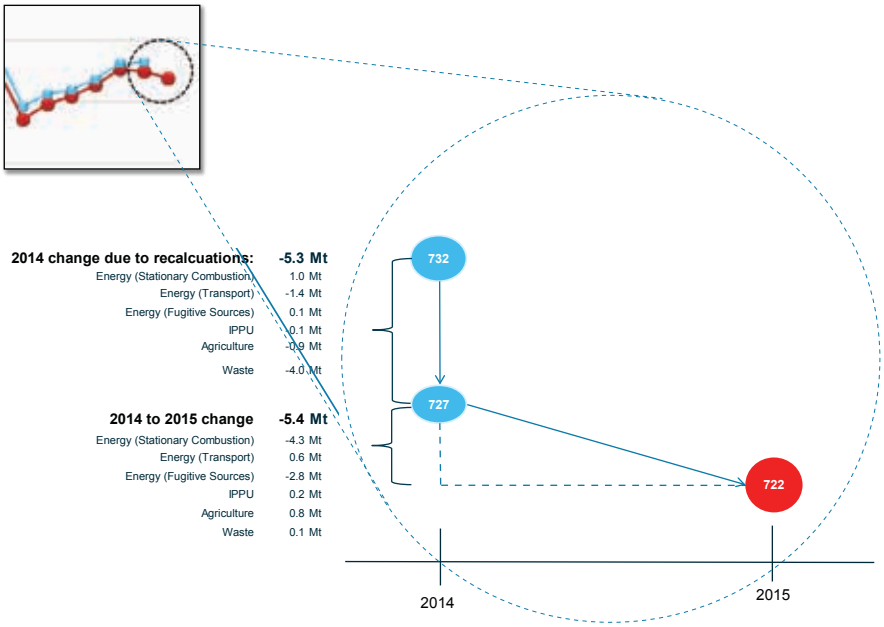


Table 8–1 Summary of Recalculations in the 2017 National Inventory (excluding LULUCF)

NATIONAL TOTAL	Annual Emissions (kt CO_2 eq)								Trend	
	1990	2000	2005	2010	2011	2012	2013	2014	(1990-2014)	(2005-2014)
Previous Submission (2016 NIR)	612 866	744 241	747 458	706 403	709 764	718 347	731 424	732 433	19.5%	-2.0%
Current Submission (2017 NIR)	610 993	738 178	738 253	700 828	707 435	716 273	729 196	727 146	19.0%	-1.5%
Change in Emissions:	- 1 873	- 6 063	- 9 205	- 5 575	- 2 329	- 2 073	- 2 228	- 5 287	-	-
Total Change: %	**-0.31%**	**-0.81%**	**-1.23%**	**-0.79%**	**-0.33%**	**-0.29%**	**-0.30%**	**-0.72%**	-	-

Figure 8–2 Explanation of changes in emissions: From 2014 values (previous submission) to 2015 values (current submission)



is now reported as a 19.0% increase in total GHG emissions since 1990 instead of the previously reported 19.5% increase. The trend between 1990 and 2015 shows a 18.1% increase in GHG emissions.

The most significant recalculations occurred in 2005 and 2008 and resulted in revised national totals that were 9.2 Mt (1.2%) and 9.9 Mt (1.3%) lower than what was reported in the 2016 NIR (738 Mt and 729 Mt vs. 747 Mt and 739 Mt) (Table 8–1 and Figure 8–2).

8.1.2. Recalculations by Sector

As previously noted, good inventory preparation practice requires that methodological improvements and updates be applied to the entire time series of annual estimates (i.e. from 1990 to the most recent year reported). A consistent time series is required to avoid 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 IPCC sectors (Energy, Industrial Processes and Product Use (IPPU), Agriculture, LULUCF and Waste) and Energy subsectors (Stationary Combustion, Transport and Fugitive Sources), as well as for all years in the time series (1990-2014).

Overall, there are net downward recalculations of 9.2 Mt for the year 2005 and 5.3 Mt for the year 2014 (Table 8–2). These revisions are largely due to improved estimation methodologies, notably model upgrades in the waste sector and improved characterization of coal used for combustion in electricity generation. The year 2005 was also subject to revised underlying data from StatCan which resulted in additional downward recalculations compared to 2014.

