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Climate Change Canada

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# National Inventory Report 1990-2014: Greenhouse Gas Sources and Sinks in Canada

Canada's Submission to the United Nations  
Framework Convention on Climate Change

1990–2014

## 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 by Annex I Parties to the UNFCCC by April 15 of each year. This report is part of Canada's annual inventory submission under the Convention.

Canada's 2016 National GHG Inventory complies with the requirements of the Revised UNFCCC reporting guidelines for national GHG inventories (24/CP.19), which require Annex I Parties to develop their national inventories using the 2006 methodological guidance by the Intergovernmental Panel on Climate Change (IPCC). Inventory reports must provide detailed and complete information on inventories, 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 data and national arrangements, the present National Inventory Report analyzes trends in emissions and removals and 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 2015. Ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce uncertainties associated with them.

April 2016

Director, Pollutant Inventories and Reporting Division  
Science and Risk Assessment Directorate  
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# List of Acronyms, Abbreviations and Units

AAC	Aluminum Association of Canada
AAFC	Agriculture and Agri-Food Canada
AC	air conditioning
AEDT	Aviation Environmental Design Tool
AER	Alberta Energy Regulator
AGEM	Aviation Greenhouse Gas Emission Model
AIA	Association de l'industrie d'aluminium du Québec
Al	aluminium
Al <sub>2</sub> O <sub>3</sub>	alumina
API	American Petroleum Institute
ASH	manure ash content
Asha	Ash content in baked anodes
Ashp	Ash content in pitch
ATV	all-terrain vehicle
AWMS	animal waste management system
BADA	Base of Aircraft Data
B <sub>0</sub>	maximum methane production potential
BC	average binder content in paste
BOF	basic oxygen furnace
BOD <sub>5</sub>	five-day biochemical oxygen demand
BOD <sub>u</sub>	biological oxygen demand ultimate
BSM	emissions of benzene-soluble matter
C	carbon
C&D	construction & demolition
CAC	Criteria Air Contaminant (for Land Use, Land-use Change and Forestry Sector)
CAC	Cement Association of Canada (for Industrial Processes and Product Use Sector)
CaC <sub>2</sub>	calcium carbide
CaCO <sub>3</sub>	calcium carbonate; limestone
CaMg(CO <sub>3</sub> ) <sub>2</sub>	dolomite (also CaCO <sub>3</sub> ·MgCO <sub>3</sub> )
CanFI	Canada's National Forest Inventory
CANSIM	Statistics Canada's key socioeconomic database
CanSIS	Canadian Soil Information System
CanWEA	Canadian Wind Energy Association
CaO	lime; quicklime; calcined limestone
CAPP	Canadian Association of Petroleum Producers
CBM	Carbon Budget Model
CBM-CFS3	Carbon Budget Model for the Canadian Forest Sector, version 3
CBSA	Canada Border Services Agency
CC	baked anode consumption per tonne of aluminium
CCS	carbon capture and storage
CEA	Canadian Electricity Association
CEPA 1999	Canadian Environmental Protection Act, 1999
CESI	Canadian Environmental Sustainability Indicators
CF <sub>4</sub>	carbon tetrafluoride
C <sub>2</sub> F <sub>6</sub>	carbon hexafluoride
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
CGA	Canadian Gas Association
CH <sub>3</sub> OH	methanol

CH <sub>4</sub>	methane
C <sub>2</sub> H <sub>6</sub>	ethane
C <sub>3</sub> H <sub>8</sub>	propane
C <sub>4</sub> H <sub>10</sub>	butane
C <sub>2</sub> H <sub>4</sub>	ethylene
C <sub>6</sub> H <sub>6</sub>	benzene
CHCl <sub>3</sub>	chloroform
CIEEDAC	Canadian Industrial Energy End-Use Data Analysis Centre
CKD	cement kiln dust
CLRTAP	Convention on Long-range Transboundary Air Pollution
CNFDB	Canadian National Fire Database
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
CO <sub>2</sub> eq	carbon dioxide equivalent
COD	chemical oxygen demand
CORINAIR	Core Inventory of Air Emissions in Europe
CPI	Chemical Process Industry
CPPI	Canadian Petroleum Products Institute
CRF	Common Reporting Format
CRW	crown cover area growth rate
CSI	Cement Sustainability Initiative
CSPA	Canadian Steel Producers Association
CTS	crop and tillage system
CVS	Canadian Vehicle Survey
DE	digestible energy
DEF	diesel exhaust fluid
DM	dry matter
DMI	dry matter intake
DOC	dissolved organic carbon (for LULUCF Sector)
DOC	degradable organic carbon (for Waste Sector)
DOCF	degradable organic carbon dissimilated
DOM	dead organic matter
DRI	direct reduced iron
DSL	Domestic Substances List
EAF	electric arc furnace
ECCC	Environment and Climate Change Canada
EDC	ethylene dichloride
EF	emission factor
EF <sub>BASE</sub>	base emission factor
EMEP	European Monitoring and Evaluation Programme
EO	Earth Observation
EPA	Environmental Protection Agency (United States)
EPGTD	Electric Power Generation, Transmission and Distribution
EPS	Environmental Protection Series
eq	equivalent
ERCB	Energy Resources Conservation Board
ERS	Economic Research Service (USDA)
ERT	Expert Review Team
EU	European Union
FAA	Federal Aviation Administration (United States)
FAACS	Feasibility Assessment of Afforestation for Carbon Sequestration
FCR	fuel consumption ratio
FGD	flue gas desulphurization

FLCL	forest land converted to cropland
FLFL	forest land remaining forest land
FLWL	forest land converted to wetland
FOCA	Federal Office of Civil Aviation
FOD	first-order decay
FOI	Swedish Defence Research Agency
F <sub>TILL</sub>	tillage ratio factor
FWD	food waste disposal
g	gram
GCD	great-circle distance
GCV	gross calorific value
GDP	gross domestic product
GE	gross energy
Gg	gigagram
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
GIS	geographic information system
GL	guidelines
GO	gross output
Gt	gigatonne
GRI	Gas Research Institute
GTIS	Global Trade Information Services
GVWR	gross vehicle weight rating
GWP	global warming potential
H <sub>2</sub>	hydrogen
H <sub>2</sub> O	water
H <sub>2</sub> S	hydrogen sulphide
ha	hectare
HCFC	hydrochlorofluorocarbon
HCl	hydrochloric acid
HDD	heating degree-day
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
HE	harvest emissions
HF	hydrogen fluoride
HFC	hydrofluorocarbon
HHV	higher heating value
HNO <sub>3</sub>	nitric acid
HQ	Hydro-Québec
HRAI	Heating, Refrigeration and Air Conditioning Institute of Canada
HSS	horizontal stud Söderberg
HW	hazardous waste
HWP	harvested wood products
HWP-C	carbon stored in harvested wood products
IAI	International Aluminium Institute
ICAO	International Civil Aviation Organization
ICI	institutional, commercial and industrial
IE	included elsewhere
IEA	International Energy Agency
IESO	Independent Electricity System Operator
I/M	inspection and maintenance
Impa	fluorine and other impurities
IPCC	Intergovernmental Panel on Climate Change



IPPU	Industrial Processes and Product Use
IT	intensive tillage
KAR	kilometre accumulation rate
$K_2CO_3$	potassium carbonate
kg	kilogram
kha	kilohectare
km	kilometre
kt	kilotonne
kWh	kilowatt-hour
$L_0$	methane generation potential
LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LFG	landfill gas
LHV	lower heating value
LINEST	Microsoft Excel least squares linear fit function
LMC	land management change
LPG	liquefied petroleum gases
LTO	landing and takeoff
LULUCF	Land Use, Land-use Change and Forestry
m	metre
MARS	Monitoring, Accounting and Reporting System
MC	motorcycle
MCF	methane conversion factor (Agriculture)
MCF	methane correction factor (Waste)
Mg	magnesium; also megagram
$MgCO_3$	magnesite; magnesium carbonate
MGEM	Mobile Greenhouse Gas Emission Model
MgO	magnesia; dolomitic lime
Mha	megahectare, equivalent to a million hectares
MI	Manufactured Items
mm	millimetre
MMIC	Motorcycle & Moped Industry Council
MOVES	Motor Vehicle Emission Simulator
MODTF	Modeling and Database Task Force
mol	mole
MOU	Memorandum of Understanding
MP	total aluminum production
MS	manure system distribution factor
MSW	municipal solid waste
Mt	megatonne
MTOW	maximum takeoff weight
MW	megawatt
N	nitrogen
$N_2$	nitrogen gas
$Na_2CO_3$	sodium carbonate; soda ash
$Na_3AlF_6$	cryolite
NA	not applicable
N/A	not available
NAICS	North American Industry Classification System
NAP	National Action Plan
NBAC	National Burn Area Composite

NCASI	National Council for Air and Stream Improvement
NCV	net calorific value
NE	not estimated
NEB	National Energy Board
NEU	non-energy use
NF <sub>3</sub>	nitrogen trifluoride
NFI	National Forest Inventory
NFR	nomenclature for reporting
NFDP	National Forestry Database Program
NGL	natural gas liquid
NH <sub>3</sub>	ammonia
NH <sub>4</sub> <sup>+</sup>	ammonium
NH <sub>4</sub> NO <sub>3</sub>	ammonium nitrate
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
N <sub>2</sub> O	nitrous oxide
N <sub>2</sub> O-N	Nitrous oxide emissions represented in terms of nitrogen
NO	nitric oxide; also used for not occurring
NO <sub>2</sub>	nitrogen dioxide
NO <sub>3</sub> <sup>-</sup>	nitrate
NO <sub>x</sub>	nitrogen oxides
NOC	Nitrous Oxide of Canada
NOPP	National Office of Pollution Prevention
NPRI	National Pollutant Release Inventory
NRCan	Natural Resources Canada
NSCR	non-selective catalytic reduction
NT	no tillage
O <sub>2</sub>	oxygen
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
OS/HOU	oil sands and heavy oil upgrading
PC	paste consumption
PCI	pulverized coal injection
PFC	perfluorocarbon
PIRD	Pollutant Inventories and Reporting Division
PJ	petajoule
POP	persistent organic pollutant
P/PE	precipitation/potential evapotranspiration
PTRC	Petroleum Technology Research Centre
P&P	pulp and paper
QA	quality assurance
QC	quality control
RA	reference approach
RESO	Report on Energy Supply and Demand in Canada
RPP	refined petroleum product
RT	reduced tillage
RTI	Research Triangle Institute
RU	Reconciliation Unit
SA	sectoral approach
Sa	sulphur content in baked anodes
SAGE	System for assessing Aviation's Global Emissions
SBR	styrene-butadiene

Sc	sulphur content in calcinated coke
SCR	selective catalytic reduction
SF <sub>6</sub>	sulphur hexafluoride
SIC	Standard Industrial Classification
SiC	silicon carbide
SLC	Soil Landscapes of Canada
SMR	steam methane reforming
SO <sub>2</sub>	sulphur dioxide
SOx	sulphur oxides
SOC	soil organic carbon
SON	soil organic nitrogen
Sp	sulphur content in pitch
SUV	sport utility vehicle
t	tonne
TWh	terrawatt-hour
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UPCIS	Use Patterns and Controls Implementation Section
UOG	upstream oil and gas
U.S.	United States
UTC	urban tree crown
USDA	United States Department of Agriculture
VCN	vinyl chloride monomer
VKT	vehicle kilometres travelled
VSS	vertical stud Søderberg
VS	volatile solids
WBCSD	World Business Council for Sustainable Development
WMIS	Waste Management Industry Survey
WMO	World Meteorological Organization

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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. At the 15th session of the Conference of the Parties (COP15) to the UNFCCC in 2009, Canada committed to reducing its GHG emissions to 17% below the 2005 level by the year 2020.<sup>1</sup> 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.

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 COP their national inventories of anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol.<sup>2</sup>

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). The annual inventory submission consists of the National Inventory Report (NIR) and the Common Reporting Format (CRF) tables.

This inventory submission follows the revised UNFCCC Reporting Guidelines, adopted through Decision 24/CP.19 at COP 19 in Warsaw in 2013.

The inventory GHG estimates include carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF<sub>6</sub>), and

nitrogen trifluoride (NF<sub>3</sub>) in 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.

Section ES.2 of this Executive Summary summarizes the latest information on Canada's net anthropogenic GHG emissions over the period 1990–2014 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.

There are several methods to categorize the sources of GHG emissions. For the purposes of analyzing economic trends and policies, it is useful to allocate emissions to the economic sector from which they originate. Section ES.4 presents Canada's emissions by the following economic sectors: Oil and Gas, Electricity, Transportation, Emissions-Intensive and Trade-Exposed Industries, Buildings, Agriculture, Waste and Others. This breakdown is also used for reporting against Canada's 2020 target<sup>3</sup> in the annual *Canada's Emissions Trends* report (Environment Canada 2014a) and in *Canada's Sixth National Communication and First Biennial Report* (Environment Canada 2014b). 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.4 also presents a synopsis of GHG emissions by economic sector, consistent with that submitted to the UNFCCC.

Canada is a federation composed of a federal government, 10 provincial governments, and 3 territorial governments. Section ES.5 details GHG emissions for Canada's 13 sub-national jurisdictions.

Canada's annual inventory submission to the UNFCCC embodies almost two decades of learning and improvements. Section ES.6 provides some detail on the components of this submission and outlines key elements of its preparation.

## ES.2 Overview, National GHG Emissions

In 2014, the most recent annual dataset in this report, Canada's total GHG emissions were estimated to be 732 megatonnes of

<sup>1</sup> See [http://unfccc.int/meetings/copenhagen\\_dec\\_2009/items/5264.php](http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php).

<sup>2</sup> 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.

<sup>3</sup> See [http://unfccc.int/meetings/copenhagen\\_dec\\_2009/items/5264.php](http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php).

carbon dioxide equivalent (Mt CO<sub>2</sub> eq<sup>4</sup>), excluding Land Use, Land-Use Change and Forestry (LULUCF) estimates.<sup>5</sup>

The Energy Sector (consisting of Stationary Combustion Sources, Transport, and Fugitive Sources) accounted for the majority of Canada's total GHG emissions in 2014, at 81% or 594 Mt (Figure S-1). The remaining emissions were largely generated by

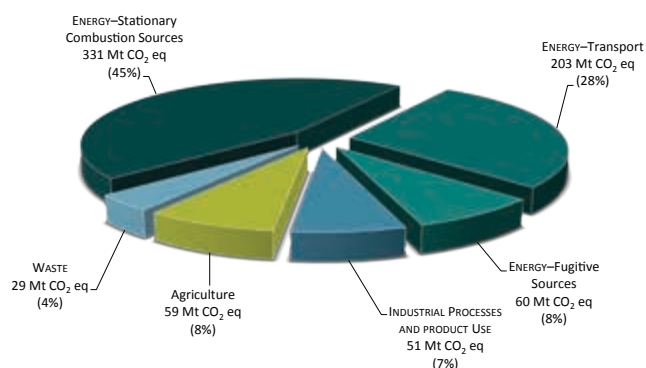
4 Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO<sub>2</sub> equivalent.

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

the Agriculture (8% of total emissions) and Industrial Processes and Product Use (7%) sectors, with minor contributions from the Waste Sector (4%). The LULUCF Sector emitted 72 Mt in 2014; these emissions are excluded from national inventory totals.

In 2014, CO<sub>2</sub> accounted for 78% of Canada's total emissions (Figure S-2). The majority of these emissions result from the combustion of fossil fuels. CH<sub>4</sub> accounted for 15% of Canada's total emissions, largely from fugitive emissions from oil and natural gas systems, as well as domestic livestock and landfills. N<sub>2</sub>O emissions, largely from agricultural soil management and

Figure S-1 Canada's Emissions Breakdown by IPCC Sector (2014)\*



Total: 732 Mt CO<sub>2</sub> eq

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

Figure S-2 Canada's Emissions Breakdown by GHG (2014)\*

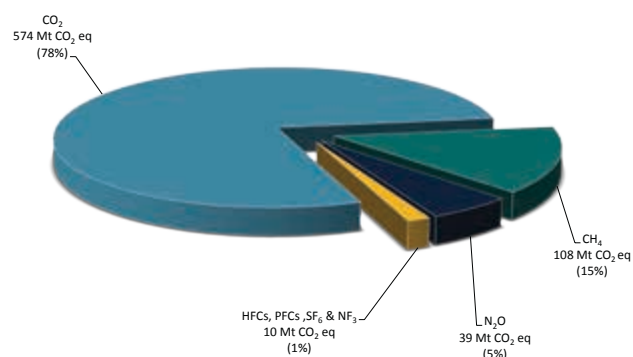
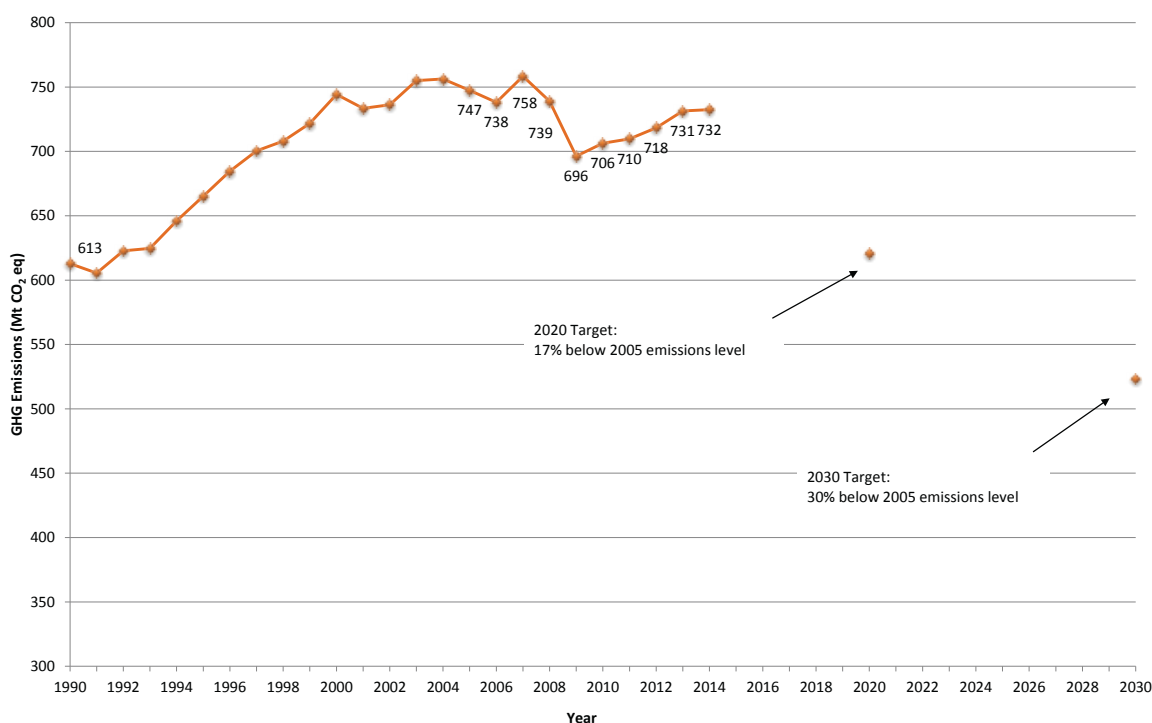


Figure S-3 Canadian GHG Emissions Trend (1990–2014), 2020 Target, 2030 Target



transportation, accounted for 5% of emissions. Emissions of the synthetic gases (HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub>) constituted the remainder (slightly more than 1%).

Canada's emissions in 2014 were 120 Mt (20%) above the 1990 total of 613 Mt (Figure S-3). Steady increases in annual emissions characterized the first 10 years of this period, followed by fluctuating emission levels between 2000 and 2008, a steep drop in 2009, and a gradual increase thereafter. From 2005 to 2009, emissions decreased by 51 Mt (6.8%), and from 2009 to 2014, emissions increased by 36 Mt (5.2%), resulting in an overall decrease of 15 Mt between 2005 and 2014.

Though GHG emissions have risen by 20% since 1990, Canada's economy grew more rapidly, with the gross domestic product (GDP) rising by 75%. As a result, the emission intensity for the entire economy (GHG per GDP) has declined by 32% (Figure S-4 and Table S-1). Early in the period, emissions rose nearly in step with economic growth, with their paths beginning to diverge in 1995 (Figure S-4). This pattern can be attributed to fuel switch-

ing, 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 since the late 1990s. Section ES.3 provides more information on trends in GHG emissions.

Although Canada represented approximately 1.6% of total global GHG emissions in 2012 (CAIT 2015), it is one of the highest per capita emitters. In 1990, Canadians released 22.1 tonnes (t) of GHGs per capita. In 2000, this indicator had risen to 24.3 t; however, by 2009, it had dropped to 20.7 t and has remained at historic lows ever since (Figure S-5).

## ES.3 Emissions and Trends by IPCC Sectors

### Overall Trends in Emissions

Over the period 1990–2014, total emissions grew by 120 Mt or 20%.

Figure S-4 Indexed Trend in GHG Emissions and GHG Emissions Intensity (1990–2014)

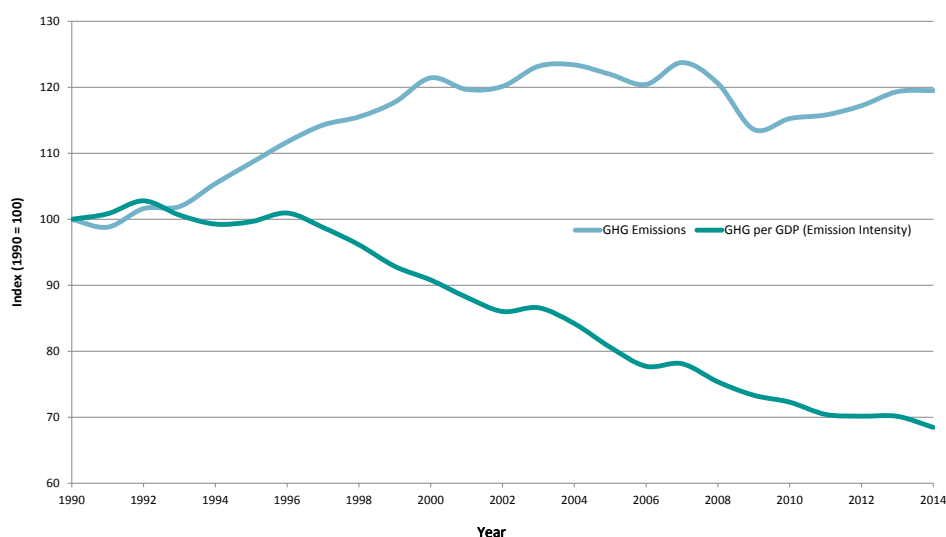


Table S-1 Trends in Emissions and Economic Indicators, Selected Years

Year	1990	2005	2009	2010	2011	2012	2013	2014
<b>Total GHG (Mt)</b>	<b>613</b>	<b>747</b>	<b>696</b>	<b>706</b>	<b>710</b>	<b>718</b>	<b>731</b>	<b>732</b>
Change Since 2005 (%)	NA	NA	-6.8%	-5.5%	-5.0%	-3.9%	-2.1%	-2.0%
Change Since 1990 (%)	NA	22.0%	13.6%	15.3%	15.8%	17.2%	19.3%	19.5%
<b>GDP (Billions 2007\$)</b>	<b>993</b>	<b>1 503</b>	<b>1 539</b>	<b>1 584</b>	<b>1 633</b>	<b>1 659</b>	<b>1 690</b>	<b>1 734</b>
Change Since 2005 (%)	NA	NA	2.4%	5.4%	8.6%	10.4%	12.4%	15.4%
Change Since 1990 (%)	NA	51.4%	55.0%	59.5%	64.5%	67.1%	70.2%	74.6%
<b>GHG Intensity (Mt/\$B GDP)</b>	<b>0.62</b>	<b>0.50</b>	<b>0.45</b>	<b>0.45</b>	<b>0.43</b>	<b>0.43</b>	<b>0.43</b>	<b>0.42</b>
Change Since 2005 (%)	NA	NA	-9.0%	-10.3%	-12.6%	-12.9%	-13.0%	-15.1%
Change Since 1990 (%)	NA	-19.4%	-26.7%	-27.7%	-29.6%	-29.8%	-29.9%	-31.6%

GDP data source: Statistics Canada (2015a) Table 380-0106 - Gross domestic product at 2007 prices, expenditure-based, annual (dollars), CANSIM (database)

Figure S-5 Canadian per Capita GHG Emissions (1990–2014)

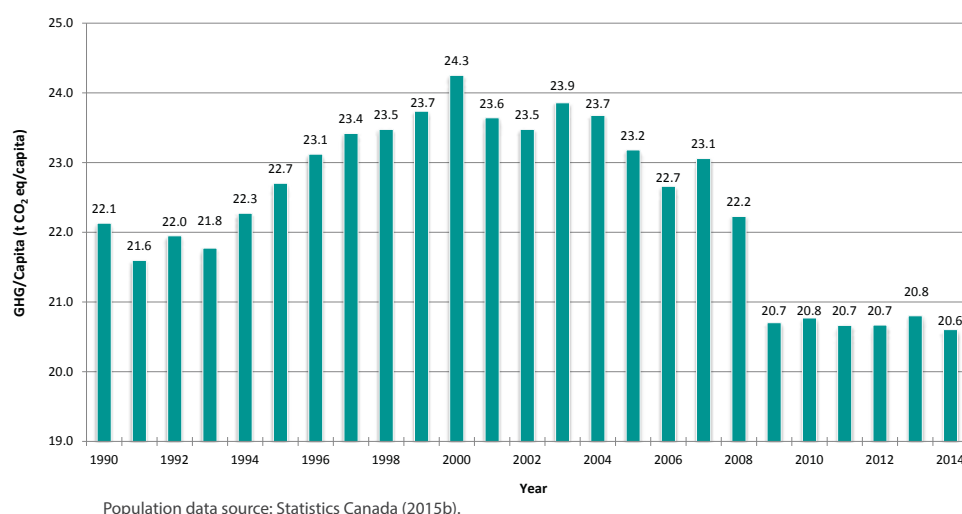
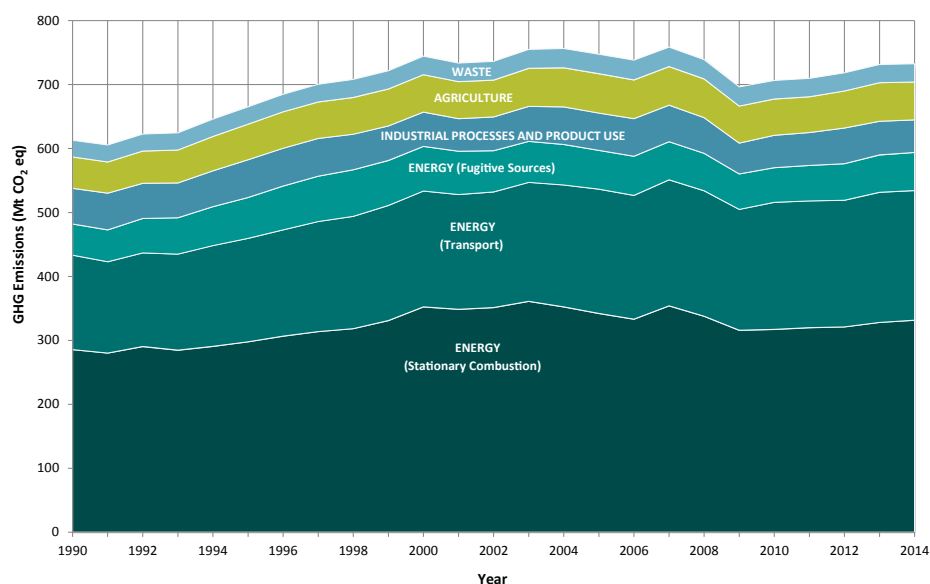


Figure S-6 Trends in Canadian GHG Emissions by IPCC Sector (1990–2014)



The Energy Sector dominated the long-term trend, with increases of 55 Mt in Transport, 46 Mt in Stationary Combustion and 11 Mt in Fugitive Sources (Table S-2). There were also increases of 10 Mt (21%) in the Agriculture Sector and 2 Mt in the Waste Sector. Over the same period, the Industrial Processes and Product Use Sector saw a decrease of 5 Mt.

Table S-2 provides additional details about Canada's emissions and removals by IPCC sector for the years 1990, 2005 and (2009–2014). Further breakdowns by subsector and gas, and a complete time series, can be found in Annex 9.

In contrast to the increase in emissions over the longer term (1990–2014), total Canadian GHG emissions have decreased overall by 15 Mt since 2005. Over this time period, emissions from different source categories exhibit different patterns that

can mutually offset each other. For example, the 11-Mt decrease in emissions from Stationary Combustion Sources since 2005 are offset by a similar increase in emissions from Transport sources (Figure S-7). In addition, emissions from Industrial Processes and Product Use, Agriculture, and Waste have decreased by 7 Mt, 2 Mt and 2 Mt, respectively, since 2005.

The principal drivers of the upward trend in emissions since 2009 are energy consumption in Mining and Upstream Oil and Gas Production (an increase of 23 Mt since 2009) and manufacturing industries (6-Mt increase), the consumption of diesel fuel for off-road mobile equipment (9-Mt increase), and fugitive emissions in Oil and Gas (4-Mt increase).

Chapter 2 provides more information on trends in GHG emissions and their drivers.

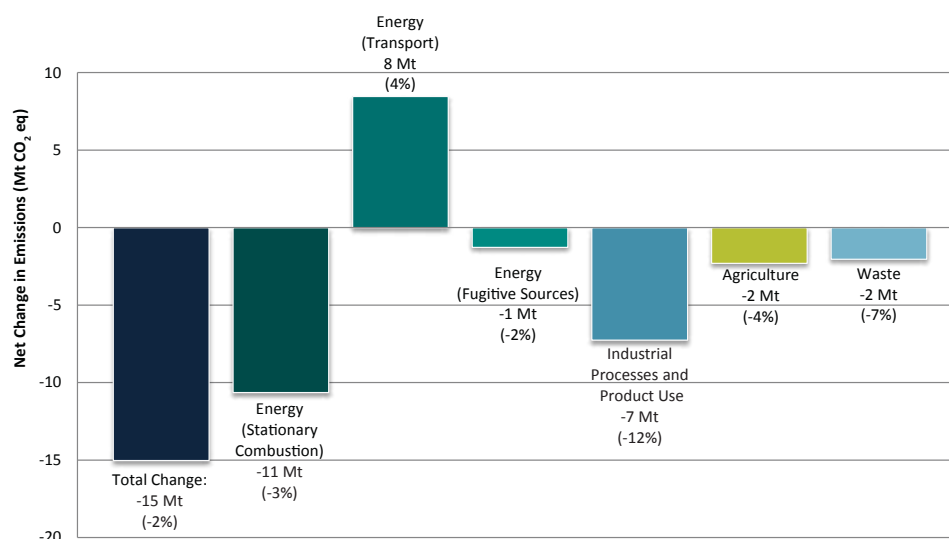
Table S-2 Canada's GHG Emissions by IPCC Sector, Selected Years

Greenhouse Gas Categories		1990	2005	2009	2010	2011	2012	2013	2014
		<i>Mt CO<sub>2</sub> equivalent</i>							
<b>TOTAL<sup>1,2</sup></b>		<b>613</b>	<b>747</b>	<b>696</b>	<b>706</b>	<b>710</b>	<b>718</b>	<b>731</b>	<b>732</b>
<b>ENERGY</b>		<b>482</b>	<b>597</b>	<b>560</b>	<b>570</b>	<b>574</b>	<b>576</b>	<b>590</b>	<b>594</b>
a.	Stationary Combustion Sources	285	342	316	317	320	321	328	331
	Public Electricity and Heat Production	95	124	100	102	95	92	88	86
	Petroleum Refining Industries	17	20	19	18	18	19	18	17
	Mining and Upstream Oil and Gas Production	41	68	78	80	82	91	99	101
	Manufacturing Industries	56	49	40	41	45	44	45	46
	Construction	2	1	1	2	1	1	1	1
	Commercial & Institutional	26	32	30	28	30	28	29	31
	Residential	46	45	45	42	46	42	44	46
	Agriculture & Forestry	2	2	3	3	3	4	4	4
b.	Transport	148	195	189	199	199	198	204	203
	Domestic Aviation	7	8	6	6	6	7	8	7
	Road Transportation	100	136	140	142	140	141	144	140
	Railways	7	7	5	7	8	8	7	8
	Domestic Navigation	5	6	6	7	6	6	5	5
	Other Transportation	29	38	31	37	39	37	39	43
c.	Fugitive Sources	49	61	55	54	55	57	58	60
	Coal Mining	3	1	1	1	1	1	2	1
	Oil and Natural Gas	46	59	54	53	54	56	57	58
d.	CO <sub>2</sub> Transport and Storage	-	0	0	0	0	0	0	0
<b>INDUSTRIAL PROCESSES AND PRODUCT USE</b>		<b>56</b>	<b>58</b>	<b>48</b>	<b>50</b>	<b>51</b>	<b>56</b>	<b>53</b>	<b>51</b>
a.	Mineral Products	8	10	7	8	8	8	8	8
b.	Chemical Industry	17	9	6	5	6	6	6	6
c.	Metal Production	24	20	16	16	17	17	15	15
d.	Production and Consumption of Halocarbons, SF <sub>6</sub> and NF <sub>3</sub>	1	6	7	7	8	8	9	9
e.	Non-Energy Products from Fuels and Solvent Use	5	12	12	13	12	15	15	13
f.	Other Product Manufacture and Use	0	1	0	0	0	1	1	0
<b>AGRICULTURE</b>		<b>49</b>	<b>61</b>	<b>58</b>	<b>57</b>	<b>56</b>	<b>58</b>	<b>60</b>	<b>59</b>
a.	Enteric Fermentation	23	31	27	26	25	25	25	25
b.	Manure Management	8	10	9	8	8	8	8	8
c.	Agricultural Soils <sup>3</sup>	17	19	20	21	20	22	24	23
d.	Liming, Urea Application and Other Carbon-containing Fertilizers	1	1	2	2	2	2	3	3
<b>WASTE</b>		<b>26</b>	<b>31</b>	<b>30</b>	<b>29</b>	<b>29</b>	<b>28</b>	<b>28</b>	<b>29</b>
a.	Solid Waste Disposal	24	28	27	26	26	26	26	26
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.	Waste Incineration and Open Burning of Waste	1	1	1	1	1	1	1	1
<b>LAND USE, LAND-USE CHANGE AND FORESTRY</b>		<b>-87</b>	<b>1</b>	<b>-40</b>	<b>55</b>	<b>69</b>	<b>41</b>	<b>-30</b>	<b>72</b>
a.	Forest Land and Harvested Wood Products	-108	-0	-38	56	71	41	-29	72
b.	Cropland	10	-9	-10	-9	-9	-9	-9	-8
c.	Grassland	1	1	0	0	1	2	1	1
d.	Wetlands	6	4	4	4	4	4	4	3
e.	Settlements	4	4	4	4	4	4	4	4

## 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
  3. Includes emissions from Field Burning of Agricultural Residues
- Sectors shaded in green represent those sectors with significant contributions to trends as described in Section ES.3

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



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

## Energy—2014 GHG Emissions (594 Mt)

### Short-term Trends

In 2014, GHG emissions from the IPCC Energy Sector (594 Mt) were very close to 2005 levels (597 Mt). Within the Energy Sector, the 34-Mt increase in emissions from Mining and Upstream Oil and Gas Production was offset by a 39-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 Electricity Production between 2005 and 2014. The permanent closure of all coal generating stations in the province of Ontario by 2014 was the determinant factor.<sup>6</sup> However, emissions fluctuated over the period, largely as a result of changes in the mix of electricity generation sources.<sup>7</sup>

GHG emissions from Manufacturing Industries decreased by 2.9 Mt between 2005 and 2014, consistent with both a 6% decrease in energy use and an observed decline in output<sup>8</sup> in these industries.

### Long-term Trends

The long-term emission trends in the Energy Sector (1990–2014) show a net growth of 112 Mt or 23%. The majority of the increase has taken place in Mining and Upstream Oil and Gas Production (60 Mt) and Road Transportation (41 Mt). The largest decreases in Energy Sector emissions were observed in the Manufacturing Industries (10 Mt), followed by Public Electricity and Heat Production (9 Mt).

In 2014, emissions from Mining and Upstream Oil and Gas Production were more than twice their 1990 values. This trend is consistent with a 91% increase in total production of crude oil and natural gas over the period, largely for export, which has grown by over 200%.

Oil production has been driven primarily by a rapid rise in the extraction of bitumen and synthetic crude oil from Canada's oil sands. In addition, per-barrel GHG emissions from oil and gas production have been rising, due to an increase in the complexity of techniques used to produce conventional oil and the increasing proportion of synthetic crude oil produced from the oil sands. Since 2004 however, the emissions intensity from oil sands operations has remained fairly static.

The majority of transport emissions in Canada are related to Road Transportation, which contributed 74% of the net increase in total transport GHG emissions since 1990. The primary source of this net trend of rising emissions is the increase in the vehicle population and total vehicle kilometres travelled despite a reduction in average kilometres driven per vehicle. In addition, vehicles are becoming more efficient, and the 43% increase in emissions since 1990 remains lower than the 47% increase in vehicle kilometres travelled.

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, 2014, Statistics Canada Daily, November 2, 2015; <http://www.statcan.gc.ca/daily-quotidien/151102/dq151102a-eng.htm> (accessed January 25, 2016).



The most significant sources of emissions in road transportation are light-duty (i.e. passenger) vehicles and heavy-duty diesel vehicles for freight transport. Within the light-duty vehicle<sup>9</sup> segment, the use of sport-utility vehicles, pickups and minivans increased much more rapidly than cars. These vehicles typically have higher fuel consumption ratios than cars, therefore influencing overall emission rates for light-duty vehicles.

Emissions from heavy-duty diesel vehicles (large freight trucks) rose by 28 Mt (142%) between 1990 and 2014. Growth in emissions reflected a substantial increase in the use of heavy trucks, which are primarily used to transport freight between urban centres (NRCan 2015). As with the light-duty vehicle segment, improvements to fuel consumption ratios in this segment were offset by large increases in vehicle kilometres travelled.

### Industrial Processes and Product Use—2014 GHG Emissions (51 Mt)

The Industrial Processes and Product Use Sector covers non-energy GHG emissions from industrial sources, such as limestone calcination (CO<sub>2</sub>) in cement production and the use of HFCs and PFCs as replacement refrigerants for ozone-depleting substances (ODSs). Since 1990, emissions have fluctuated, with peaks in 1996 and 2004. In 2014, emissions were 9% (5 Mt) below their 1990 level and 12% (7 Mt) below the 2005 level.

Emissions of most industries decreased in 2008 and 2009 and have remained at similar levels since then. A notable exception includes the 3.3-Mt (59%) increase in emissions from the use of HFCs since 2005.

The aluminium industry, while increasing its production by over 80% since 1990, shows a 4.5-Mt (43%) decrease in its process emissions, largely due to emission control technology introduced to mitigate PFC emissions. The 65% overall decrease in GHG emissions from Chemical Industries between 1990 and 2014 is primarily a result of the closure in 2009 of an adipic acid plant in Ontario.

### Agriculture—2014 GHG Emissions (59 Mt)

Emissions directly related to animal and crop production accounted for 59 Mt or 8.0% of total 2014 GHG emissions for Canada, an increase of 10 Mt or 21% since 1990. Agriculture accounts for 27% and 70% of the national CH<sub>4</sub> and N<sub>2</sub>O emissions, respectively. Livestock emissions currently account for 62% of total agricultural emissions.

The main drivers of the trend in emissions in the Agriculture Sector since 1990 are sustained increases in the application of inorganic nitrogen fertilizers, mainly on the Prairies, and the

intensification, expansion and then subsequent decline of the beef cattle and swine industries.

From 1990 to 2005, fertilizer and livestock emissions increased by 1.3 and 12 Mt, respectively. Since 2005, fertilizer use continued to increase, but by 2011 livestock populations had decreased sharply. Emissions reached 59 Mt in 2014 as livestock populations have remained stable since 2011, while fertilizer use and crop production were higher than in 2011.

### Waste—2014 GHG Emissions (29 Mt)

The primary source of emissions in the Waste Sector is CH<sub>4</sub> from Solid Waste Disposal, which accounts for about 91% of emissions for this sector. The CH<sub>4</sub> emissions from publicly and privately owned municipal solid waste landfills (MSW) make up the bulk of emissions from Solid Waste Disposal (approximately 84%). The remainder (approximately 16%) originates from on-site industrial landfills of wood residues; such landfills are declining in number as markets for wood residues grow.