Important recalculations also occurred in emissions and removals from the Land Use, Land-use Change and Forestry (LULUCF) Sector. These recalculations were mainly due to the implementation of a new approach to exclude emissions and removals from natural disturbances in managed forests (wildfires and insects) to more clearly identify trends associated with anthropogenic activities in the forest sector. In addition, volume-to-biomass conversion parameters were updated, corrections were made to model algorithms in the handling of yield tables and there were improvements to activity data through the introduction of a new British Columbia forest inventory and yield tables. The cumulative impact of these recalculations on LULUCF estimates resulted in a decrease of 12 Mt in the calculated sink for 1990, a decrease of 37 Mt in 2005 (from a source to a sink) and a change of 105 Mt in 2014 (from a source to a sink). These recalculations have largely corrected the erratic emission pattern due to natural disturbances in managed forests.

The details of the sector specific recalculations can be found in Chapters 3-7.

8.2. Inventory Improvements

Canada's inventory arrangements for the estimation of emissions incorporate all of the elements needed to estimate, report, archive and improve Canada's GHG estimates, including the institutional, legal and procedural arrangements. Having these arrangements in place ensures that Canada can produce a high quality inventory on an annual basis. However, continuous improvement remains an important principle throughout the development of Canada's inventory.

Inventory improvements can improve the accuracy of GHG estimates or enhance components of the inventory arrangements. Improvements that

Table 8–2 Summary of Recalculations by Category

		Annual Emissions (kt CO_2 eq)								Trend	
		1990	2000	2005	2010	2011	2012	2013	2014	(1990-2014)	(2005-2014)
ENERGY (Stationary Combustion)											
Previous Submission (2016 NIR)		285 360	352 129	341 872	316 852	319 584	320 844	327 908	331 237	16.1%	-3.1%
Current Submission (2017 NIR)		285 580	350 583	339 443	317 627	320 032	321 519	328 519	332 238	16.3%	-2.1%
Change in Emissions:	kt CO_2 eq	- 220	1 546	2 429	- 775	- 448	- 675	- 611	- 1 001	-	-
	%	-0.1%	0.4%	0.7%	-0.2%	-0.1%	-0.2%	-0.2%	-0.3%	-	-
ENERGY (Transportation)											
Previous Submission (2016 NIR)		147 788	181 487	194 522	198 895	198 572	198 164	203 602	202 996	37.4%	4.4%
Current Submission (2017 NIR)		148 324	181 752	195 086	199 348	199 855	199 657	204 289	201 592	35.9%	3.3%
Change in Emissions:	kt CO_2 eq	537	266	563	453	1 283	1 493	687	- 1 404	-	-
	%	0.4%	0.1%	0.3%	0.2%	0.6%	0.8%	0.3%	-0.7%	-	-
ENERGY (Fugitive)											
Previous Submission (2016 NIR)		48 803	69 851	60 848	54 399	55 385	57 264	58 436	59 584	22.1%	-2.1%
Current Submission (2017 NIR)		48 803	69 851	60 849	54 400	55 392	57 142	58 894	59 675	22.3%	-1.9%
Change in Emissions:	kt CO_2 eq				1	7	- 122	458	92	-	-
	%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.8%	0.2%	-	-
IPPU											
Previous Submission (2016 NIR)		55 880	53 524	58 262	50 482	51 431	55 753	52 676	51 004	-8.7%	-12.5%
Current Submission (2017 NIR)		55 875	52 261	54 396	48 475	52 115	56 487	53 501	50 901	-8.9%	-6.4%
Change in Emissions:	kt CO_2 eq	- 4	- 1 263	- 3 866	- 2 007	684	734	825	- 103	-	-
	%	0.0%	-2.4%	-6.6%	-4.0%	1.3%	1.3%	1.6%	-0.2%	-	-
AGRICULTURE											
Previous Submission (2016 NIR)		49 008	58 503	61 396	56 805	55 950	57 934	60 371	59 096	20.6%	-3.7%
Current Submission (2017 NIR)		48 517	57 956	60 903	56 193	55 298	57 191	59 606	58 193	19.9%	-4.5%
Change in Emissions:	kt CO_2 eq	- 491	- 547	- 493	- 612	- 652	- 744	- 765	- 903	-	-
	%	-1.0%	-0.9%	-0.8%	-1.1%	-1.2%	-1.3%	-1.3%	-1.5%	-	-
WASTE											
Previous Submission (2016 NIR)		26 028	28 747	30 557	28 970	28 843	28 388	28 431	28 517	9.6%	-6.7%
Current Submission (2017 NIR)		23 901	25 783	27 586	24 795	24 753	24 288	24 397	24 558	2.7%	-11.0%
Change in Emissions:	kt CO_2 eq	- 2 127	- 2 964	- 2 971	- 4 175	- 4 091	- 4 101	- 4 034	- 3 960	-	-
	%	-8.2%	-10.3%	-9.7%	-14.4%	-14.2%	-14.4%	-14.2%	-13.9%	-	-
LULUCF											
Previous Submission (2016 NIR)		- 87 189	- 81 616	507	54 633	69 420	40 702	- 29 632	71 793		
Current Submission (2017 NIR)		- 99 275	- 62 412	- 36 723	- 28 186	- 26 051	- 29 519	- 29 398	- 32 926		
Change in Emissions:	kt CO_2 eq	- 12 086	19 204	- 37 230	- 82 818	- 95 471	- 70 221	234	- 104 719	-	-
	%	13.9%	-23.5%	-7340.3%	-151.6%	-137.5%	-172.5%	-0.8%	-145.9%	-	-