Since 1990, overall emissions from the Waste Sector have grown by 10%, mostly from increases in emissions from landfill operations. Emission releases in this sector are significantly mitigated by the growing volumes of landfill gas (LFG) captured and combusted at the landfill sites. While the CH<sub>4</sub> emissions generated by all MSW landfills increased by 37% to 33 Mt, the amount of CH<sub>4</sub> captured increased by 134% to 11 Mt in 2014. Of the overall CH<sub>4</sub> captured, 49% was combusted for energy recovery applications and the remainder was flared. The number of landfill sites with LFG capture systems is rapidly rising in Canada, with 81 such systems operating in 2014.

### Land Use, Land-use Change and Forestry—2014 (Net Emissions of 72 Mt)

The Land Use, Land-use Change and Forestry (LULUCF) Sector reports 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. All emissions and removals in the LULUCF Sector are excluded from the national totals.

In this sector, the net GHG flux is the net sum of CO<sub>2</sub> emissions to and removals from the atmosphere, plus emissions of non-CO<sub>2</sub> gases. In 2014, this net flux amounted to emissions of 72 Mt, which, if included, would increase the total Canadian GHG emissions by about 9.8%.

Trends in emissions/removals from LULUCF are primarily driven by those in Forest Land in conjunction with HWP. In contrast with other inventory estimates, GHG emissions and removals from Canada's managed lands can include very large fluxes from non-anthropogenic events, such as wildfires and insect epidemics in

<sup>9</sup> Light-duty vehicles (LDVs) include all light-duty vehicles and trucks regardless of fuel type.



Forest Land. The net flux from Forest Land is dominated by inter-annual variability and trends due to natural disturbances, which mask the impact of human activities in managed forests. For example, between 1990 and the peak harvest year of 2004, there was a 24% increase in the carbon removed in harvested wood. Since then, significant reductions in forest harvest have occurred, reaching a 25-year low in 2009, with levels in 2014 still at 25% below their peak. Nevertheless, the immediate and long-term effect of major natural disturbances in managed forests, notably the mountain pine beetle infestation in western Canada and periodic wildfires, dominate the apparent trend of emissions and removals from Forest Land. The area burned by wildfires in 2014 was significantly larger than in 2013 (1.3 million ha compared to 0.5 in 2013), which resulted in higher wildfire emissions (175 Mt compared to 66 Mt in 2013).

Emissions from HWP fluctuate between 128 Mt in 2009, the year of the lowest harvest rates, and peaks of 160 Mt in 1995 and 2000. HWP emissions are mainly influenced by recent harvest trends but also by the long-term impact of forest harvesting that occurred before 1990, since a significant proportion of emissions result from the decay of long-lived wood products reaching the end of their economic life decades after the wood was harvested.

The conversion of forests to other land uses is a prevalent, yet declining, practice in Canada, mainly due to forest conversion to settlements for resource extraction and cropland expansion. Emissions from forest conversion totalled 12 Mt in 2014, down from 19.2 Mt in 1990.

The net flux in emissions from cropland shows a steady decline in the period 1990–2006, from 10 Mt in 1990 to net removals of 9.9 Mt in 2006. This trend is a result of changes in agricultural land management practices, mainly in western Canada, including the adoption of conservation tillage practices ( $\approx 17$  million hectares of cropland since 1990), an 81% reduction in summerfallow, as

well as a decline in the conversion of forest land to cropland. However, since 2006, net removals have gradually declined to 8.4 Mt as a result of the soil sink approaching equilibrium and an observed increase in conversion of perennial to annual crops, a trend that is consistent with the increasing  $N_2O$  emissions from crop production observed in the Agriculture Sector.

## ES.4 Economic Sectors

For the purposes of analyzing economic trends and policies, it is useful to allocate emissions to the economic sector from which the emissions originate. These emissions are presented in Figure S–8 and Table S–3. 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.

Similar to the trends under IPCC sectors, the increase in GHG emissions between 1990 and 2014 was driven by growth in the oil and gas and transportation sectors. Increased production of crude oil as well as the expansion of the oil sands resulted in an increase in emissions of 85 Mt in the oil and gas sector. In the transportation sector, changes in subsectors such as light-duty and heavy-duty vehicles caused an increase in emissions of 42 Mt when compared to 1990 levels. These increases were offset by decreases in emissions in the Electricity and Emissions Intensive and Trade Exposed Industries, where emissions fell 17 Mt and 19 Mt, respectively.

Further information on 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.

Figure S–8 Canada's Emissions Breakdown by Economic Sector (2014)

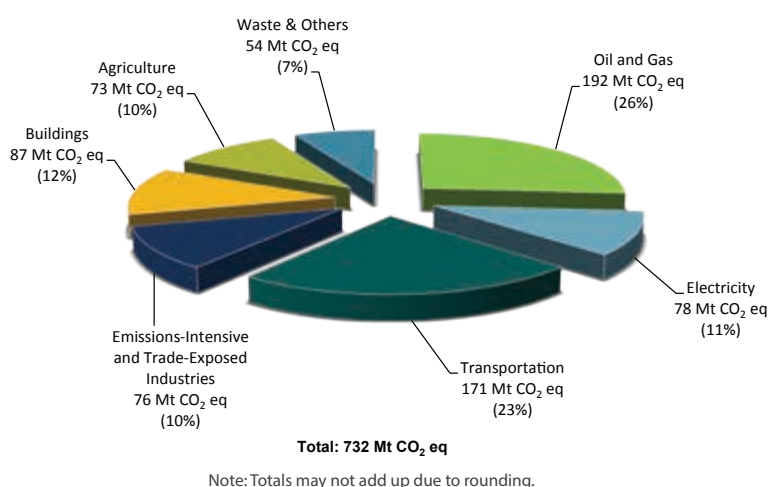


Table S-3 Canada's GHG Emissions by Economic Sector, Selected Years

	1990	2005	2009	2010	2011	2012	2013	2014
	<i>Mt CO<sub>2</sub> equivalent</i>							
<b>NATIONAL GHG TOTAL</b>	<b>613</b>	<b>747</b>	<b>696</b>	<b>706</b>	<b>710</b>	<b>718</b>	<b>731</b>	<b>732</b>
Oil and Gas	107	159	160	162	164	176	187	192
Electricity	95	118	94	95	87	83	80	78
Transportation	129	171	168	173	170	171	174	171
Emission Intensive and Trade Exposed Industries <sup>1</sup>	95	88	72	74	79	79	77	76
Buildings	73	85	83	81	86	84	85	87
Agriculture	57	70	67	68	69	70	73	73
Waste & Others <sup>2</sup>	49	48	52	53	53	53	54	54

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. Recalculations resulting from methodological improvements are presented in Chapter 8, and recalculations resulting from changes to underlying activity data are presented in the chapter(s) associated with the sector where the changes occurred (Chapters 3-7).

1. The Emissions Intensive and Trade Exposed Industries 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.

## ES.5 Provincial and Territorial GHG Emissions

Emissions vary significantly by province, due to factors such as population, energy sources and economic structure. All else being equal, economies based on resource extraction will tend to have higher emission levels than service-based economies. Likewise, provinces that rely on fossil fuels for their electricity generation will have higher emissions than those that rely more on hydroelectricity.

Historically, Alberta has been one of the highest emitting province; its emissions increased from 233 Mt in 2005 to 274 Mt in

2014 (17%), primarily due to 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 40 Mt or 19%), primarily due to the closure of coal-fired electricity generation plants.

Quebec and British Columbia, which rely on abundant hydroelectric resources for their electricity production, show more stable emission patterns across the time series and a decreasing pattern since 2005. Quebec experienced a 7.8% (7.0 Mt) decrease from its 2005 emissions level, while British Columbia had a decline of 3.4% (2.2 Mt). Emissions in Nova Scotia, New Brunswick and

Prince Edward Island have also decreased since 2005, especially in Nova Scotia (29% reduction).

Figure S-9 Emissions by Province in 1990, 2005 and 2014

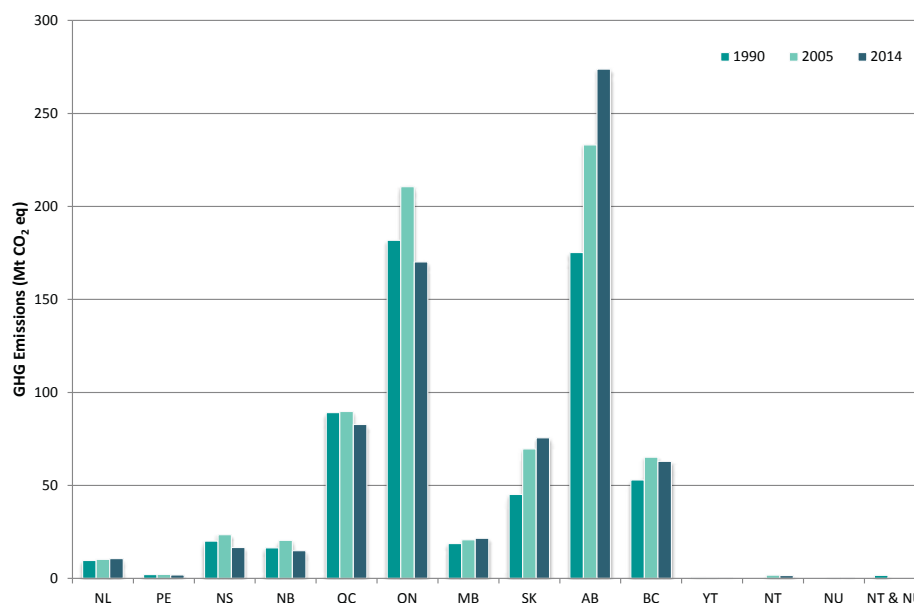


Table S-4 GHG Emissions Provinces / Territories, Selected Years

Year	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)
	1990	2005	2009	2010	2011	2012	2013	2014	1990-2014
<b>GHG Total (Canada)</b>	<b>613</b>	<b>747</b>	<b>696</b>	<b>706</b>	<b>710</b>	<b>718</b>	<b>731</b>	<b>732</b>	<b>20%</b>
NL	9.6	10.2	10.1	10.3	10.3	9.8	9.6	10.6	10%
PE	2.0	2.1	1.9	2.0	2.1	2.1	1.8	1.8	-8%
NS	20	23	21	20	21	19	18	17	-17%
NB	16	20	19	19	19	17	15	15	-9%
QC	89	90	87	82	84	82	83	83	-7%
ON	182	211	171	179	175	171	171	170	-6%
MB	19	21	20	20	19	21	21	21	15%
SK	45	70	70	70	69	72	74	76	68%
AB	175	233	234	242	246	260	272	274	56%
BC	53	65	61	61	61	63	63	63	19%
YT	0.5	0.5	0.3	0.3	0.4	0.4	0.4	0.3	-50%
NT <sup>2</sup>	NA	1.7	1.2	1.4	1.4	1.5	1.4	1.5	-
NU <sup>2</sup>	NA	0.3	0.4	0.4	0.2	0.2	0.2	0.3	-
NT&NU <sup>2</sup>	1.6	NA	NA	NA	NA	NA	NA	NA	-

Notes:

1. Totals may not add up due to rounding.

2. To account for the creation of Nunavut in 1999, a time series from 1999–2014 is provided for both Nunavut and the Northwest Territories and the years 1990–1998 are presented as a combined region (see Annex A11 for more information).

Emissions in Saskatchewan increased by 8.6% (6.0 Mt) between 2005 and 2014, as a result of activities in the oil and gas industry as well as potash and uranium mining. Emissions in Manitoba and Newfoundland and Labrador have also increased since 2005 but to a lesser extent.

## ES.6 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. Canada's arrangements for the estimation of anthropogenic emissions from sources and removals by sinks of all GHGs not controlled by the Montreal Protocol encompass the institutional, legal and procedural arrangements necessary to ensure that it meets its reporting obligations.

The inventory arrangements consist of institutional arrangements for the preparation of the inventory, including: 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 for improvement of the inventory; procedures for official approval; and a working archives 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.

# 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.

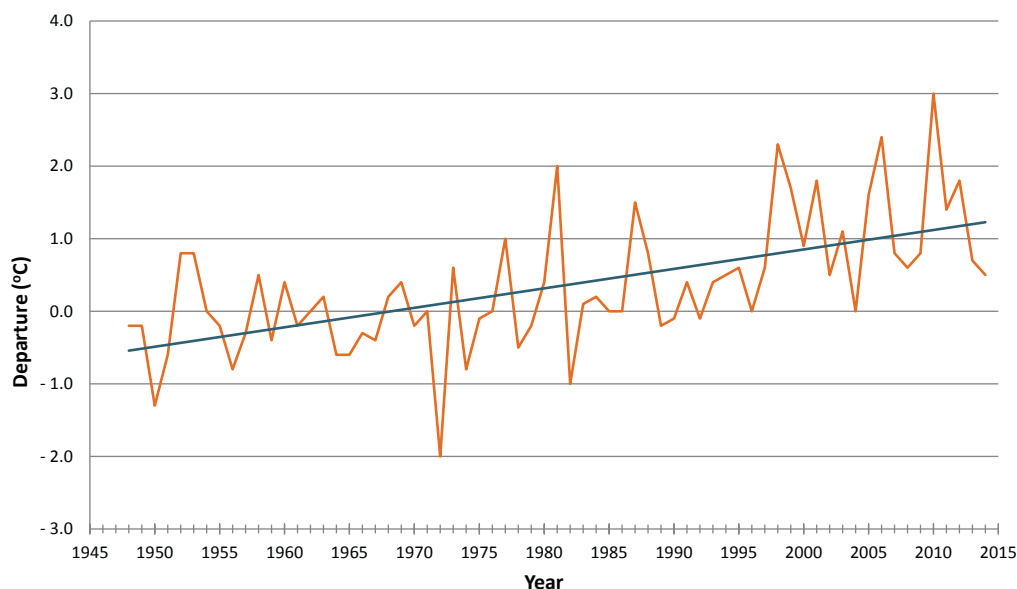
It is now well known that atmospheric concentrations of greenhouse gases (GHGs) have grown significantly since pre-industrial times. Since 1750, the concentration of atmospheric CO<sub>2</sub> has increased by 143%, CH<sub>4</sub> by 254% and nitrous oxide (N<sub>2</sub>O) by 121% (WMO 2015). These increases are caused by the use of fossil fuels as a source of energy and by land use and landuse changes, in particular agriculture (IPCC 2013).

Recent climate changes have had widespread impacts on human and natural systems. (IPCC 2014). In Canada, the impact of climate change may be felt in extreme weather events, the reduction of fresh water resources, increased risk and severity of forest fires and pest infestations, a reduction in Arctic ice and an acceleration of glacial melting. Canada’s national average temperature for 2014 was 0.5°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 67 years (Environment Canada 2015(a)).

#### 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

Figure 1–1 Annual Canadian Temperature Departures and Long-term Trend, 1948–2014



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 adapting to those impacts. Specifically, Articles 4 and 12 and Decision 24/CP.19 of the Convention commit all Parties to develop, periodically update,<sup>1</sup> publish and make available to the Conference of the Parties (COP) national inventories of anthropogenic<sup>2</sup> emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol<sup>3</sup> that use comparable methodologies.

This National Inventory Report (NIR) documents Canada's annual GHG emissions estimates for the period 1990–2014. 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 emissions and removals of the following GHGs: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, PFCs, HFCs, sulphur hexafluoride (SF<sub>6</sub>) and nitrogen trifluoride (NF<sub>3</sub>). 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<sub>x</sub>), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO<sub>x</sub>).

### Carbon Dioxide (CO<sub>2</sub>)

CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> concentrations since pre-industrial times across the globe (Hengeveld et al. 2005). Anthropogenic sources of CO<sub>2</sub> 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<sub>4</sub>)

CH<sub>4</sub> is a colourless, odourless, flammable gas that is the simplest hydrocarbon. CH<sub>4</sub> is present in the Earth's atmosphere at low concentrations and acts as a GHG. CH<sub>4</sub> 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<sub>4</sub> 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<sub>4</sub> is also released from industrial processes, fossil fuel extraction, coal mines, incomplete fossil fuel combustion and garbage decomposition in landfills.

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

N<sub>2</sub>O 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<sub>2</sub>O is most commonly produced via the heating of ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>). It is also released naturally from oceans, by bacteria in soils, and from animal wastes. Other sources of N<sub>2</sub>O 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.

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.

## Hydrofluorocarbons (HFCs)

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

## Sulphur hexafluoride (SF<sub>6</sub>)

SF<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub> 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<sub>3</sub>)

NF<sub>3</sub> is a colourless, non-flammable gas that is used in the electronics industry as a replacement for PFCs and SF<sub>6</sub>. It has a higher percentage of conversion to fluorine, which is the active agent in the industrial process, than PFCs and SF<sub>6</sub> for the same amount of electronics production. It is used in the manufacture of semiconductors, liquid crystal display (LCD) panels and photovoltaics. NF<sub>3</sub> 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<sub>3</sub> 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 heattrapping potential. The radiative forcing<sup>4</sup> 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<sub>2</sub>. 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<sub>2</sub>. It also allows characterization of GHG emissions in terms of how much CO<sub>2</sub> would be required to produce a similar warming effect over a given time period. This is called the carbon dioxide equivalent (CO<sub>2</sub> eq) value and is calculated by multiplying the amount of the gas by its associated GWP. This normalization to CO<sub>2</sub> eq enables the quantification of “total national emissions” expressed as CO<sub>2</sub> eq.

The IPCC develops and updates the GWPs for all GHGs. As GWP values are based on background conditions of GHG concentrations and climate, they need to be adjusted on a regular basis to capture the increase of gases already existing in the atmosphere and changing atmospheric conditions. Consistent with Decision 24/CP.19, 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<sub>4</sub>) 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<sub>2</sub> eq.

## 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

<sup>4</sup> 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 <sup>1</sup>
Carbon Dioxide	CO <sub>2</sub>	1
Methane <sup>2</sup>	CH <sub>4</sub>	25
Nitrous Oxide	N <sub>2</sub> O	298
Sulphur Hexafluoride	SF <sub>6</sub>	22 800
Nitrogen Trifluoride	NF <sub>3</sub>	17 200
Hydrofluorocarbons (HFCs)		
HFC-23	CHF <sub>3</sub>	14 800
HFC-32	CH <sub>2</sub> F <sub>2</sub>	675
HFC-41	CH <sub>3</sub> F	92
HFC-43-10mee	CF <sub>3</sub> CHFCHFCF <sub>2</sub> CF <sub>3</sub>	1 640
HFC-125	CHF <sub>2</sub> CF <sub>3</sub>	3 500
HFC-134	CHF <sub>2</sub> CHF <sub>2</sub>	1 100
HFC-134a	CH <sub>2</sub> FCF <sub>3</sub>	1 430
HFC-143	CH <sub>2</sub> FCHF <sub>2</sub>	353
HFC-143a	CH <sub>3</sub> CF <sub>3</sub>	4 470
HFC-152	CH <sub>2</sub> FCH <sub>2</sub> F	53
HFC-152a	CH <sub>3</sub> CHF <sub>2</sub>	124
HFC-161	CH <sub>3</sub> CH <sub>2</sub> F	12
HFC-227ea	CF <sub>3</sub> CHFCF <sub>3</sub>	3 220
HFC-236cb	CH <sub>2</sub> FCF <sub>2</sub> CF <sub>3</sub>	1 340
HFC-236ea	CHF <sub>2</sub> CHFCF <sub>3</sub>	1 370
HFC-236fa	CF <sub>3</sub> CH <sub>2</sub> CF <sub>3</sub>	9 810
HFC-245ca	CH <sub>2</sub> FCF <sub>2</sub> CHF <sub>2</sub>	693
HFC-245fa	CHF <sub>2</sub> CH <sub>2</sub> CF <sub>3</sub>	1 030
HFC-365mfc	CH <sub>3</sub> CF <sub>2</sub> CH <sub>2</sub> CF <sub>3</sub>	794
Perfluorocarbons (PFCs)		
Perfluoromethane	CF <sub>4</sub>	7 390
Perfluoroethane	C <sub>2</sub> F <sub>6</sub>	12 200
Perfluoropropane	C <sub>3</sub> F <sub>8</sub>	8 830
Perfluorobutane	C <sub>4</sub> F <sub>10</sub>	8 860
Perfluorocyclobutane	c-C <sub>4</sub> F <sub>8</sub>	10 300
Perfluoropentane	C <sub>5</sub> F <sub>12</sub>	9 160
Perfluorohexane	C <sub>6</sub> F <sub>14</sub>	9 300
Perfluorodecalin	C <sub>10</sub> F <sub>18</sub>	7 500
Perfluorocyclopropane	c-C <sub>3</sub> F <sub>6</sub>	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.