involve a methodological change or refinement are reviewed and agreed to by the Prioritization and Planning Committee (P&PC) within PIRD prior to implementation. Any improvements that lead to recalculations of estimates must be applied to all estimation years in order to maintain time series consistency.

This year, improvements to Canada's inventory resulted from either 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.

8.2.1. ERT Recommendations

Canada's inventory submission is reviewed annually by an expert review team (ERT) following agreed-upon UNFCCC review guidelines[1] as adopted in Decision 13/CP.20 at COP 20 in Lima in 2014. Reviews are coordinated by the UNFCCC Secretariat, and the ERT is composed of inventory experts from developed and developing countries. The purpose of the review is to provide

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

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.

Inventory reviews can be conducted either as a desk review, centralized review or an in-country review. The review of Canada's 2015 inventory took place as a centralized review and within the 2015 ARR,[2] the ERT recommended a variety of ways Canada could enhance and improve its GHG inventory. These recommendations were taken into consideration when identifying potential improvements for this year.

The 2016 ARR was not finalized until after the development of the inventory and preparation of this NIR. While attempts were made to implement some of the anticipated recommendations, the bulk of the recommendations arising from last year's review will be considered for the 2018 submission.

8.2.2. 2006 IPCC Guidelines

The 2006 IPCC Guidelines contain internationally agreed methodologies for use by countries to estimate greenhouse gas emissions and to report to the UNFCCC (IPCC 2006). These guidelines were developed by the IPCC at the invitation of the UNFCCC. They replace the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 1997), the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000), and the Good Practice Guidance for Land Use, Land-use Change and Forestry (IPCC 2003), which were previously used to produce GHG inventories.

Compared to the other IPCC Inventory Guidelines and Good Practice Guidance, the 2006 IPCC Guidelines allow for more complex modelling approaches and provide refined methodologies for estimating emissions, particularly at higher tiers. They also include new reporting requirements (e.g. Harvested Wood Products, CH_4 emissions from underground abandoned mines), improved default emission factors and parameters (e.g. updated oxidation factors), and changes to reported source/sink categories.

Starting in 2015, Canada and other Annex I Parties began reporting their national GHG inventories 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, which required use of the 2006 IPCC Guidelines. Many methodological changes were required, and not all could be completed that year. Therefore, this submission reflects continued improvement to ensure consistency with the 2006 IPCC Guidelines.

8.2.3. Continuous Improvements

The GHG inventory team is also encouraged to use its knowledge and experience in developing inventory estimates to propose ways to improve future inventories. Improvements are identified based on evolving science, QA/QC and verification activities (as outlined in the QA/QC Plan), new and innovative modelling approaches or newly discovered sources of activity data. Implementation of the improvements is prioritized by

2 Canada's 2015 ARR report entitled *Canada. Report of the individual review of the inventory submission of Canada submitted in 2015* is available on the UNFCCC website at http://unfccc.int/documentation/documents/advanced_search/items/6911.php?priref=600008912#beg

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 implementation of an equipment based model for off-road transportation emissions, improved representation of indirect N_2O emissions from Ammonia volatilization through modelling (rather than a tier 1 approach) and adjustments to provincial methane generation rates for the years 2008-present with updated precipitation data.

Table 8–3 provides additional information and justification regarding the improvements implemented this year.

Table 8–3 Improvements to Canada's 2017 NIR

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Energy	Energy, Fuel Combustion (1.A) - Solid Fuel - Coal	Revised carbon dioxide emission factors	Revised country specific emission factors for Canadian bituminous, lignite and sub-bituminouse coals developed based on industry data.	Continuous inventory improvement	Annex 6 and Chapter 3
	Energy, Fuel Combustion (1.A) - Solid Fuel - Coal	Country specific oxidation factors	Applied country specific (C.S.) oxidation factos to all combusted coals based on assessments of industry data. New emission factors (above) contain these C.S. oxidation factors.	ERT recommendation	Annex 6 and Chapter 3
	Energy, Residential (1.A.4.b) - Biomass	Expanded activity data estimates to include firewood consumption in the territories.	Added National Forestry Database estimates of firewood consumption for the territories.	Continuous inventory improvement	Chapter 3
	Road Transportation (CRF 1.A.3.b)	Migration from MGEM to MOVES	The MGEM model was replaced by the peer-reviewed MOVES model, thereby comprehensively harmonizing activity data (energy allocation, vehicle kilometres traveled and vehicle populations) for Environment and Climate Change Canada's GHG and air pollutant emissions from on-road transportation sources.	Continuous inventory improvement	A3.1.4.2.1
	Road Transportation (CRF 1.A.3.e.ii Other (Off-road)	Improved, bottom-up methodology for off-road GHGs	The method of using residual fuel allocations (from on-road transportation) was replaced by the peer-reviewed NONROAD model, thereby comprehensively harmonizing activity data (fuel/energy allocation, hours of use and engine populations) for Environment and Climate Change Canada's GHG and air pollutant emissions from off-road transportation sources. A secondary benefit improved allocation of emissions to economic sectors and more detailed reporting in the CRF.	Continuous inventory improvement	A3.1.4.2.1
IPPU	Product Uses as Substitutes for Ozone Depleting Substances - HFCs (CRF 2.F)	Updated activity data and emission factors.	Activity data were updated for HFC bulk sales and imports for 2013 to 2015 for all subcategories. Country specific emissions factors derived from the 2012 survey for refrigeration and air conditioning were applied to entire time series. In addition, the fire protection emission factor values are now based on IPCC 2006 guidelines.	Continuous inventory improvement / Implementation of the 2006 IPCC Guidelines	Section 4.15
Agriculture	Enteric Fermentation/ Manure Management/ Agricultural Soils (CRF 3.A/3.B/3.D)	Revised wild boar population numbers prior to 2001	Wild boar population estimates from the 1991 and 1996 census of agriculture were incorporated. Previously, wild boar populations prior to 2001 were extrapolated to 0.	ERT Recommendation	Annex 3.4
	Liming (CRF 3.G)	Revision of data on lime application	Agricultural use of lime for 2013 and 2014 was updated.	ERT Recommendation	Section 5.6.5
	Enteric Fermentation/ Manure Management/ Agricultural Soils/ Residue Burning (CRF 3.A/3.B/3.D/3.F)	Update of livestock distribution, crop areas and tillage practices for alignment of EO data with the Census of Agriculture.	Small changes in the spatial distribution of crops and livestock were made because of corrections to the alignment of EO based data with that of the Census of Agriculture.	Continuous inventory improvement	Section 5.4
	Agricultural Soils (3.D)	Change in the method for estimating ammonia emissions from synthetic N fertilizers	Canada uses a tier 3 method for estimating ammonia emissions from synthetic N application on agricultural soils, instead of the default IPCC method.	Continuous inventory improvement	Section 5.4.2.1