A detailed description of the functions of the Pollutant Inventories and Reporting Division is provided in Section “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.

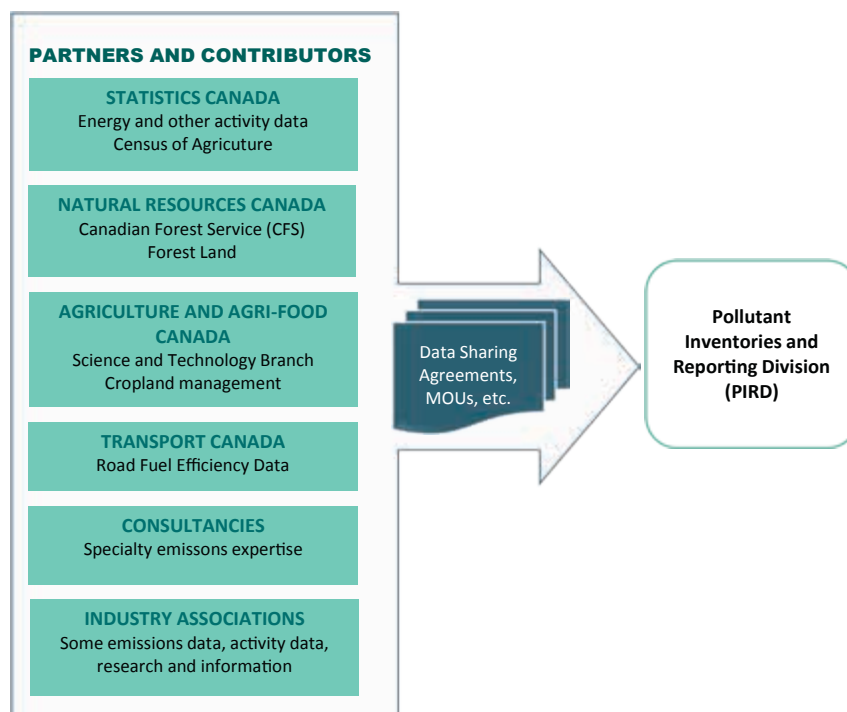
Sources and sinks of GHGs originate from a tremendous range of economic sectors and activities. Recognizing the need to draw on the best available technical and scientific expertise and information, Environment and Climate Change Canada has defined

roles and responsibilities for the preparation of the inventory, both internally and externally. As such, Environment and Climate 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.



Figure 1–2 Partners and Contributors to National Inventory Arrangements



### 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* (RESO). 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 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 RESO 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 nonenergy-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. In addition, the Earth Science Sector of NRCAN has 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.

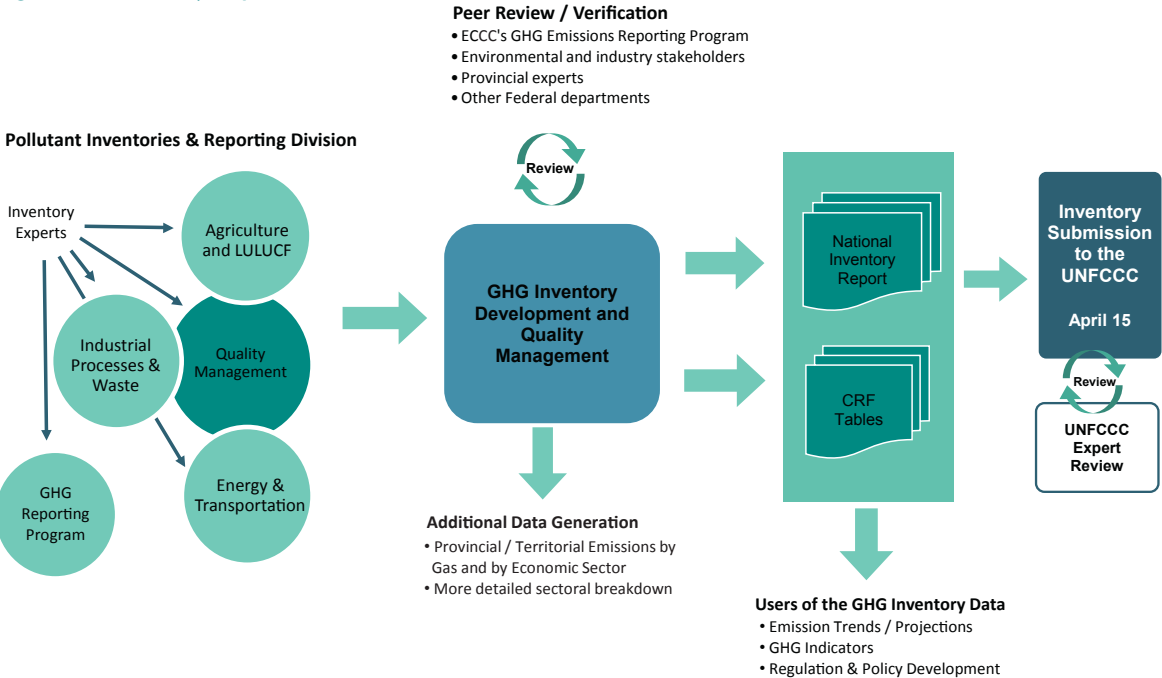
A bilateral agreement with the Aluminum Association of Canada (AAC) has been signed, under which process-related emission estimates for CO<sub>2</sub>, PFCs and SF<sub>6</sub> are to be provided annually to Environment and Climate Change Canada. A similar agreement has been negotiated with the Canadian Electricity Association (CEA) for provision of SF<sub>6</sub> 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 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.

Figure 1–3 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 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 development 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).
- Emissions from Croplands are aggregated across reporting zones at a national level 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 (Wnvironment Canada 2015 b).

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

#### 1.3.2.2. Quality Assurance Procedures

As per the 2006 IPCC Guidelines (IPCC 2006), QA activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process, and is performed in parallel with QC procedures. QA helps to ensure that the inventory represents the best possible

estimates of emissions and removals given the current state of scientific knowledge and data availability, and it supports the effectiveness of the QC program. As with QC, QA is undertaken every year on components of the inventory. Selected underlying data and methods are independently assessed each year by various groups and individual experts in industry, provincial governments, academia and other federal government departments. QA is undertaken for the assessment of the activity data, methodology and emission factor utilized for developing estimates, and is preferably carried out prior to making a decision on implementing a methodological change.

### 1.3.3. Planning and Prioritization of Improvements

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<sub>2</sub> 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.

Environment and Climate Change Canada's GHGRP website<sup>5</sup> provides public access to the reported GHG emission information (GHG totals by gas by facility). The total facility-reported GHG emissions for 2014 represent just over one third (36%) of Canada's total GHG emissions in 2014 (732 Mt) and over half (56%) 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 2014 Emissions* (Environment and Climate Change Canada 2016).

## 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.<sup>6</sup> Review reports are posted on-line by the UNFCCC Secretariat once finalized.<sup>7</sup> At the time of preparing this NIR, the results of Canada's last review were still forthcoming.

## 1.5. Methodologies and Data Sources

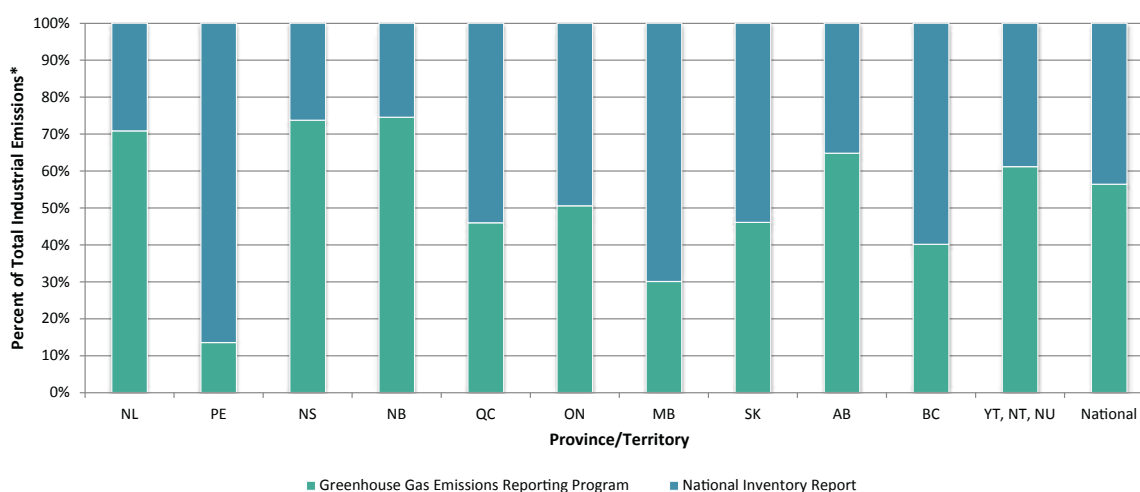
The inventory is structured to match the reporting requirements of the UNFCCC and is divided into the following five main sectors: Energy, Industrial Processes and Product Use, Agriculture,

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](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/inventory\\_review\\_reports/items/8452.php](http://unfccc.int/national_reports/annex_i_ghg_inventories/inventory_review_reports/items/8452.php).

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](http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=040E378D-1).

Figure 1–4 2014 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 1990–2014: Greenhouse Gas Sources and Sinks in Canada*: Stationary Combustion Sources (except Residential), Other Transportation, Fugitive Sources, Industrial Processes and Product Use, and Waste

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<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub>.

While not mandatory, the UNFCCC reporting guidelines encourage Parties to provide information on the following indirect GHGs: SO<sub>x</sub>, NO<sub>x</sub>, 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.<sup>8</sup>

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

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

Manipulated biological systems, such as agricultural lands, forestry and land converted to other uses, are sources or sinks diffused over very large areas. Processes that cause emissions and removals display considerable spatial and interannual variability, and they also span several years or decades. The most practical approach to estimating emissions and removals requires a combination of repeated measurements 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.

Information on Canada’s ozone and aerosol precursors, including carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO<sub>x</sub>) is available online at <http://www.ec.gc.ca/inrp-npri/donnees-data/ap/index.cfm?process=true&sector=&lang=en&year=1990-2013&substance=all&location=CA&submit=Submit>.

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 1990–2014 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 Off-road Transport. 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<sup>9</sup> 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 indepth 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. The calculation of trend uncertainties was only performed without the LULUCF Sector. 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  $\pm 4\%$ , consistent with the previously reported range of  $-3\%$  to  $+6\%$ . The Energy Sector had the lowest uncertainty, at  $\pm 5\%$ , while the Waste Sector had the highest uncertainty, at  $\pm 41\%$ . The Industrial Processes and Product Use and Agriculture Sectors had uncertainties of  $\pm 9$  and  $\pm 17\%$ , respectively.

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

- Energy – Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries, CO<sub>2</sub>;
- Waste – Solid Waste Disposal - Managed Waste Disposal Sites, CH<sub>4</sub>;

- Energy – Fuel Combustion – Public Electricity and Heat Production, CO<sub>2</sub>;
- Waste – Solid Waste Disposal - Uncategorized Waste Disposal Sites - Wood Waste Landfills, CH<sub>4</sub>; and
- Energy – Fuel Combustion – Other Transportation (Off-Road) N<sub>2</sub>O.

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 0.93%. Therefore, the total increase in emissions since 1990 has a 95% probability of being in the range of 19.5 to 21.4%. Given the high interannual variability in the LULUCF estimates, and the fact that it is primarily driven by highly variable natural disturbance factors, this sector is not considered in the analysis of anthropogenic GHG emissions and removals trends uncertainties.

## 1.8. Completeness Assessment

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

1. Categories that are not occurring in Canada;
2. Data unavailability at the category level;
3. Methodological issues specific to national circumstances; and/or
4. Emission estimates are considered insignificant<sup>10</sup>.

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).

<sup>10</sup> 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<sub>2</sub> 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)

<sup>9</sup> Uncertainty is the lack of knowledge of the true value of a variable that can be described as a probability density function characterizing the range and likelihood of possible values (IPCC 2006).



# Chapter 2

## Greenhouse Gas Emission Trends

### 2.1. Summary of Emission Trends

In 2014, Canada's greenhouse gas (GHG) emissions, excluding the Land Use, Land-use Change and Forestry (LULUCF) Sector, were 732 megatonnes of carbon dioxide equivalent (Mt CO<sub>2</sub> eq),<sup>1</sup> a net increase of 120 Mt in total emissions or 20% over 1990 emissions (Figure 2-1).<sup>2</sup> Steady increases in annual emissions characterized the first 10 years of this period, followed by fluctuating emission levels between 2000 and 2008, a steep drop in 2009, and a gradual increase thereafter. Emission increases since 2009 can be attributed to increases in energy consumption in Mining and Upstream Oil and Gas Production (24 Mt) and Manufactur-

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

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

ing Industries (5 Mt), the consumption of diesel fuel for off-road mobile equipment (9 Mt), and fugitive emissions from oil and natural gas (4 Mt). During the same period, there was a 15-Mt decrease in emissions from Public Electricity and Heat Generation, which partly offset emission growth. Section 2.3 provides more detail on these and other key drivers of these trends.

#### 2.1.1. GHG Emissions Intensity

Though GHG emissions have risen by 20% since 1990, Canada's economy grew more rapidly, with the gross domestic product (GDP) rising by 75%. As a result, the emissions intensity for the entire economy (or GHGs per GDP) has declined by 32% (Figure 2-2, Table 2-1). Early in the period, emissions rose nearly in step with economic growth, with their paths beginning to diverge in 1995 (Figure 2-2). This pattern 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 since the late 1990s.

#### 2.1.2. Emissions Trends per Capita

Although Canada represented approximately 1.6% of total global GHG emissions in 2012 (CAIT 2015), it is one of the highest per capita emitters. In 1990, Canadians released 22.1 tonnes (t) of GHGs per capita. In 2000, this indicator had risen to 24.3 t; however, by 2009, it had dropped to 20.7 t and has remained at historic lows ever since (Figure 2-3).

Figure 2-1 Canadian GHG Emissions Trend (1990-2014), 2020 Target, 2030 Target

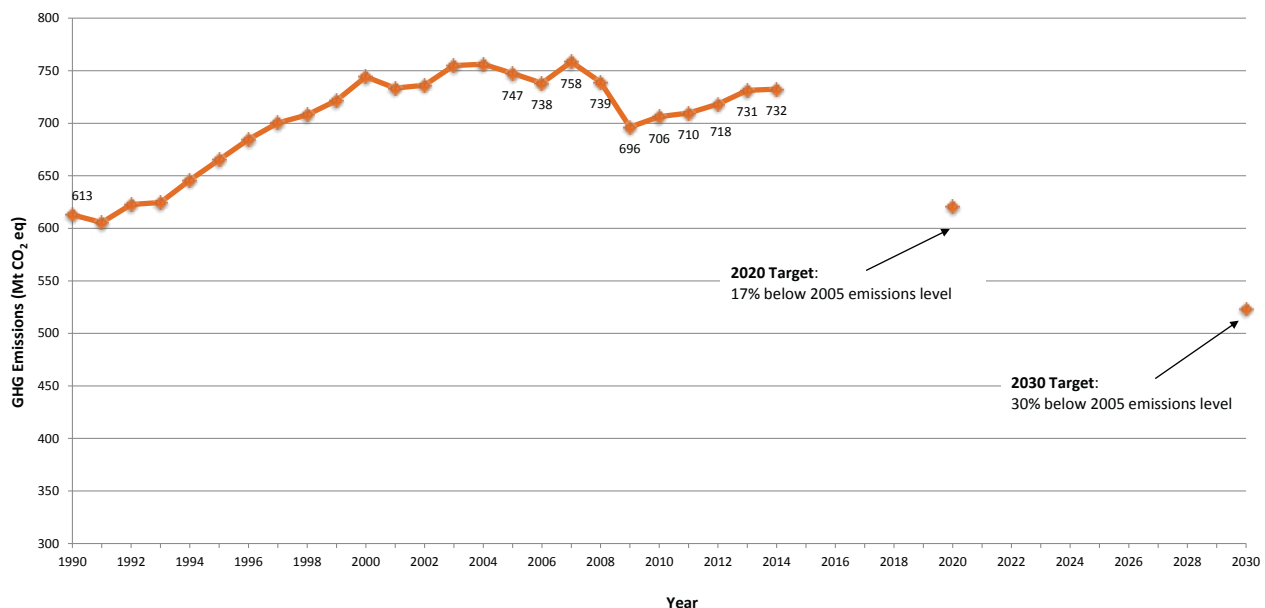
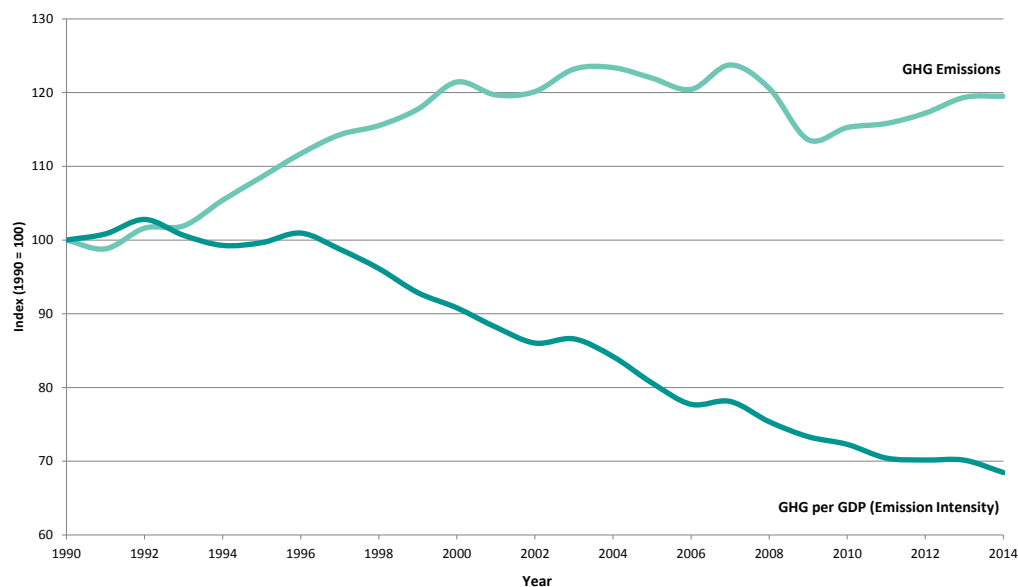


Figure 2–2 Indexed Trend in GHG Emissions and GHG Emissions Intensity (1990–2014)



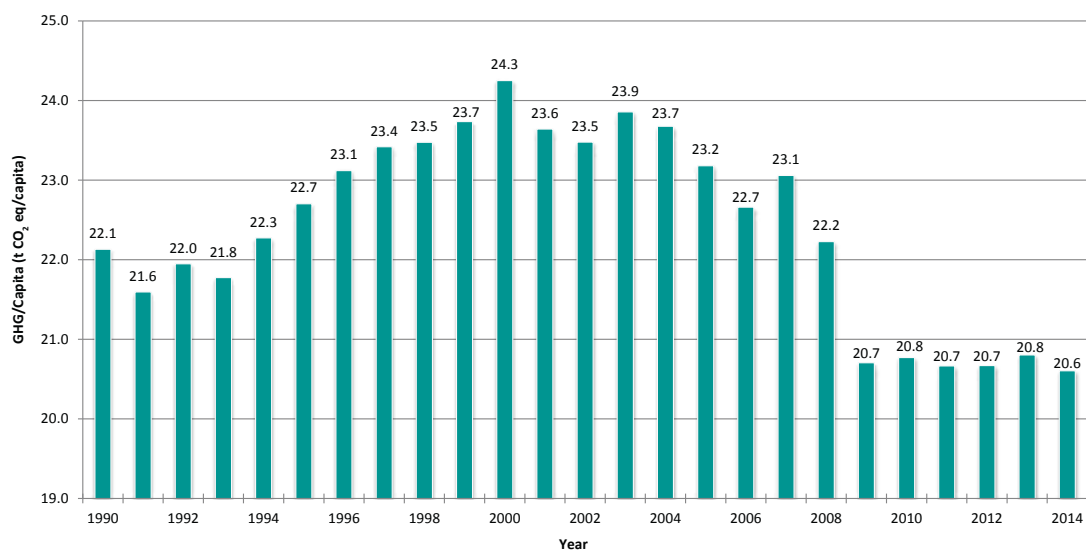
GDP data source: Statistics Canada (2015a) Table 380-0106 - Gross domestic product at 2007 prices, expenditure-based, annual (dollars). CANSIM (database)

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

Year	1990	2005	2009	2010	2011	2012	2013	2014
<b>Total GHG (Mt)</b>	<b>613</b>	<b>747</b>	<b>696</b>	<b>706</b>	<b>710</b>	<b>718</b>	<b>731</b>	<b>732</b>
Change since 2005 (%)	NA	NA	-6.8%	-5.5%	-5.0%	-3.9%	-2.1%	-2.0%
Change since 1990 (%)	NA	22.0%	13.6%	15.3%	15.8%	17.2%	19.3%	19.5%
<b>GDP (Billions 2007\$)</b>	<b>993</b>	<b>1 503</b>	<b>1 539</b>	<b>1 584</b>	<b>1 633</b>	<b>1 659</b>	<b>1 690</b>	<b>1 734</b>
Change since 2005 (%)	NA	NA	2.4%	5.4%	8.6%	10.4%	12.4%	15.4%
Change since 1990 (%)	NA	51.4%	55.0%	59.5%	64.5%	67.1%	70.2%	74.6%
<b>GHG Intensity (Mt/\$B GDP)</b>	<b>0.62</b>	<b>0.50</b>	<b>0.45</b>	<b>0.45</b>	<b>0.43</b>	<b>0.43</b>	<b>0.43</b>	<b>0.42</b>
Change since 2005 (%)	NA	NA	-9.0%	-10.3%	-12.6%	-12.9%	-13.0%	-15.1%
Change since 1990 (%)	NA	-19.4%	-26.7%	-27.7%	-29.6%	-29.8%	-29.9%	-31.6%

GDP data source: Statistics Canada (2015a) Table 380-0106 - Gross domestic product at 2007 prices, expenditure-based, annual (dollars)., CANSIM (database)

Figure 2–3 Canadian Per Capita Greenhouse Gas Emissions (1990–2014)



### 2.1.3. Emission Trends by Province/Territory

Emissions vary significantly by province, due to factors such as population, energy sources and economic structure. All else being equal, economies based on resource extraction will tend to have higher emission levels than service-based economies. Likewise, provinces that rely on fossil fuels for their electricity generation will have higher emissions than those that rely more on hydroelectricity (Figure 2–4).