Table A8-3 Improvements to Canada's 2017 NIR (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
LULUCF	General: land transition matrix	Land transition matrix was revised by including annual values of land-use changes where applicable	Non-diagonal cells in the land transition matrix are now filled out with annual data, i.e. annual area converted.	ERT recommendation	Section 6.2
	Forest Land (CRF 4.A)	Improved estimation of anthropogenic emissions and removals in Forest Land	An improved approach to estimate anthropogenic emissions and removals in managed forests was implemented	Continuous inventory improvement	Section 6.3.1
	Wetlands, peat extraction (CRF 4.D.1.1, 4.D.2.1)	Implementation of a new approach to estimate emissions from peat extraction	A new approach to estimate emissions from peatland conversion for peat extraction was implemented. This approach incorporates guidance from the 2014 IPCC Wetlands Supplement, domestic emission factors and activity data from mapping.	Continuous inventory improvement	Section 6.7.1
	Land Converted to Settlements (CRF category 4.E.2)	Areas of Cropland converted to Settlements have been estimated using available land-use maps of the agricultural region.	Areas of Cropland converted to Settlements have been included in CRF Table 4.1 (Land Transition Matrix) and 4E.2.2. by reporting zone	ERT recommendation	Section 6.8.2.2
	Settlements remaining Settlements (CRF category 4.E.1)	Emission estimates were updated based on more precise activity data for 1990	Areas of tree crown cover density were updated based on new data available for 1990	Continuous inventory improvement	Section 6.8.1
	Harvested Wood Products (CRF 4.G)	Improved uncertainty estimates by considering the uncertainty of carbon input resulting from CBM-CFS3.	This year's uncertainty analysis includes two additional runs using minimum and maximum HWP inputs resulting from CBM-CFS3 (ecosystem) uncertainty analyses.	Continuous inventory improvement	Section 6.4.3
	Harvested Wood Products (CRF 4.G)	Improved activity data and parameters related to residential firewood.	Updated provincial/territorial firewood proportions from Forest Land, emission and appliance breakdown factors.	Continuous inventory improvement / Implementation of the 2006 IPCC Guidelines	Section 6.4.4
Waste	Waste (CRF - 5)	Additional details provided on the MSW waste streams.	A detailed summary table of waste streams, including the information provided to the ERT during the 2014 review process (i.e. amounts of waste generated, waste disposal (landfill and incineration) and waste diversion (recycling and composting)), was added to the NIR.	ERT Recommendation	Section 7.2.2.1
	Solid Waste Disposal (CRF - 5.A)	Updated to the the SWD landfill model	The equation in the Solid Waste Disposal landfil model was updated to the 2006 IPCC Guidelines' version of the First Order Decay (FOD) method, for all provinces and territories.	Implementation of the 2006 IPCC Guidelines	Section A3.6.1.1
	Solid Waste Disposal (CRF - 5.A)	Adjustment of the fraction of degradable organic carbon (DOC) for the years 2008 - 2015.	A multi-year study on waste composition and associated degradable organic carbon (DOC) values was conducted and the DOC values were updated. The updated DOC values are now reflective of current waste management practices.	ERT Recommendation	Section A3.6.1.1
	Solid Waste Disposal (CRF - 5.A)	Revision of methane rate decay constants (k) for 1990 to 2007 and derviation of new constants for 2008 to 2015	Provincial and territorial methane rate decay constants (k) have been revised for past years and new k values were derived for the time period 2008 to 2015 in order to concur with DOC values for the same period.	Continuous inventory improvement	Section A3.6.1.1
	Solid Waste Disposal on Land - CH_4 (CRF - 5.A.2)	Wood waste landfill emissions allocated to unmanaged landfills (CRF 5.A.2).	Emissions were previously accounted for under uncategorized landfills (CRF 5.A.3). Upon review it was determined that emissions are more appropriately allocated under unmanaged landfills.	ERT Recommendation	Section A3.6.1.1

Table A8-3 Improvements to Canada's 2017 NIR (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement	Section in NIR for more details
Waste (cont'd)	Biological Treatment of Solid Waste (CRF - 5.B)	Updated N_2O emission factor to align with 2006 IPCC Guidelines.	The IPCC has provided corrected values for N_2O emission factors for wet weight. The emission factor was implemented in accordance with 2006 IPCC Guidelines.	ERT Recommendation	Section 7.3.2.2
	Wastewater Treatment and Discharge (CRF - 5.D)	Updated industrial wastewater treatment activity data.	The in-house biennial industrial wastewater treatment survey was conducted during the summer of 2016. The activity data collected was implemented for 2014 and 2015 and replaced the previously held constant values (2013).	Continuous inventory improvement	Sections A3.6.2 and A3.6.3

8.3. Planned Inventory Improvements

Canada has identified planned improvements in Table 8–4 that, when implemented, will impact the inventory time series from 1990 onwards. The planned improvements are based on recommendations from both internal sources and external review processes and on collaborative work between inventory sector experts and industry, other government departments, and academia.

Canada's planned improvement activities are contained in an *Inventory Improvement Plan* that 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, documentation and archiving processes, uncertainty and key categories).

Potential improvement activities are identified by sector experts and 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.

As many improvements will stretch over multiple years, regular status updates are provided in the *Inventory Improvement Plan* and ERTs can assess progress towards implementation of the improvements and planned improvements during annual reviews.