Historically Alberta has been one of the highest emitting provinces; its emissions increased from 233 Mt in 2005 to 274 Mt in 2014 (17%), primarily due to the expansion of oil and gas opera-

tions (Table 2–2). In contrast, Ontario's emissions have steadily decreased since 2005 (by 40 Mt or 19%), resulting in large part from the closure of its coal-fired electricity generation plants.

Elsewhere across Canada, emissions in Saskatchewan have increased by 8.6% (6.0 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 (4% and 3% respectively). Electricity production in Quebec and British Columbia relies on abundant hydroelectric resources, resulting in more stable emission patterns across the time series, with decreasing emissions in both provinces since 2005. Quebec experienced a 7.8% (7.0 Mt) decrease from its 2005 emissions level, while British

Figure 2–4 Emissions by Province in 1990, 2005 and 2014

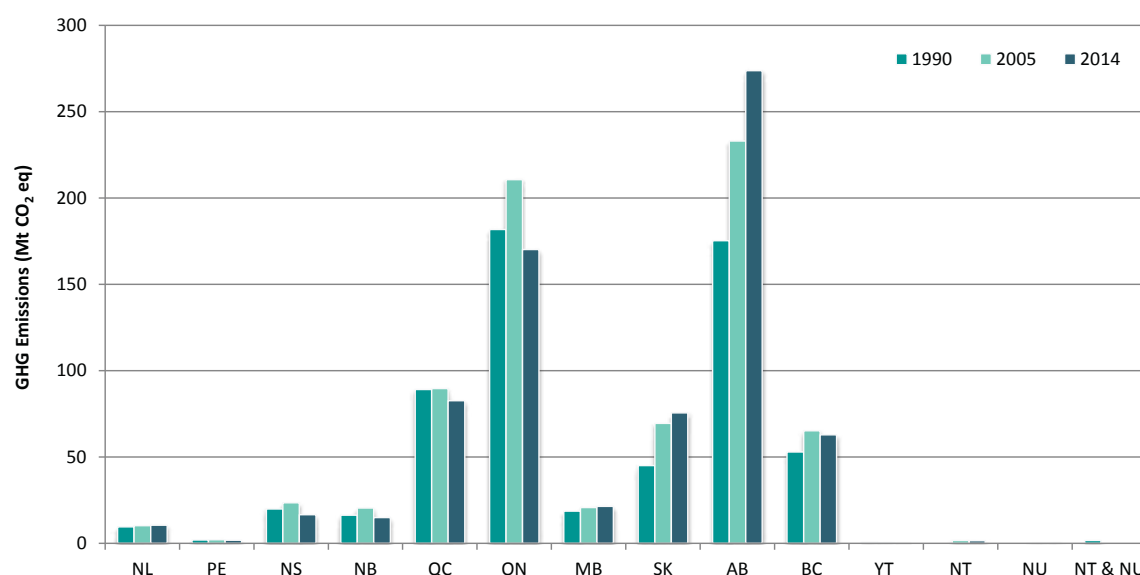


Table 2–2 GHG Emissions Provinces / Territories, Selected Years

Year	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)
	1990	2005	2009	2010	2011	2012	2013	2014	
GHG Total (Canada)	613	747	696	706	710	718	731	732	20%
NL	9.6	10.2	10.1	10.3	10.3	9.8	9.6	10.6	10%
PE	2.0	2.1	1.9	2.0	2.1	2.1	1.8	1.8	-8%
NS	20	23	21	20	21	19	18	17	-17%
NB	16	20	19	19	19	17	15	15	-9%
QC	89	90	87	82	84	82	83	83	-7%
ON	182	211	171	179	175	171	171	170	-6%
MB	19	21	20	20	19	21	21	21	15%
SK	45	70	70	70	69	72	74	76	68%
AB	175	233	234	242	246	260	272	274	56%
BC	53	65	61	61	61	63	63	63	19%
YT	0.5	0.5	0.3	0.3	0.4	0.4	0.4	0.3	-50%
NT <sup>2</sup>	NA	1.7	1.2	1.4	1.4	1.5	1.4	1.5	-
NU <sup>2</sup>	NA	0.3	0.4	0.4	0.2	0.2	0.2	0.3	-
NT&NU <sup>2</sup>	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 1999–2014 is provided for both Nunavut and the Northwest Territories, and the years 1990–1998 are presented as a combined region (see Annex A<sub>11</sub> for more information).

Columbia had a decline of 3.4% (2.2 Mt). Emissions in Nova Scotia, New Brunswick and Prince Edward Island have also decreased since 2005, especially in Nova Scotia (29% reduction).

## 2.2. Emission Trends by Gas

Canada's emissions profile is similar to that of most industrialized countries. Carbon dioxide (CO<sub>2</sub>) is the largest contributor to Canada's GHG emissions, accounting for 574 Mt in 2014, an increase of 111 Mt (or 24%) over 1990 values of 463 Mt. The majority of the CO<sub>2</sub> emissions in Canada result from the combustion of fossil fuels. The relative contribution of CO<sub>2</sub> to Canada's total emissions profile changed only slightly between 1990 and 2014 (76% vs. 78%, respectively). (Figure 2–5).

Methane (CH<sub>4</sub>) emissions in 2014 amounted to 108 Mt and accounted for 15% of Canada's total emissions. These emissions are largely from fugitive sources in oil and natural gas systems (45%–50% of total CH<sub>4</sub> emissions), as well as agriculture (26%–30% of total CH<sub>4</sub> emissions) and landfills (24%–26% of total CH<sub>4</sub> emissions). Nationally, CH<sub>4</sub> emissions have increased by 14% (13 Mt) since 1990, largely due to the development of petroleum resources, although emissions have also increased in all CH<sub>4</sub> sources.

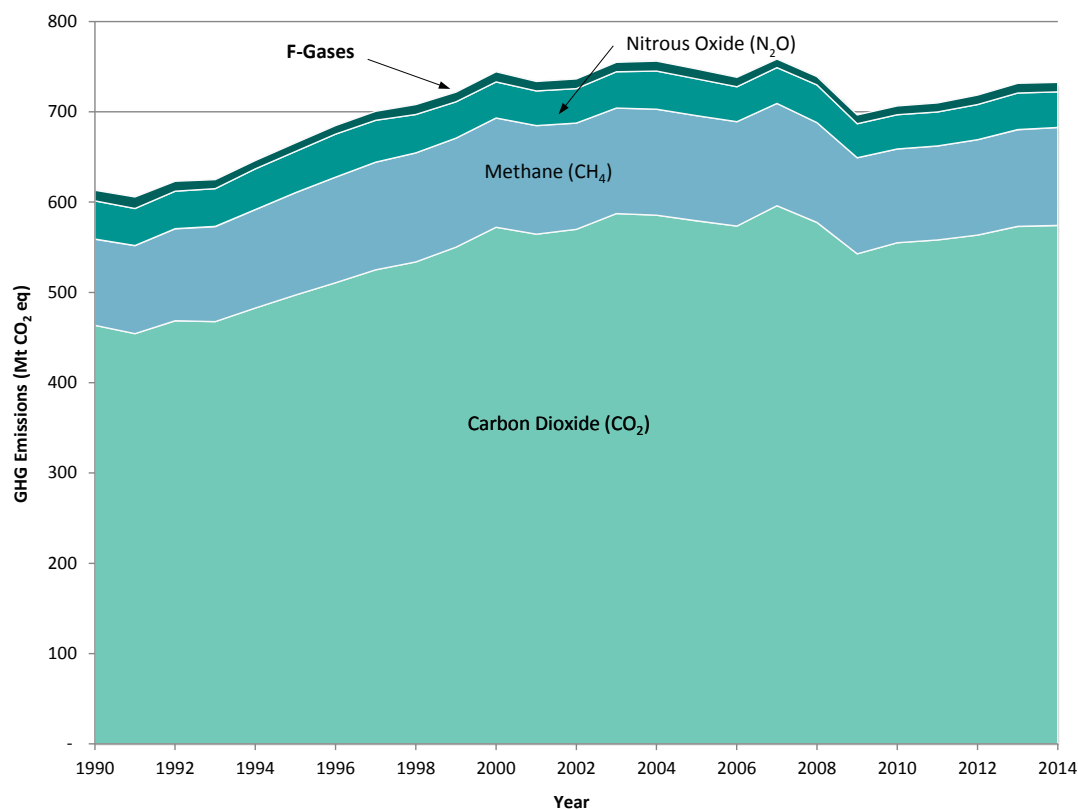
Nitrous oxide (N<sub>2</sub>O) emissions arise from activities such as agriculture soil management and transport and accounted for 5% or 39 Mt of Canada's emissions in 2014, down 7% (3 Mt) from 1990 levels. Since 1990, a 10-Mt decrease in N<sub>2</sub>O emissions has occurred in the Industrial Processes and Product Use Sector, due to cessation of adipic acid production in Canada. At the same time, emissions from the Agriculture Sector have increased by 30% (6 Mt), due to increased fertilizer use and animal emissions. As a result, in 2014 agriculture accounted for 70% of national N<sub>2</sub>O emissions, up from 50% in 1990.

Together, perfluorocarbons (PFCs), sulphur hexafluoride (SF<sub>6</sub>), hydrofluorocarbons (HFCs) and nitrogen trifluoride (NF<sub>3</sub>) accounted for 10 Mt or slightly more than 1% of Canada's emissions in 2014. From 1990 to 2014, emissions of HFCs rose by 8.1 Mt (830%), while emissions of PFCs and SF<sub>6</sub> decreased by 6.5 Mt (85%) and 2.9 Mt (89%), 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

The Energy Sector (consisting of Stationary Combustion, Transport, and Fugitive Sources) accounted for the majority of

Figure 2–5 Trends in Canadian GHG Emissions by Gas (1990–2014)



Note: F-gases consist of HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub>.

Canada's total emissions in 2014, at 81% or 594 Mt. 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 (4%). The LULUCF Sector emitted 72 Mt in 2014; in accordance with UNFCCC reporting guidelines, these emissions are excluded from national inventory totals.

Over the period 1990–2014, total emissions grew by 120 Mt or 20%. The Energy Sector dominated the long-term trend, with increases of 55 Mt (37%) in Transport, 46 Mt (16%) in Stationary Combustion and 11 Mt (22%) in Fugitive Sources. Over the same period, emissions in the Agriculture and Waste sectors increased by 10 Mt (21%) and 2 Mt (10%), respectively, while the IPPU Sector saw a decrease of 5 Mt (9%) (Figure 2–6 and Table 2–3).

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 826% (or 8.1 Mt) from Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub>, a 161% (8.1 Mt) increase from Non-Energy Products from Fuel and Solvent Use, a 111% (1.3 Mt) increase from Liming, Urea Application and Other Carbon-Containing Fertilizers, and a 79% (0.18 Mt) decrease in emissions from Field Burning of Agricultural Residues.

### 2.3.1. Energy Sector (2014 GHG emissions, 594 Mt)

Energy consumption is by far the largest source of GHG emissions in Canada. The Energy Sector includes emissions from the production of fuels and their combustion for the primary purpose of delivering energy. 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<sub>2</sub> Transport and Storage. A detailed description of each category is provided in Chapter 3.

In 2014, the Energy Sector accounted for 594 Mt or 81% of total emissions in Canada. Emissions from Stationary Combustion and Transport dominate the trends in this sector; between 1990 and 2014, emissions from Transport increased by 55 Mt, emissions from Stationary Combustion rose by 46 Mt and emissions from Fugitive Sources increased by 11 Mt.

#### 2.3.1.1. Stationary Combustion (2014 GHG Emissions, 331 Mt)

Stationary Combustion accounts for the largest portion (56%) of emissions from the Energy Sector. In 2014, emissions totaled

Figure 2–6 Trends in Canadian GHG Emissions by IPCC Sector (1990–2014)

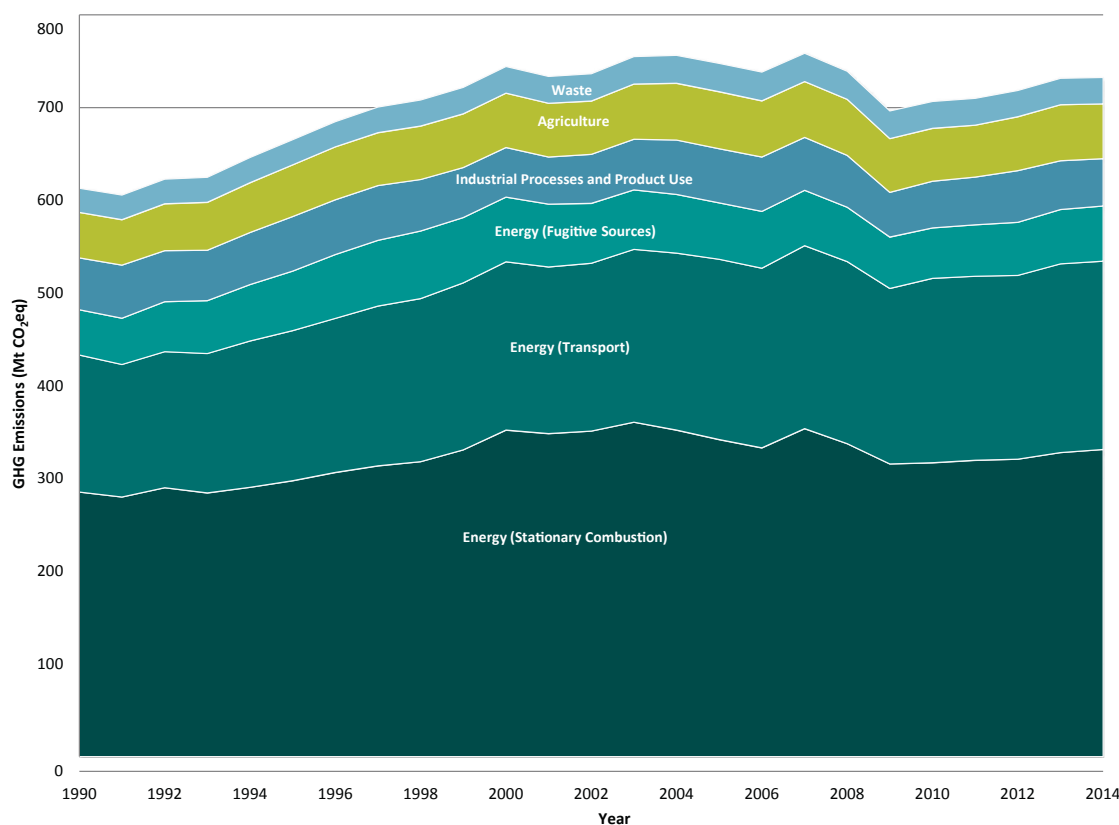


Table 2–3 Canada's GHG Emissions by IPCC Sector, Selected Years

Greenhouse Gas Categories		1990	2005	2009	2010	2011	2012	2013	2014
		<i>Mt CO<sub>2</sub> equivalent</i>							
<b>TOTAL</b> <sup>1,2</sup>		<b>613</b>	<b>747</b>	<b>696</b>	<b>706</b>	<b>710</b>	<b>718</b>	<b>731</b>	<b>732</b>
<b>ENERGY</b>		<b>482</b>	<b>597</b>	<b>560</b>	<b>570</b>	<b>574</b>	<b>576</b>	<b>590</b>	<b>594</b>
a.	Stationary Combustion Sources	285	342	316	317	320	321	328	331
	Public Electricity and Heat Production	95	124	100	102	95	92	88	86
	Petroleum Refining Industries	17	20	19	18	18	19	18	17
	Mining and Upstream Oil and Gas Production	41	68	78	80	82	91	99	101
	Manufacturing Industries	56	49	40	41	45	44	45	46
	Construction	2	1	1	2	1	1	1	1
	Commercial & Institutional	26	32	30	28	30	28	29	31
	Residential	46	45	45	42	46	42	44	46
	Agriculture & Forestry	2	2	3	3	3	4	4	4
b.	Transport	148	195	189	199	199	198	204	203
	Domestic Aviation	7	8	6	6	6	7	8	7
	Road Transportation	100	136	140	142	140	141	144	140
	Railways	7	7	5	7	8	8	7	8
	Domestic Navigation	5	6	6	7	6	6	5	5
	Other Transportation	29	38	31	37	39	37	39	43
	Off-Road Gasoline	5	6	5	5	5	5	4	6
	Off-Road Diesel	17	21	20	26	29	27	28	29
	Pipeline Transport	7	10	6	6	6	6	7	8
c.	Fugitive Sources	49	61	55	54	55	57	58	60
	Coal Mining	3	1	1	1	1	1	2	1
	Oil and Natural Gas	46	59	54	53	54	56	57	58
d.	CO <sub>2</sub> Transport and Storage	-	0	0	0	0	0	0	0
<b>INDUSTRIAL PROCESSES AND PRODUCT USE</b>		<b>56</b>	<b>58</b>	<b>48</b>	<b>50</b>	<b>51</b>	<b>56</b>	<b>53</b>	<b>51</b>
a.	Mineral Products	8	10	7	8	8	8	8	8
b.	Chemical Industry	17	9	6	5	6	6	6	6
c.	Metal Production	24	20	16	16	17	17	15	15
d.	Production and Consumption of Halocarbons, SF <sub>6</sub> and NF <sub>3</sub>	1	6	7	7	8	8	9	9
e.	Non-Energy Products from Fuels and Solvent Use	5	12	12	13	12	15	15	13
f.	Other Product Manufacture and Use	0	1	0	0	0	1	1	0
<b>AGRICULTURE</b>		<b>49</b>	<b>61</b>	<b>58</b>	<b>57</b>	<b>56</b>	<b>58</b>	<b>60</b>	<b>59</b>
a.	Enteric Fermentation	23	31	27	26	25	25	25	25
b.	Manure Management	8	10	9	8	8	8	8	8
c.	Agricultural Soils <sup>3</sup>	17	19	20	21	20	22	24	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	2	3	3
<b>WASTE</b>		<b>26</b>	<b>31</b>	<b>30</b>	<b>29</b>	<b>29</b>	<b>28</b>	<b>28</b>	<b>29</b>
a.	Solid Waste Disposal	24	28	27	26	26	26	26	26
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
<b>LAND USE, LAND-USE CHANGE AND FORESTRY</b>		<b>-87</b>	<b>1</b>	<b>-40</b>	<b>55</b>	<b>69</b>	<b>41</b>	<b>-30</b>	<b>72</b>
a.	Forest Land and Harvested Wood Products	-108	-0	-38	56	71	41	-29	72
b.	Cropland	10	-9	-10	-9	-9	-9	-9	-8
c.	Grassland	1	1	0	0	1	2	1	1
d.	Wetlands	6	4	4	4	4	4	4	3
e.	Settlements	4	4	4	4	4	4	4	4

## 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
3. Includes emissions from Field Burning of Agricultural Residues

331 Mt, an increase of 16% from the 1990 level of 285 Mt (Figure 2-7, Table 2-4).

Dominant categories in Stationary Combustion are Mining and Upstream Oil and Gas Production, which contributes 31% of the total Stationary Combustion emissions, and Public Electricity and Heat Production, which contributes 26%. Manufacturing Industries and Residential each contribute 14% of the total Stationary Combustion emissions, while Commercial and Institutional contributes 9%.