Table 8–4 Summary of Canada's Inventory Improvement Plan

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Energy	General	Reallocation of waste incineration with energy recovery emissions to the Energy Industries category	A waste incineration survey is underway for recent historical years. The incorporation of the resulting data, as well as data from previous surveys, and the subsequent reallocation of the relevant estimated emissions to the Energy Sector, will be reviewed by the Party for completeness and accuracy before incorporation in its future annual submissions.	ERT recommendation	Data analysis underway
	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.	ERT ecommendation	Data analysis underway
	Oil and Natural Gas - Fugitive (1.B.2)	Updating GHG Emissions from Oil Sands Mining and Upgrading	A study is underway to update the GHG and air pollutant emission estimates from the oil sands mining and upgrading industry in Canada. This study will provide new fugitive emission estimates which will be incorporated into the National Inventory.	Continuous Improvement / ERT recommendation	Initiated data collection / study
	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 emissons. 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 emission factors 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
	Road Transportation (CRF 1.A.3.e.ii Other (Off-road))	Update current bottom-up NONROAD equipment populations, hours of use and emission factors.	The project will update EFs for NONROAD based on a literature review and lab test data. Activity based review (hours of use and provincial distribution) of equipment is also planned.	Continuous Improvement	Data analysis underway
	Road Transportation (CRF 1.A.3.b)	Review of carbon content of diesel and update as needed	Review the carbon content of motor gasoline and diesel to determine if they are still applicable.	ERT Recommendation	Initiated data collection / study
	Transport CRF Category 1.A.3)	Update GCVs, to improve transparency in reporting in the CRF (note: does not impact emissions)	Review of GCV for motor gasoline and diesel and update if necessary (with Statistics Canada)	ERT Recommendation	Data analysis underway
IPPU	Lime Production (CRF 2.A.2)	Include a lime kiln correction factor in the estimate of CO_2 emissions from lime production.	The method to estimate CO_2 emissions from lime production in Canada currently does not take into account lime kiln dust (LKD) correction factor, therefore it is planned to introduce an LKD correction factor in the estimate for future inventory submissions.	2006 IPCC Guidelines	No significant progress made
	Other Process Uses of Carbonates - Ceramics (CRF 2.A.4)	Assess whether CO_2 emission from organic carbon contained in raw materials used in production of ceramics should be included in the inventory.	IPCC 2006 Guidelines requires reporting of the subject Category in the national inventories. Canada is active in production of ceramics and needs development of a quantification methodology and activity data stream to assess the significance of this emission source.	2006 IPCC Guidelines	No significant progress made
	Ethylene Oxide Production (CRF 2.B.8.d)	Integrate new Statistics Canada data in the Inventory and develop method/model to estimate CO_2 and CH_4 emissions.	Production of ethylene oixde is a source of CO_2 and CH_4 emissions that is currently not estimated in Canada's inventory. It is therefore planned to develop a method/model in order ot estiamte and report these emissions in future inventory submissions.	2006 IPCC Guidelines	Initiated data collection / study

Table A8-4 Summary of Canada's Inventory Improvement Plan (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
	Iron and Steel Production (CRF 2.C.1)	Allocate natural gas and coal emissions associated with manufacturing of iron and steel to Iron and Steel Production instead of 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 reductant in 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 Iron and Steel Production Category.	Continuous Improvement	No significant progress made
	Magnesium Casting (CRF 2.C.4)	Obtain up-to-date SF_6 use data from magnesium casting facilities	The last data set collected from facilities were for the year 2009. Due to the unavailability of data for years 2010-2015, the SF_6 emission and production values are extrapolated using provincial gross output values.	Continuous Improvement	No significant progress made
	Product Uses as Substitutes for ODS (HFCs, CRF 2.F)	HFC 245fa update and explore means to better characterize commercial and Industrial refrigeration.	Old survey data will be mined for additional HFC 245fa information. Research into the commercial and industrial emission factors, market share and other characteristics in Canada will be examined for incorporation into the inventory.	Continuous Improvement	Data analysis underway
	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
Agriculture	Enteric Fermentation (CRF 3.A)	Use of country-specific Ym for Dairy Cattle	Recent research has demonstrated that the methane conversion rate (Ym) for dairy in Canada is lower than the default 2006 IPCC Guidelines. A new factor can be derived from recent literature and related more closely to animal diet. Methodology has been reviewed and options identified accepted in principle by expert livestock committee. For review and adoption, requires approval and alignment with AAFC methodologies. To be followed by database implementation.	Continuous Improvement	New parameters are under development
	Enteric Fermentation/ Manure Management (CRF 3.A/3.B)	Integrate new information on animal nutrition.	Based on a compilation of multiple data sources, a time series of nutrition data for dairy cattle and swine is being derived which will affect the fraction of digestible energy of feed as well as nitrogen excretion rates for animals. Data has been collected, and analyzed. Approval and alignment with AAFC methodologies are required, to be followed by database implementation	Continuous improvement	Developing new parameters
	Enteric Fermentation / Manure Management (CRF 3.A / 4B)	Revision of beef production model.	Currently the beef production model is considered to be static in the Canadian emission model. An in depth survey of beef production was carried out and in combination with other surveys a consistent representation of the changes in production systems over the reporting period is being developed to improve the accuracy of emission estimates and trends. The survey and survey analysis is complete and the next step is to begin development of Tier 2 parameters for modified production model.	Continuous Improvement	Developing new parameters
	Manure Management (CRF 3.B)	Integrate new information on manure management systems.	Currently manure management systems are considered to be static in the Canadian emission model. We are currently combining information from multiple surveys to attempt to develop a consistent representation of the changes in manure storage systems over the reporting period to better capture changes in farm practices and improve the accuracy of emission estimates. Data has been collected, and analyzed, requires approval and alignment with AAFC methodologies, followed by database implementation.	Continuous improvement	New parameters are under development
	Manure Management / Agricultural Soils (CRF 3.B/3.D)	Revision of methodologies for estimating ammonia emissions for Dairy Cattle from manure storage and agricultural soils	Currently, ammonia emissions from dairy cattle are calculated using the default 2006 IPCC guidelines for emissions from manure storage, and a fixed N loss factor for emissions from agricultural soils. Work is underway to implement tier 2 methodologies to estimate ammonia volatilization from manure storage and agricultural soils.	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)	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

Table A8-4 Summary of Canada's Inventory Improvement Plan (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Agriculture (cont'd)	Field Burning of Agricultural Residues (3.F)	Improve estimates of crop residue burning	Data on crop residue burning are available from 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.	ERT Recommendation	Alternative methods being considered
	Forest Land Conversion LCL, LWL, LSL (CRF 4.B.2, 4.D.2, 4.E.2)	Updated forest conversion data	Ongoing quality control activities, associated with addition of a new mapping time period (2008–2013) will lead to improved estimates for earlier time periods.	Continuous improvement	Data analysis underway
	Cross-cutting	Development of a plan and time frame for estimating and reporting uncertainties for all LULUCF subcategories.	Canada provides detailed uncertainty analysis for most LULUCF subcategories. However, uncertainty analysis for all subcategories has not been undertaken due to resource limitations. Uncertainty estimates for new and updated categories have been included in recent submissions. Canada aims to develop a plan for estimating, updating and reporting uncertainties for all LULUCF subcategories.	ERT recommendation	Alternative methods being considered
	Forest Land (CRF 4.A)	Further work to improve the estimation of anthropogenic emissions and removals in Forest Land	Revisions will be made to criteria that determine the stands that have undergone natural disturbance that are included in reporting, specifically to create regionally specific criteria based on forest management practices or stand dynamics.	Continuous improvement	Data analysis underway
	Forest Land (CRF 4.A) and Cropland (CRF 4.B)	Develop and refine estimates for drainage of organic soils in Forest land and Cropland.	Develop new estimates for Forest Land and revise estimates for Cropland on drainage of organic soils considering guidance from the IPCC Wetlands Supplement.	Continuous improvement	Data analysis underway
	Cropland (CRF 4.B)	Develop methods for estimating changes in soil organic carbon stocks from addition/removal of crop residues and manure application	Refine estimates of C & N inputs from crop residues, taking into account of 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 addition/removal of crop residues and manure application	Continuous improvement	Data analysis underway
	Settlements, Land converted to Settlements (CRF 4.E.2)	Update estimates for non-forest land conversion to Settlements in the north	Planned improvements for this category will focus on improving estimates of above-ground biomass loss due to land-use change events in the Arctic and Sub-Arctic regions. Activity data has been collected with updated areas of conversion from 1990 to 2010. Work is planned this year to derive emissions of above ground biomass lost based on remote sensing approaches.	Continuous improvement	Data analysis underway
	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, Land converted to Settlements (CRF 4.E.2)	Integrate estimates of Cropland conversion to settlements across Canada	Areas of Cropland converted to Settlements have been included in CRF Tables 4.1 (Land Transition Matrix) and 4E.2.2 (Cropland converted to Settlements). Work is planned this year to assess different approaches to estimate above ground biomass lost.	ERT recommendation	Initiated data collection / study
	Harvested Wood Products (CRF 4.G)	Improve uncertainty estimates, development of country-specific half-lives, and expansion of temporal coverage	Improvements are planned to improve 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. w	Continuous improvement	New parameters are under development
	Harvested Wood Products (CRF 4.G)	Improve activity data related to residential firewood, and estimate long-term emissions from solid waste disposal sites	Work is ongoing to improve activity data related to residential firewood harvest and use in Canada, and to include the incorporation of the effects of wood and paper waste in solid waste disposal sites.	Continuous improvement / 2006 IPCC Guidelines	Data analysis underway
	General: land transition matrix	Revise land transition matrix (including information on the annual values of land-use changes) and revise and improve the consistency and completeness of the land transition matrix.	Include in the next NIR the revision of the land transition matrix (including information on the annual values of changes) as planned improvement, along with 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