## Public Electricity and Heat Production (2014 GHG emissions, 86 Mt)

The Public Electricity and Heat Production category accounts for 14% (86 Mt) of the 2014 GHG emissions in the Energy Sector and saw a 10% decrease in emissions between 1990 and 2014.

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

Figure 2-7 Trends in Canadian GHG Emissions from Stationary Combustion Sources (1990–2014)

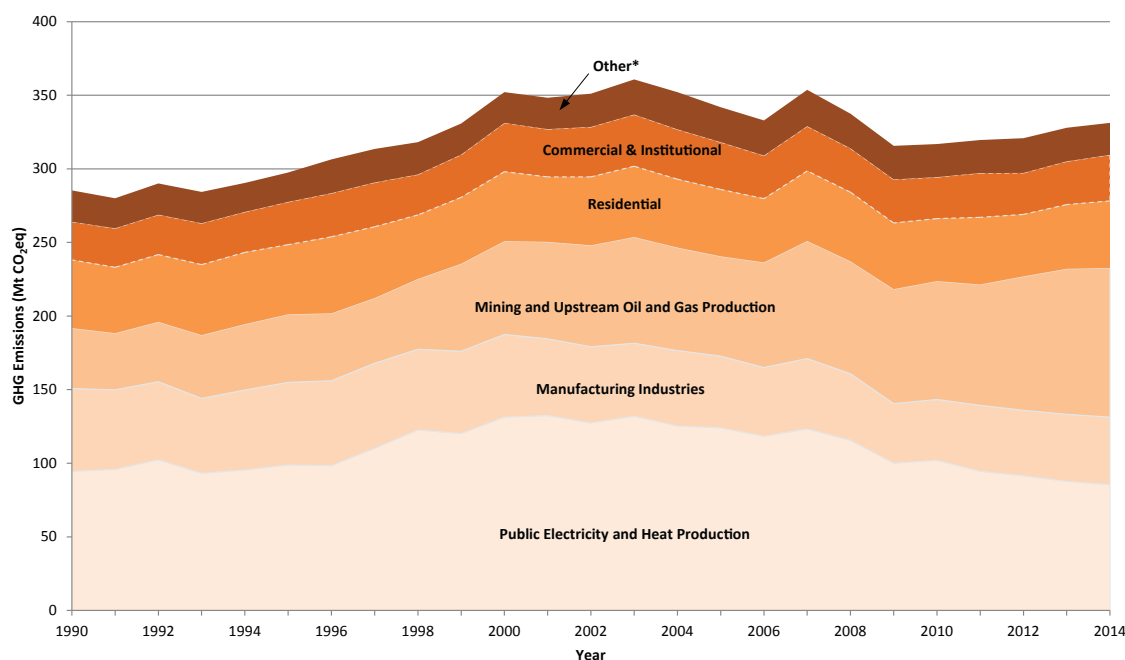
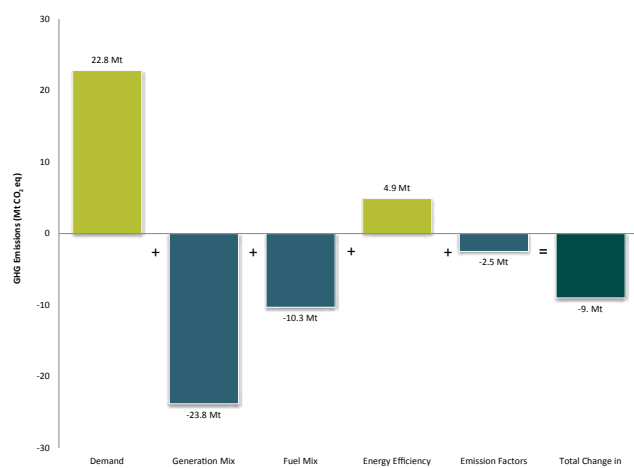


Table 2-4 GHG Emissions from Stationary Combustion Sources, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)
	1990	2005	2009	2010	2011	2012	2013	2014	
<b>Stationary Combustion Sources<sup>1</sup></b>	<b>285</b>	<b>342</b>	<b>316</b>	<b>317</b>	<b>320</b>	<b>321</b>	<b>328</b>	<b>331</b>	<b>16%</b>
Public Electricity and Heat Production	95	124	100	102	95	92	88	86	-10%
Petroleum Refining	17	20	19	18	18	19	18	17	-1.8%
Mining and Upstream Oil and Gas Production	41	68	78	80	82	91	99	101	147%
Manufacturing Industries	56	49	40	41	45	44	45	46	-19%
Iron and Steel	5	6	4	4	5	5	6	6	23%
Non Ferrous Metals	3	4	3	3	3	3	3	3	-14%
Chemical	8	8	9	10	11	11	12	12	46%
Pulp and Paper	15	9	6	6	6	6	6	6	-57%
Cement	4	5	4	4	4	4	4	4	2.5%
Other Manufacturing	21	17	14	14	15	15	15	14	-32%
Construction	2	1	1	2	1	1	1	1	-32%
Commercial and Institutional	26	32	30	28	30	28	29	31	21%
Residential	46	45	45	42	46	42	44	46	-1.6%
Agriculture and Forestry	2	2	3	3	3	4	4	4	53%

Note:

1. Totals may not add up due to rounding.

**Figure 2–8 Influence of Contributing Factors on the Change in GHG Emissions from the Public Electricity and Heat Production Category, 1990–2014 (Mt CO<sub>2</sub> 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.

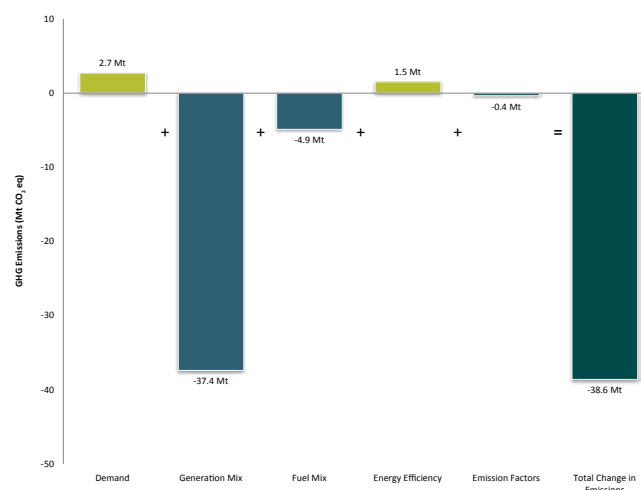
**Emission factors** – The emission factor effect reflects changes to fuel energy content over time.

between non-GHG-emitting and high-GHG-emitting sources. Electricity generation increased by 30% between 1990 and 2014 (Statistics Canada 1990–2004, 2015b, 2015c), from 491 TWh<sup>3</sup> to 641 TWh, due to increased demand in all but the commercial sector.

Despite the increase in demand between 1990 and 2014, GHG emissions dropped by 9 Mt. In fact, between 2005 and 2014, electricity generation rose by 3%, while emissions fell by 31% (39 Mt). The principal cause of the decrease in emissions is a less GHG-intensive mix of sources used to generate electricity (Figure 2–8). This, in turn, is a result of a decrease in the use of GHG-intensive fuels for combustion, and an increase in non-combustion sources of generation (nuclear and renewable generation, i.e. hydroelectric generation, wind turbines, solar photovoltaic cells and tidal energy).

Non-combustion sources accounted for 100% of the increased generation between 1990 and 2014. Generation from combustion sources has actually decreased by 1% since 1990. Renewable sources contributed 63% of the total electricity generated in Canada in 2014, with hydroelectric generation responsible for 61% and other renewables, 2%. Overall, renewable generation has increased by 37% since 1990. The increased level of non-combustion sources in the generation mix in 2014 was the largest contributor to emission reductions since 1990 (-24 Mt) and 2005 (-37 Mt).

3 1 TWh is 1 billion kWh. It is the amount of electricity consumed by about 90,000 households in Canada in approximately one year.

**Figure 2–9 Influence of Contributing Factors on the Change in GHG Emissions from the Public Electricity and Heat Production Category, 2005–2014 (Mt CO<sub>2</sub> eq)**

Combustion generation sources have been steadily switching from high to low GHG-intensive fossil fuels. Between 1990 and 2014, the quantity of electricity generated by natural-gas-fired units increased by 660% (27 TWh), while the amount generated by coal and refined petroleum products decreased by about 26% (22 TWh) and 81% (12 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 2014.

### Mining and Upstream Oil and Gas Production (2014 GHG emissions, 101 Mt)

Mining and Upstream Oil and Gas Production accounted for 17% (101 Mt) of Energy Sector emissions in 2014 and saw a 147% (60 Mt) increase in emissions between 1990 and 2014. This category includes emissions associated with the combustion of fuel in the oil extraction, natural gas and coal extraction industries, and non-energy mining such as iron ore, gold, diamonds, potash and aggregates.

All elements of the upstream oil and gas (UOG) industry, which includes the natural gas production and processing, conventional oil production and oil sands mining, extraction and upgrading industry segments, have seen significant growth since



1990. Natural gas production has increased by 51% since 1990 (Statistics Canada 2015d), conventional oil production by 21% (Statistics Canada 2015e), and crude oil from the oil sands industry (comprised of synthetic crude oil and non-upgraded crude bitumen) by 528% (AER 2015). The increased production volumes in all UOG segments have resulted in additional energy demands for extraction, which has led to increased emissions. The large increase in emissions from non-upgraded bitumen production is strongly correlated to the increased use of steam-assisted gravity drainage (SAGD) to extract crude bitumen. SAGD 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 produced by combusting large amounts of natural gas, leading to increased emissions. In fact, over the past decade, natural gas consumption in this subcategory has increased by over 200%, and SAGD production has increased by almost 800% (AER 2015).

Between 2013 and 2014, emissions from Mining and Upstream Oil and Gas Production increased by 2.5% (2.5 Mt). This is consistent with a 4% increase in natural gas production and an almost 20% increase in the production of non-upgraded bitumen production. There was a 6% increase in natural gas consumption in upstream oil and gas between 2013 and 2014, which is consistent with the 26% increase in crude bitumen produced using SAGD (AER 2015).

Note that the breakdown of emissions by IPCC categories for the Energy Sector does not provide a transparent sectoral view of trends within Canada's oil and gas sector. 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) and where emissions from Fugitive Sources, Off-Road Transportation and cogeneration units are allocated to their respective economic sectors. Some discussion of trends in the oil and gas industry by economic sector is also presented in Section 2.4.1.

## Manufacturing Industries (2014 GHG emissions, 46 Mt)

Combustion-based GHG emissions from the Manufacturing Industries and Construction 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 2014, GHG emissions from the Manufacturing Industries category were 46 Mt, which represents a 19% decrease from 1990. While emissions from the Manufacturing Industries category declined from 1996 until 2009, they have been steadily increasing since 2009; however, they still remain below 1990 levels. This

category was responsible for 7.7% of emissions in the Energy Sector in 2014.

The Pulp, Paper and Print subcategory has shown the largest decrease within the Manufacturing Industries category. Between 1990 and 2014, the emissions from this subcategory decreased by 8.3 Mt (57%). This can be attributed to closures in the industry along with substitution of biomass-based fuels in place of conventional generation sources (a 4.5% increase from 1990 to 2014). On the opposite end, the Chemicals subcategory has shown the largest increase within the Manufacturing Industries category, with emissions increasing by 3.8 Mt (46%). This is generally consistent with a 19% increase in the economic output (GDP) of the chemical industry in the same period (CIEEDAC 2015).

## Residential, Commercial and Institutional (2014 GHG emissions, 77 Mt)

GHG emissions in the Residential and Commercial & Institutional subcategories come primarily from the combustion of fuel to heat residential, commercial and institutional buildings, excluding electricity. Emissions in these categories contributed 77 Mt of GHG emissions in 2014, a 6.5% increase since 1990. Fuel combustion in the Residential and Commercial & Institutional categories<sup>4</sup> accounted for 7.7% (46 Mt) and 5.3% (31 Mt), respectively, of emissions from the Energy Sector in 2014.

Overall, residential emissions decreased by 0.7 Mt (1.6%) between 1990 and 2014, while commercial emissions increased by 5.4 Mt. Analysis shows that weather, 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 & Institutional subcategories (Figure 2–7 and Figure 2–11). As demonstrated, these factors impact space heating requirements and, therefore, demand for natural gas, home heating oil and biomass fuels.

In the Residential subcategory, population and floor space per capita are the most significant upward drivers of emissions. Since 1990, the 28% increase in population (Statistics Canada 2015f) and 29%<sup>5</sup> increase in floor space per capita account for emission increases of 11.2 Mt and 11.6 Mt, respectively (Figure 2–10). (The sum of these two drivers represents the total impact of floor space). These increases have been offset by improvements in energy efficiency, which are equivalent to a 24-Mt decrease in emissions between 1990 and 2014.

4 Commercial & institutional subcategory emissions are based on fuel use as reported in the *Report on Energy Supply and Demand in Canada* (RES-D) (Statistics Canada 1990–) 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.

5 Lam, M. 2016. Personal communication (email from Lam, M. to Tracey, K., Program Engineer, PIRD dated January 14, 2016). 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 2014)

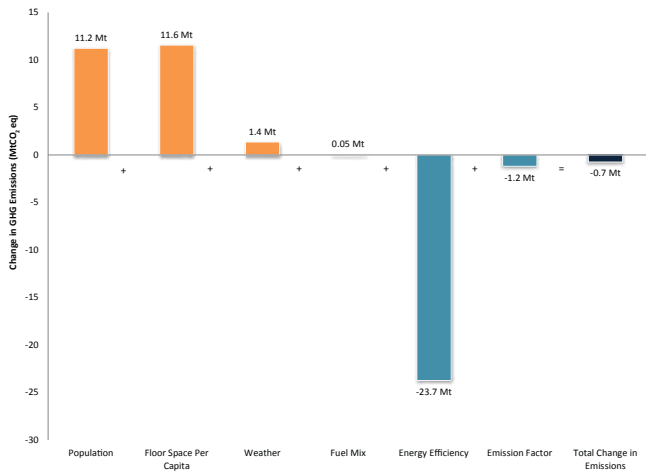
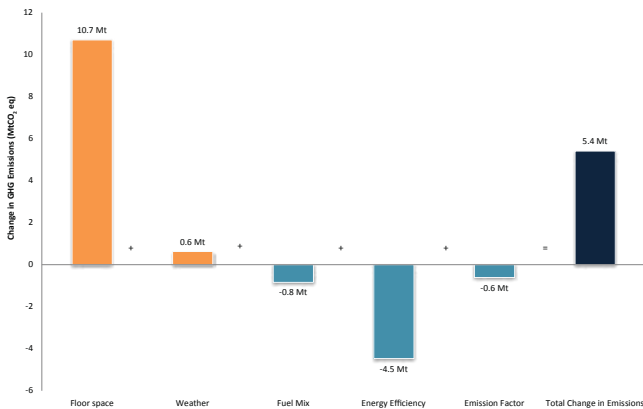


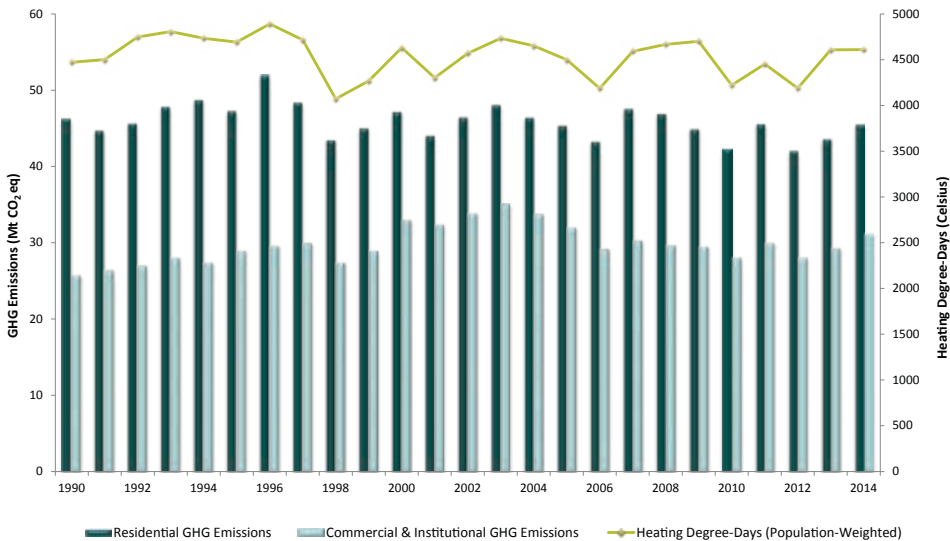
Figure 2–11 Influence of Contributing Factors on the Change in Stationary GHG Emissions from the Commercial and Institutional Subcategory between 1990 and 2014



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 which can have an effect on GHG emissions.  
**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 fuel energy content over time

Figure 2–12 GHG Emissions and Heating Degree-Days (HDDs) from the Residential and Commercial & Institutional Subcategories, 1990–2014



In the Commercial & Institutional subcategory, floor space was the most significant upward driver, having increased by 47% since 1990,<sup>6</sup> associated with a 10.7-Mt increase in emissions between 1990 and 2014 (Figure 2–11). The largest offset to these impacts is caused by improvements in energy efficiency, equivalent to a 4.5-Mt decrease in GHG emissions.

Weather was one of the smaller impacts on the change in emissions between 1990 and 2014 for both the Residential and the Commercial & Institutional subcategories. However, weather 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 2–12). The influence that weather can have on space heating requirements and demand for fuels results in emission patterns that mirror the variability of weather.

<sup>6</sup> Behidj, N. 2015. Personal communication (email from Behidj, N. to Tracey, K., Program Engineer, PIRD dated January 11, 2016). Office of Energy Efficiency, Natural Resources Canada.

## Other Stationary Combustion Sources (2014 GHG emissions, 22 Mt)

Other Stationary Combustion Sources comprise fuel combustion emissions from the Petroleum Refining category, as well as the Construction, and Agriculture and Forestry subcategories. Overall, this group exhibited increases in GHG emissions of 1.8% (0.38 Mt) from 1990 to 2014.

### 2.3.1.2. Transport (2014 GHG emissions, 203 Mt)

Transport is a large and diverse subsector. With 203 Mt of GHG emissions, it accounted for 34% of Canada's Energy Sector emissions in 2014. 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 2014, Transport emissions rose 37% (55 Mt), accounting for a significant portion of Canada's emissions growth.

Emissions from Transport result primarily from Road Transportation, which includes personal transportation (light-duty gasoline vehicles and trucks) and heavy-duty diesel trucks (Figure 2-13). Off-road is the second largest subcategory, accounting for 21% of Transport emissions, mainly through diesel fuel combustion. The Domestic Aviation, Domestic Navigation and Railways categories combined contributed to approximately 10% of the Transport

subsector's emissions in 2014 and, overall, have been stable over the 1990–2014 time series.