Table A8-4 Summary of Canada's Inventory Improvement Plan (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Waste	Solid Waste Disposal (CRF - 5.A)	Update landfill gas capture and utilization data.	The next in-house biennial landfill gas capture and utilization and waste export surveys are planned for the spring/summer of 2016. Implementation of 2014-2015 landfill gas capture and utilization and export data is planned for the 2017 NIR and will replace the assumption of 2014 data remaining constant from 2013 values.	Continuous Improvement	Data analysis underway
	Solid Waste Disposal (CRF - 5.A)	Investigate improved oxidation factor for CH_4 from solid waste disposal	The 2006 IPCC Guidelines recommend using a default value of 0.1 and estimates are currently based on an oxidation factor of zero. Further investigation is required to determine the appropriate oxidation factor for Canadian landfills.	2006 IPCC Guidelines	No significant progress made
	Solid Waste Disposal (CRF - 5.A)	Evaluate a Canada-specific DOC_f values for harvested wood products.	Evaluate Canada-specific DOC_f values for harvested wood products (wood and paper) for use in Waste and LULUCF Sectors' reporting on long term C storage and CO_2 emissions from decomposition of HWP in waste landfills.	2006 IPCC Guidelines	Literature search underway
	Solid Waste Disposal (CRF - 5.A)	Review CH_4 recovery values for 1990–1996	Document the source of data for, and the methods used to estimate, the CH_4 recovery values for 1990–1996. In the absence of such justification, assume no recovery for the 1990–1996 period.	ERT recommendation	No significant progress made
	Solid Waste Disposal (CRF - 5.A)	Investigate an improved fraction of DOC dissimilated (DOC_f) for municipal solid waste disposal.	The 2006 IPCC Guidelines recommend using a default values of 0.5. Further investigation and consultiation with a third party expert is needed to determine the appropriate value for Canadaian landfills.	2006 IPCC Guidelines	No significant progress made
	Biological Treatment of Solid Waste (CRF - 5.B)	Review and modify the composting emission estimation method.	Presently, the default emission estimation methodology is used. Expert opinion is that this method gives an overestimation of the emissions for Canada. The IPCC references supporting the default values will be critically reviewed for accuracy and suitability for Canada. The use of data collected by Statistics Canada will be seriously considered. These data cover waste quantities processed in municipal and commercial facilities. Data on residential composting activity data may be added when the estimation methodology is found to be more accurate and complete.	Continuous Improvement	Initiated data collection / study
	Biological Treatment of Solid Waste (CRF - 5.B)	Further study on anaerobic digestion of solid waste in Canada.	Further study is planned with respect to obtaining activity data related to anaerobic digestion of solid waste in Canada. An emissions estimate from anaerobic digestion of waste will be developed pending the availability of sufficient activity data.	2006 IPCC Guidelines	Initiated data collection / study
	Incineration and Open Burning of Waste (CRF 5.C)	Transfer of MSW incineration emission data associated with energy recovery to the Energy Sector.	Portion of the emissions associated with the MSW incineration where energy recovery is involved will be separated out and transferred to the Energy Sector.	ERT Recommendation	Data analysis underway
	Incineration and Open Burning of Waste (CRF 5.C)	Update of CH_4 and N_2O emission factors.	Canada is planning to use the updated methodology and emission factors for estimating CH_4 and N_2O emissions from this Category.	2006 IPCC Guidelines	New parameters are under development
	5.D Wastewater treatment and discharge – CH_4 and N_2O	Additional transparency in NIR text.	Include a detailed overview of wastewater streams and of wastewater treatment discharge pathways in the NIR to improve transparency and to underpin the use of the selected EFs	ERT recommendation	No significant progress made

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