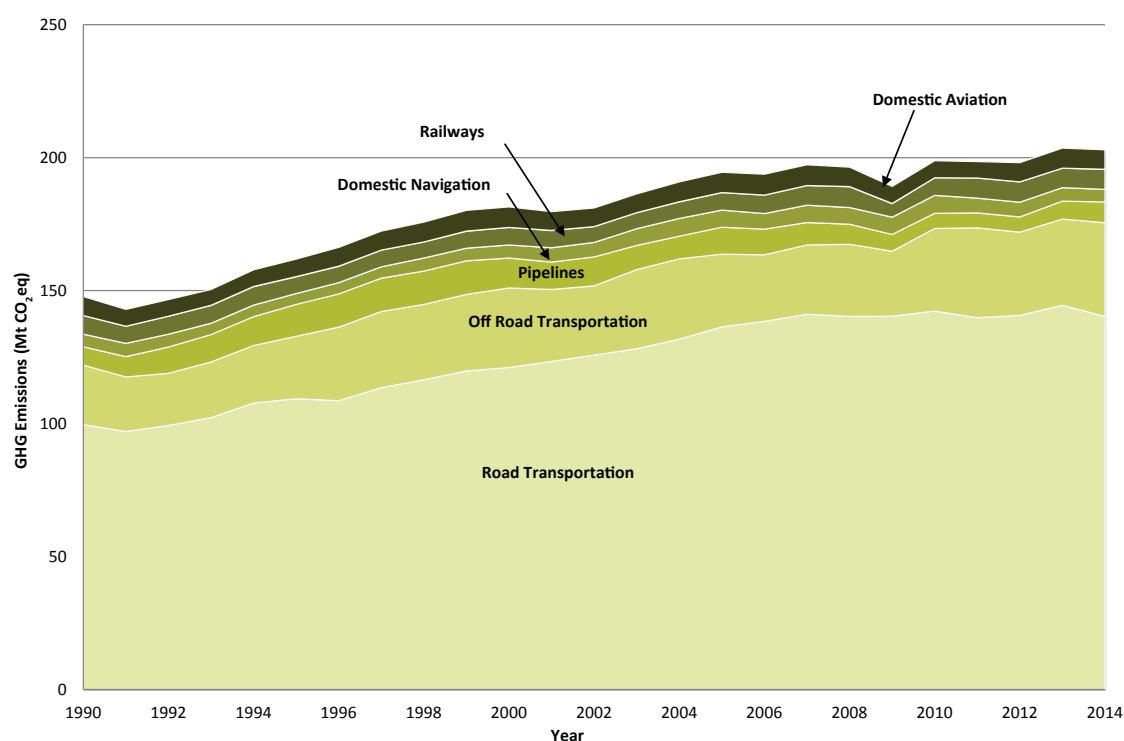
## Road Transportation (2014 GHG emissions, 140 Mt)

The growth in road transport emissions is largely due to more driving in both the light- and heavy-duty subclasses. The total vehicle fleet has increased by 66% since 1990 (20% since 2005) most notably for light-duty trucks and heavy-duty vehicles (Table 2-6). Despite a reduction in kilometres driven per vehicle, the total kilometres travelled for the entire vehicle fleet increased by 47% over the same time period.

## Light-duty gasoline vehicles (2014 GHG emissions, 34 Mt)

Within the light-duty gasoline vehicle (LDGV) subcategory, the total number of vehicles and associated vehicle kilometres travelled (VKTs) increased, while the fleet average fuel consumption ratio decreased, resulting in a net emissions decrease of 32% (from 50 Mt in 1990 to 34 Mt in 2014). 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

Figure 2-13 Trends in Canadian GHG Emissions from Transport (1990–2014)



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

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)
	1990	2005	2009	2010	2011	2012	2013	2014	1990-2014
<b>Transport<sup>1</sup></b>	<b>148</b>	<b>195</b>	<b>189</b>	<b>199</b>	<b>199</b>	<b>198</b>	<b>204</b>	<b>203</b>	<b>37%</b>
Domestic Aviation	7.2	7.6	6.5	6.5	6.2	7.3	7.5	7.4	2.8%
Road Transportation	100	136	140	142	140	141	144	140	41%
Light-Duty Gasoline Vehicles	50	44	41	41	38	37	37	34	-32%
Light-Duty Gasoline Trucks	21	41	44	45	45	46	48	48	131%
Heavy-Duty Gasoline Vehicles	5.9	7.2	7.8	7.9	7.5	7.8	8.2	7.9	34%
Motorcycles	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	110%
Light-Duty Diesel Vehicles	0.5	0.5	0.5	0.6	0.7	0.8	0.8	0.8	77%
Light-Duty Diesel Trucks	0.2	0.4	0.4	0.5	0.5	0.5	0.6	0.6	218%
Heavy-Duty Diesel Vehicles	20	42	45	46	47	48	48	48	142%
Propane and Natural Gas Vehicles	2.2	0.7	0.8	0.8	0.8	0.9	0.7	0.8	-64%
Railways	6.9	6.6	5.1	6.6	7.5	7.6	7.3	7.5	8.5%
Domestic Navigation	4.8	6.4	6.5	6.8	5.6	5.6	5.1	4.7	-1.9%
Other Transportation	29	38	31	37	39	37	39	43	47%
Off-Road Gasoline	5.3	6.1	4.6	5.2	4.8	4.5	4.3	6.3	19%
Off-Road Diesel	17	21	20	26	29	27	28	29	69%
Pipeline Transport	6.9	10.2	6.4	5.7	5.6	5.7	6.7	7.9	14%

**Table 2-6 Trends in Vehicle Populations for Canada, 1990–2014**

Year	Number of Vehicles (000s)			
	Light-Duty Vehicles		Heavy-Duty Vehicles	All Vehicles
	Cars	Trucks		
1990	10 755	3 371	968	15 356
2005	11 008	6 875	1 690	20 017
2009	11 995	8 556	2 129	23 274
2010	12 016	8 918	2 154	23 704
2011	11 909	9 271	2 141	23 953
2012	11 895	9 621	2 267	24 444
2013	12 269	10 237	2 359	25 537
2014	12 299	10 765	2 420	26 178
Change since 1990	14%	204%	144%	66%
Change since 2005	8%	35%	27%	20%

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

total kilometres travelled and shifts in vehicle type (Figure 2-14). Implementation of emission control technologies and increased use of biofuels since the 1990s have also resulted in decreased emissions.

### Light-duty gasoline trucks (2014 GHG emissions, 48 Mt)

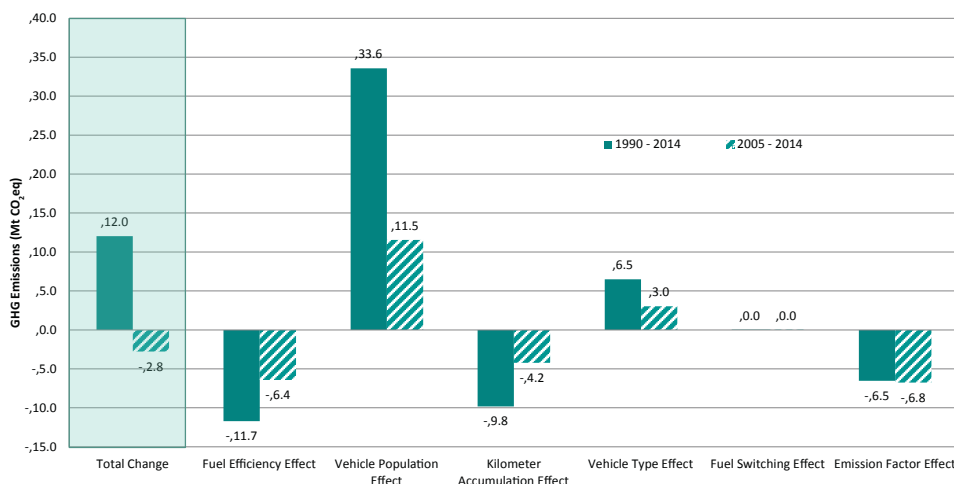
On average, light-duty trucks—including sport utility vehicles (SUVs), many pickups and all minivans—emit 45% more GHGs per kilometre than cars. Emissions from Light-duty Gasoline Trucks (LDGTs) subcategory increased 131% between 1990 and 2014 (from 21 Mt in 1990 to 48 Mt in 2014). While a decrease in the associated fleet fuel consumption ratios was observed between 1990 and 2014, 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 (2014 GHG emissions, 48 Mt)

In 2014, emissions from heavy-duty diesel vehicles (HDDVs) contributed 48 Mt to Canada's total GHG emissions (an increase of about 142% from 1990 and 13% from 2005). Emissions from heavy-duty gasoline vehicles (HDGVs) have remained relatively unchanged since 2004, indicating a preference for diesel vehicles for freight transport. 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

Figure 2-14 Contributing Factors on Change in Light-Duty Vehicle Emissions, 1990–2014 and 2005–2014



## Notes:

**Total change** is the difference in total emissions over the selected time periods, 1990–2014 and 2005–2014.

**Fuel efficiency effect** 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** refers to the change in emissions due to average annual driving rates.

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

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

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

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.

conclusively that freight hauling by heavy trucks has increased substantially and that this activity is the primary task performed by HDGVs and HDDVs (Statistics Canada 2016). 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) (2014 GHG emissions, 35 Mt)

Off-road emissions result from the combustion of diesel and gasoline in a wide variety of applications that, collectively, increased from 22 Mt in 1990 to 35 Mt in 2014 (an increase of 57%). Examples of applications include: 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 lawn-mowers and trimmers. In 2014, agriculture, mining and oil and gas extraction, and residential and recreational use represented 30%, 25% and 13% of off-road emissions, respectively.

### Pipeline Transport (2014 GHG emissions, 7.9 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 2015c).

Even though overall natural gas consumption has increased since 2005, 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 Canadian (Statistics Canada 2015g).

In the past few years, this trend has started to reverse. Since 2011, emissions from Pipeline Transport have increased by almost 40%, while imports to Ontario have decreased by 24% and inter-regional transfers have increased by over 200% (Statistics Canada 2015g).

### 2.3.1.3. Fugitive Sources (2014 GHG Emissions, 60 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 combusted before disposal (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 categories: Coal Mining and Oil and Natural Gas (Table 2–7). Emissions from the Oil and Natural Gas category contributed 98% of

Figure 2–15 Trends in Canadian GHG Emissions from Fugitive Sources (1990–2014)

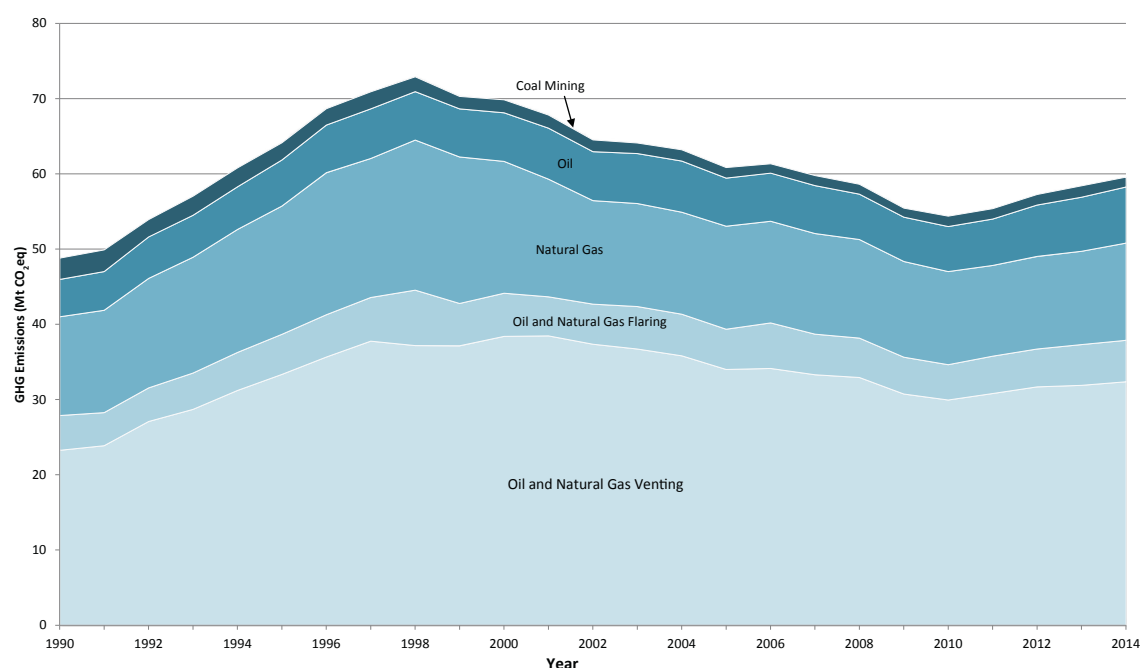


Table 2–7 GHG Emissions from Fugitive Sources, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)
	1990	2005	2009	2010	2011	2012	2013	2014	
<b>Fugitive Sources<sup>1</sup></b>	<b>49</b>	<b>61</b>	<b>55</b>	<b>54</b>	<b>55</b>	<b>57</b>	<b>58</b>	<b>60</b>	<b>22%</b>
Coal Mining	3	1	1	1	1	1	2	1	-53%
Oil and Natural Gas	46	59	54	53	54	56	57	58	27%
Oil <sub>2</sub>	5	6	6	6	6	7	7	7	50%
Natural Gas <sup>2</sup>	13	14	13	12	12	12	12	13	-1.5%
Venting	23	34	31	30	31	32	32	32	39%
Flaring	5	5	5	5	5	5	5	6	19%

Note:

1. Totals may not add up due to rounding.

2. These categories represent fugitive releases due to leakage from oil and natural gas systems.

the total fugitive emissions in 2014, with Coal Mining accounting for the remaining 2%. Overall, these sources constituted about 10% of Energy Sector emissions in 2014 and alone contributed 9% to the growth in emissions between 1990 and 2014 (Figure 2–15).

Fugitive emissions grew by 22% between 1990 and 2014, from 49 to 60 Mt (Table 2–7). Fugitive emissions from Oil and Natural Gas alone increased 27% (12.3 Mt) while releases from Coal Mining decreased by 1.5 Mt (53%) because of mine closures in eastern Canada.

The growth in Oil and Natural Gas fugitive emissions between 1990 and 2014 (Figure 2–15) is a result of increased activity in the oil and gas sector. Since 1990, over 350,000 oil and gas wells have been drilled, and the number of producing oil and gas wells has increased by 220% (CAPP 2015). 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.

This has been offset by improved inspection and maintenance programs, industry practices, technological improvements and regulations.

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.

Following Alberta's lead, British Columbia introduced the *Flaring and Venting Reduction Guideline* in 2010 (BCOGC 2015), and in 2012 the *Saskatchewan Upstream Petroleum Industry Associated Gas Conservation Directive S-10* was adopted (Sask ECON 2015), both of which are similar to Directive 060.



## 2.3.2. Industrial Processes and Product Use (2014 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<sub>6</sub> and NF<sub>3</sub>, Non-Energy Products from Fuels and Solvent Use, and Other Product Manufacture and Use.<sup>7</sup> Emissions from the IPPU Sector contributed 51 Mt (7%) to Canada's 2014 emissions, compared with 56 Mt (9%) in 1990, a decrease of approximately 5 Mt or 9%. Total emissions in this sector result

<sup>7</sup> 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.

Figure 2-16 Trends in Canadian GHG Emissions from IPPU Sources (1990–2014)

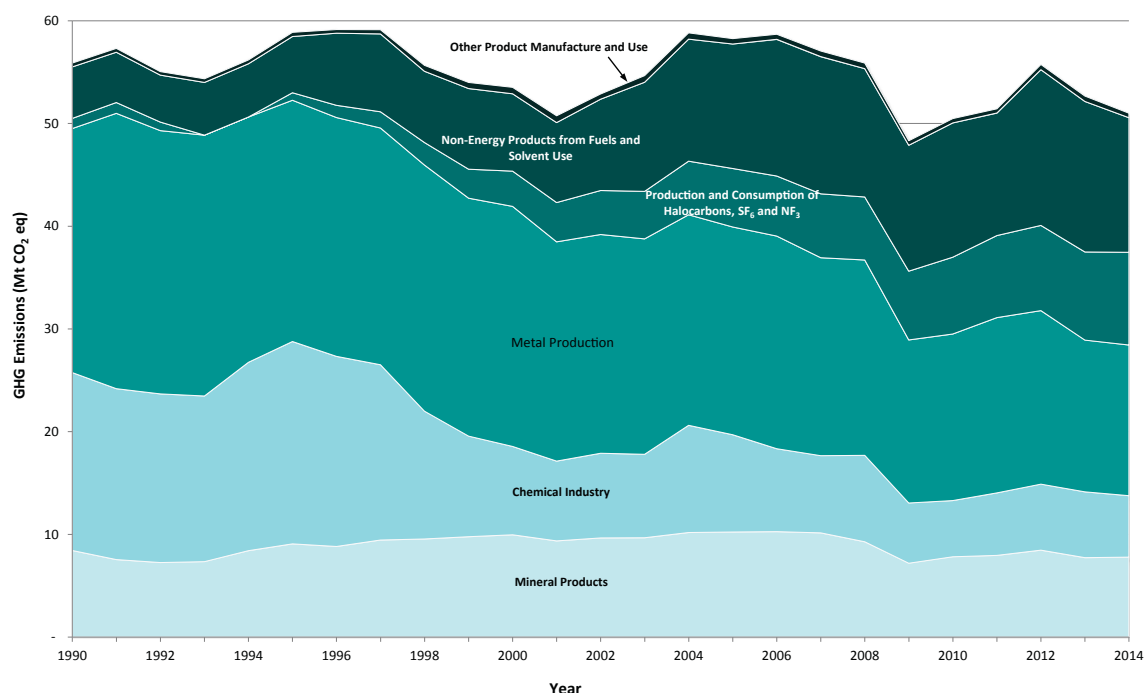


Table 2-8 GHG Emissions from IPPU Categories, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)
	1990	2005	2009	2010	2011	2012	2013	2014	
<b>Total - Industrial Processes</b>	<b>56</b>	<b>58</b>	<b>48</b>	<b>50</b>	<b>51</b>	<b>56</b>	<b>53</b>	<b>51</b>	<b>-8.7%</b>
Mineral Products	8.4	10	7.2	7.8	7.9	8.5	7.7	7.8	-7.8%
Cement Production	5.8	7.6	5.4	6.0	6.1	6.6	6.0	6.0	3.5%
Lime Production	1.8	1.7	1.2	1.4	1.4	1.4	1.4	1.4	-18%
Mineral Product Use	0.9	0.9	0.6	0.4	0.5	0.4	0.4	0.4	-58%
Chemical Industry	17	9.5	5.9	5.5	6.1	6.4	6.4	6.0	-65%
Ammonia Production	2.8	2.7	2.4	2.5	2.9	3.0	2.9	2.5	-8.6%
Nitric Acid Production	1.0	1.2	1.1	1.1	1.1	1.1	1.0	1.0	5.3%
Adipic Acid Production	10	2.5	0.6	-	-	-	-	-	-100%
Petrochemical Production & Carbon Black Production	3.3	3.0	1.7	1.9	2.1	2.3	2.5	2.4	-25%
Metal Production	24	20	16	16	17	17	15	15	-38%
Iron and Steel Production	10	10	8.1	9.2	10	10	8.0	8.6	-18%
Aluminium Production	10	8.7	7.5	6.9	6.8	6.5	6.5	5.8	-43%
SF <sub>6</sub> Used in Magnesium Smelters and Casters	3.0	1.2	0.2	0.2	0.2	0.2	0.2	0.2	-92%
Production and Consumption of Halocarbons, SF <sub>6</sub> and NF <sub>3</sub>	1.0	5.7	6.7	7.5	8.0	8.3	8.6	9.0	826%
Non-Energy Products from Fuels and Solvent Use	5.0	12	12	13	12	15	15	13	161%
Other Product Manufacture and Use	0.4	0.5	0.4	0.4	0.4	0.5	0.5	0.4	18.7%

Note: Totals may not add up due to rounding.

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<sub>2</sub>O), Aluminium Production (PFCs), and Iron and Steel Production (CO<sub>2</sub>) since 1990. These reductions were mainly offset by increases observed in Non-Energy Products from Fuels and Solvent Use (CO<sub>2</sub>),<sup>8</sup> and Production and Consumption of Halocarbons (HFCs) (Figure 2–16 and Table 2–6).

### 2.3.2.1. Mineral Products (2014 GHG Emissions, 7.8 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 0.7 Mt (7.8%) from 1990 to 2014. Emissions associated with lime production and mineral product use accounted for a decrease of 0.9 Mt, which was offset by a 0.2-Mt increase in Cement Production. Emissions from the Cement Production category followed changes in Canadian clinker production peaking in 2007 at 7.8 Mt and totalling 6.0 Mt in 2014.

### 2.3.2.2. Chemical Industry (2014 GHG Emissions, 6.0 Mt)

A decrease of 11.3 Mt (65.4%) from 1990 to 2014 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.<sup>9</sup> Further emission reductions (1.0 Mt) are consistent with decreases in ammonia and petrochemical production levels.

### 2.3.2.3. Metal Production (2014 GHG Emissions, 15 Mt)

Emission reductions in the production of magnesium, aluminium, and iron and steel dominated the overall reduction of 9.1 Mt (38%) from Metal Production between 1990 and 2014.

Magnesium production in Canada ceased in 2009 and accounted for 2.7 Mt of the reductions in Metal Production.

The aluminium industry decreased its perfluorocarbon (PFC) emissions by 6.5 Mt (86%), while increasing production by 83% between 1990 and 2014 (AAC 2014), largely due to technological improvements. The magnesium production industry also showed

a decrease in emissions as a result of the replacement of SF<sub>6</sub> with alternatives and the closure of plants over the years.

From 1990 to 2014, emissions in the iron and steel industry decreased by 1.9 Mt (18%). The main drivers behind the decrease in emissions were reductions in overall production levels and an increase in the use of scrap steel relative to pig iron consumption (Statistics Canada 1990-2003, Statistics Canada 2004-2012, CSPA 2013-2014).

### 2.3.2.4. Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub> (2014 GHG Emissions, 9 Mt)

The consumption of hydrofluorocarbons (HFCs) has accounted for an 8.3-Mt (1132%) increase in emissions since 1995. 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<sub>6</sub>, NF<sub>3</sub>) 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 (2014 GHG Emissions, 13 Mt)

The Non-energy Products from Fuels and Solvent Use category is one of the largest emission source in the IPPU Sector, with emissions increasing by 8.1Mt (161%) from 1990 to 2014. CO<sub>2</sub> emissions from the feedstock use of waxes, paraffin and unfinished petrochemical derivatives increased by 6.2 Mt (1201%). The emissions from use of coal decreased by 0.6 Mt (73%), and emissions from use of petrochemical feedstock increased by 1.0 Mt (122%).

## 2.3.3. Agriculture Sector (2014 GHG Emissions, 59 Mt)

In 2014, emissions from the Agriculture Sector accounted for 59 Mt or 8% of total 2014 GHG emissions for Canada, down 2 Mt from their peak in 2005, but nonetheless an increase of 10 Mt or 21% since 1990 (Figure 2–17, Table 2–9). In 2014, the Agriculture Sector accounted for 27% of national CH<sub>4</sub> emissions and 70% of national N<sub>2</sub>O emissions, up from 50% of the national N<sub>2</sub>O 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

<sup>8</sup> 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.

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



Figure 2-17 Trends in Canadian GHG Emissions from Agriculture Sources (1990–2014)

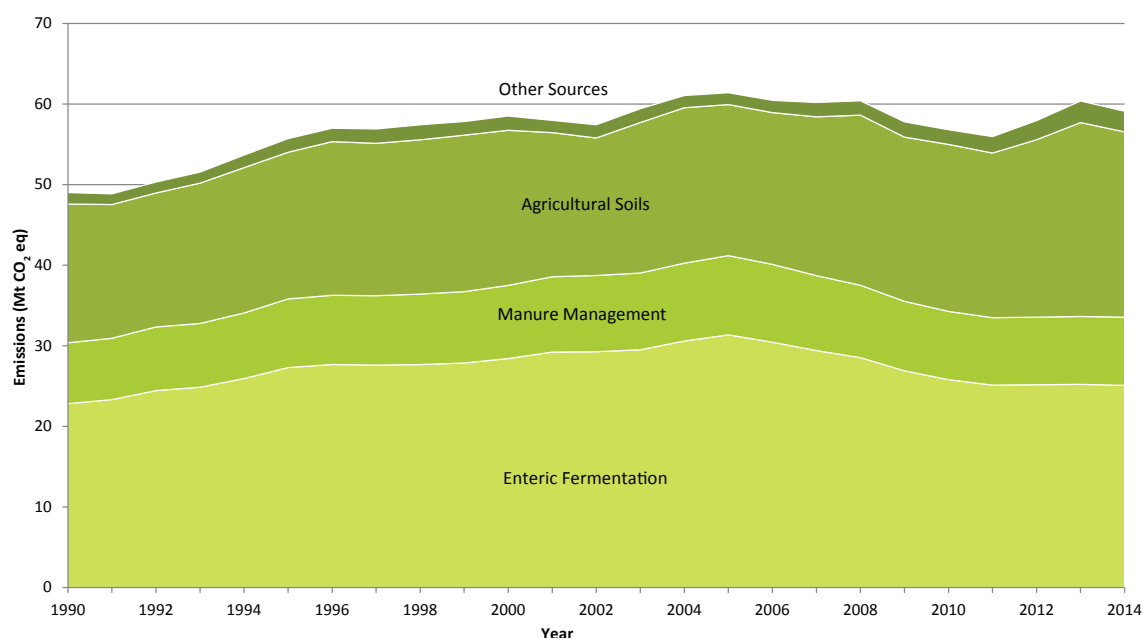
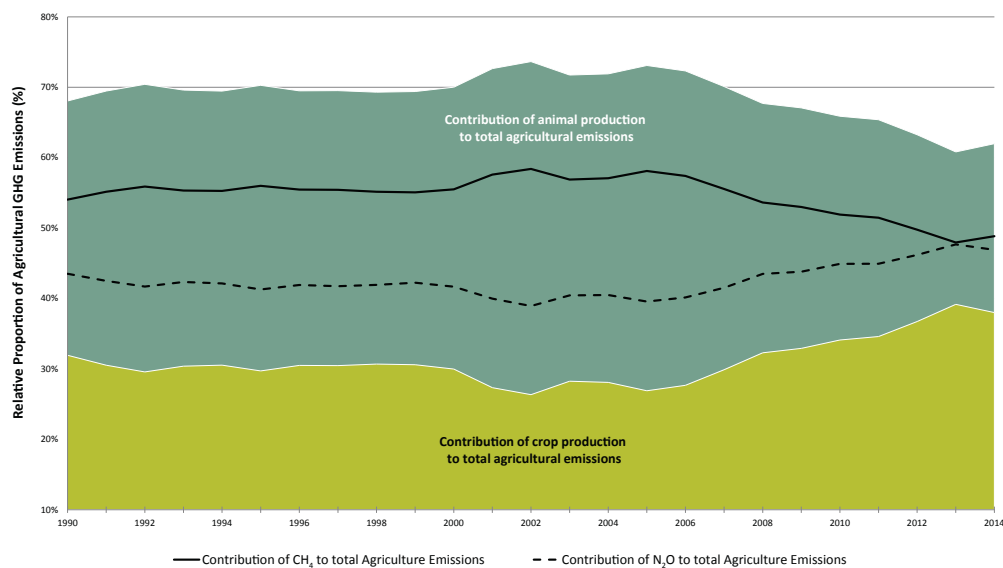


Table 2-9 GHG Emissions from Agriculture, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)							Change (%)	
	1990	2005	2009	2010	2011	2012	2013	2014	1990-2014
<b>Agriculture</b>	<b>49</b>	<b>61</b>	<b>58</b>	<b>57</b>	<b>56</b>	<b>58</b>	<b>60</b>	<b>59</b>	<b>21%</b>
Enteric Fermentation	23	31	27	26	25	25	25	25	10%
Manure Management	7.6	9.8	8.6	8.5	8.4	8.4	8.4	8.5	12%
Agricultural Soils	17	19	20	21	20	22	24	23	34%
Field Burning of Agricultural Residues	0.23	0.05	0.05	0.03	0.03	0.04	0.05	0.05	-79%
Liming, Urea Application and Other Carbon-containing Fertilizers	1.2	1.4	1.8	1.8	2.0	2.3	2.6	2.5	111%

Note: Totals may not add up due to rounding.

Figure 2-18 Proportions of Canadian Agricultural Greenhouse Gas Emissions Emitted as Methane and Nitrous Oxide, or attributed to Livestock and Crop Production (1990–2014)



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<sub>4</sub>) and all emissions (CH<sub>4</sub> and N<sub>2</sub>O) from the storage and handling of animal manure. The crop production sector includes: N<sub>2</sub>O emissions from the application of inorganic nitrogen fertilizers, crop residue decomposition, animal manure applied as fertilizers and crop management practices; CH<sub>4</sub> and N<sub>2</sub>O emissions from the burning of agricultural residues; and CO<sub>2</sub> emissions from agricultural use of lime and urea-based nitrogen fertilizers. 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 12%, 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 107% higher than in 1990 due to increases in cropping intensity resulting from changes in land management and commodity price trends.

Since 2005, as a result of the decline in animal populations and continued increase in fertilizer use, the proportion of emissions from livestock in 2013 and 2014 dropped to its lowest proportion (61% and 62% of total emissions) of the reporting period, considerably lower than the proportion in 2005 (73% of total emissions) (Figure 2–18). As a result of this shift, total agricultural emissions now consist of equivalent proportions of CH<sub>4</sub> (from livestock production) and N<sub>2</sub>O (mainly from crop production). The increasing emissions from crop production are also reflected in a decreased carbon sink in soils reported in the LULUCF Sector due to a shift from perennial crops to annual crops.

### 2.3.3.1. Enteric Fermentation (2014 GHG Emissions, 25 Mt)

In 2014, enteric fermentation emissions represented 42% of agricultural emissions. These emissions originate almost entirely from cattle production in Canada (96% of total). From 1990 to 2014, emissions increased from 23 Mt to 25 Mt, or 10%. The CH<sub>4</sub> emitted from enteric fermentation makes up 87% of total agricultural CH<sub>4</sub> and 23% of total CH<sub>4</sub> reported in the national inventory. Emissions increased from 1990 to 2005 mainly due to 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 21% 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 as well.

Increases from beef production were, however, partially offset by a 30% reduction in the dairy population from 1990 to 2014 (Statistics Canada 2015h). The dairy quota systems encouraged the dairy industry to invest in herd improvement in order to increase profitability as opposed to herd expansion. Emissions associated with dairy cows have fallen by approximately 17% since 1990, but this reduction in emissions from the dairy herd has also been partly offset by a 28% 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 (2014 GHG emissions, 8.5 Mt)

Emissions from animal manure management systems represented 14% of total agricultural emissions and increased from 7.6 Mt in 1990 to 8.5 Mt in 2014 (12%), 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<sub>4</sub> (13% total agricultural CH<sub>4</sub>) and N<sub>2</sub>O (14% total agricultural N<sub>2</sub>O). Beef and poultry production produce mainly N<sub>2</sub>O, whereas pork production produces mainly CH<sub>4</sub>, and dairy is equally divided between N<sub>2</sub>O and CH<sub>4</sub>. As a result, N<sub>2</sub>O emissions closely follow the trend in beef populations, increasing from 4.1 Mt in 1990 to 5.5 Mt (36% increase) in 2005 and subsequently declining to 4.7 Mt (-15%). As was the case with enteric fermentation, the increase in beef cattle weights also contributed to the increase in N<sub>2</sub>O emissions. Methane emissions correspond closely to swine populations, increasing from 3.5 Mt in 1990 to 4.3 Mt in 2005 (23% increase) and subsequently declining to 3.7 Mt (-13%).

### 2.3.3.3. Agricultural Soils (2014 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 2014, an increase of 34%, 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 10.6 Mt in 2014, an increase

of 87%, as inorganic nitrogen fertilizer consumption increased steadily from 1.2 Mt N to 2.5 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 2013. 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. The increase in fertilizer use since 1990 also resulted in a 1.3-Mt (110%) increase in emissions of CO<sub>2</sub> from urea-based carbon containing fertilizers.

Emissions from crop residue decomposition varied between a minimum of 3.2 Mt in 2002 (a drought year) and 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 animal manure applied as fertilizers increased from 1.7 Mt in 1990 to 1.8 Mt in 2014, or an increase of 5%, reflecting changes in livestock populations.

Emissions from cropland management practices including summerfallow, tillage and irrigation decreased from 2.1 Mt in 1990

to 0.3 Mt in 2014, a reduction of 85% due mainly to continued efforts in the adoption of conservation tillage (over 17 million hectares of cropland since 1990) and intensification of cropping systems by reducing summerfallow (81%).

### 2.3.4. Land Use, Land-use Change and Forestry Sector (2014 Net GHG Emissions, 72 Mt, Not Included in National Totals)

The Land Use, Land-use Change and Forestry (LULUCF) Sector reports 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<sub>2</sub> emissions to and removals from the atmosphere and non-CO<sub>2</sub> emissions. Net LULUCF emissions or removals are highly variable over the reporting period. In 2014, this net flux amounted to emissions of 72 Mt (Figure 2–19 and Table 2–10). All emissions and removals

Figure 2–19 Net Flux from LULUCF Relative to Total Canadian Emissions, 1990–2014

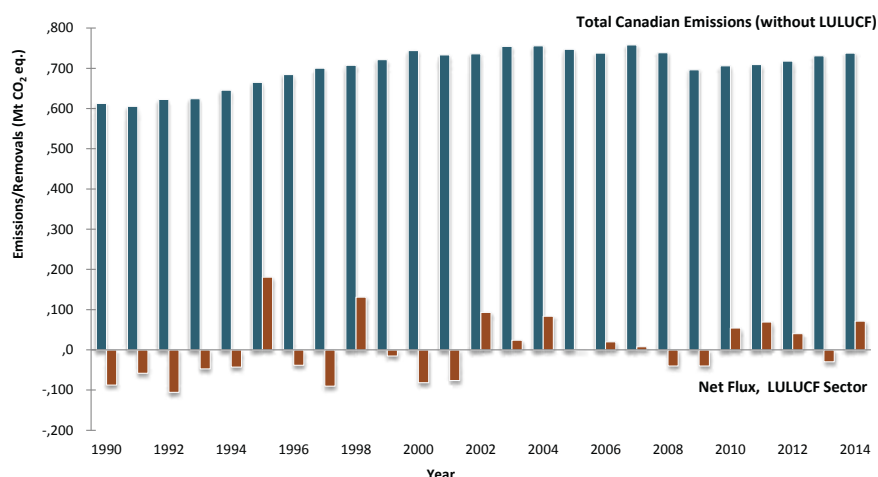


Table 2–10 GHG Emissions/Removals from LULUCF, Selected Years

Sectoral Category	Net GHG Flux (Mt CO <sub>2</sub> eq) <sup>2</sup>								Change Mt 1990–2014
	1990	2005	2009	2010	2011	2012	2013	2014	
<b>Land Use, Land-use Change and Forestry TOTAL<sup>1</sup></b>	- 87	0.5	- 40	55	69	41	- 30	72	160
a. Forest Land	- 250	- 150	- 170	- 83	- 71	- 100	- 170	- 64	180
b. Cropland	10	- 8.6	- 9.6	- 9.4	- 9.4	- 9.2	- 8.9	- 8.4	- 19
c. Grassland	0.6	0.9	0.4	0.3	0.6	1.6	0.7	0.7	0.0
d. Wetlands	5.9	4.3	3.9	3.9	3.7	3.7	3.6	3.4	- 2.5
e. Settlements	4.3	4.0	4.0	3.8	3.9	3.9	3.9	3.7	- 0.6
f. Harvested Wood Products	140	150	130	140	140	140	140	140	- 1.9

Note:

1. Totals may not add up due to rounding.

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

in the LULUCF Sector are excluded from the national totals. However, if included, the estimated 72 Mt would increase Canada's total GHG emissions by about 9.8%.

### 2.3.4.1. Forest Land and Harvested Wood Products (HWP) (2014 GHG Emissions, 72 Mt)

The combined Forest Land and Harvested Wood Products categories include GHG fluxes between the atmosphere and Canada's managed forests and emissions from harvested wood products (HWP). The total net flux from managed forests and HWP amounted to 72 Mt in 2014, which combines net removals of 64 Mt from Forest Land and net emissions of 136 Mt from HWP.

Variations and trends in the net flux from Forest Land are strongly affected by natural disturbances. The erratic pattern of forest wildfires, which are random natural events, alone represent emissions of between 11 and 277 Mt over the 1990–2014 period (Figure 2–20). The area burned by wildfires in 2014 was significantly larger than in 2013 (1.3 million ha compared to 0.5 in 2013), which resulted in higher emissions from wildfires (175 Mt compared to 66 Mt in 2013).

Forest insect epidemics in western Canada continue to have long-term impacts on trends. In general, the impacts of natural disturbances on the net flux in managed forests mask underlying patterns associated with direct human interventions in forests. Approaches are being explored to effectively remove the impact of natural disturbances on emissions variability and trends for future reporting, for example by temporarily excluding emissions/removals from managed forest lands subject to uncontrollable natural disturbances.

The predominant trend directly associated with human activities in managed forests is the 24% increase in the carbon removed from forests through harvest and transferred to HWP between 1990 and the peak harvest year 2004. Since 2004, reductions in harvest have occurred, with 2009 harvest levels reaching the lowest point in the 25-year period covered in this report. Harvest levels in 2014 are still 25% below those of 2004. This trend is driven by the reduced global demand for Canadian pulp and paper products and lumber (NRCan 2015). Around 6 Mt of the carbon (on average 12% of annual harvest) annually removed from forests and transferred to HWP consists of firewood collected for domestic residential use, with a relatively stable trend throughout the reporting period.

Emissions from HWP reflect the long-term storage of carbon in wood harvested from Canada's forests. A significant proportion of HWP emissions (25% in 2014) results from the decay of long-lived wood products reaching the end of their economic life decades after the wood was harvested, the remainder being reflective of current trends in forest harvest rates. Emissions from this source fluctuate between 128 Mt in 2009, the lowest harvest year, and peaks of 160 Mt in 1995 and 2000 (Figure 2–20).

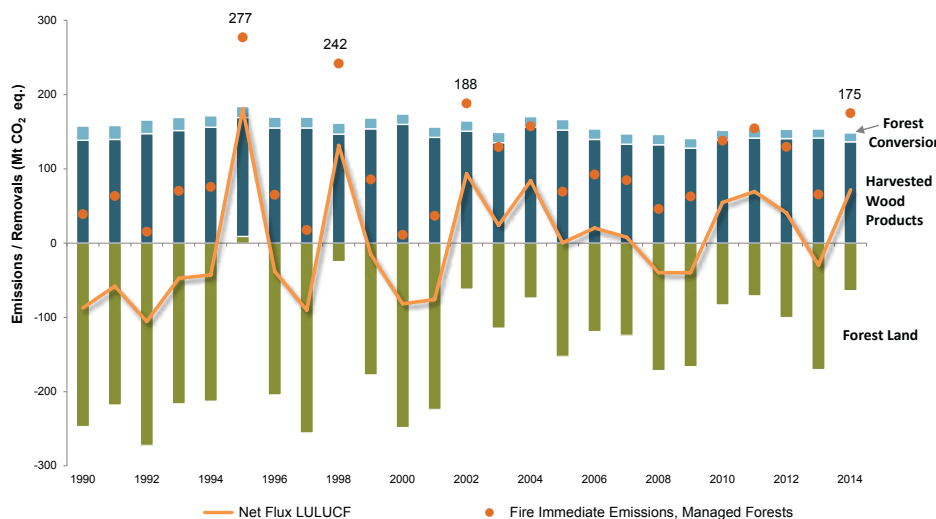
### 2.3.4.2. Forest Conversion (2014 GHG Emissions, 12 Mt<sup>10</sup>)

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.

The conversion of forests to other land uses is a prevalent yet declining practice in Canada; it is driven by a variety of circum-

<sup>10</sup> Forest conversion emissions are incorporated within sums of emissions of other land-use categories; therefore, the 12 Mt reported in this section is included in the sums associated with the other land-use category totals.

Figure 2–20 LULUCF Sector Net GHG Flux and Major Emission and Removal Components, 1990–2014



stances across the country, including policy and regulatory frameworks, market forces and resource endowment. The economic drivers are diverse and result in heterogeneous spatial and temporal patterns of forest conversion (Kurz et al. 2013). Since 1990, 1.2 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.

Emissions due to forest conversion fell from 19 Mt in 1990 to 12 Mt in 2014. This decline in emissions includes a 5.0-Mt decrease in emissions due to forest conversion to Cropland and a 1.7-Mt decrease in emissions due to forest conversion to Wetlands.

With a current annual conversion rate of 22 kha, Forest Land conversion to Settlements accounts for the largest share of forest losses, comprising 65% in 2014, up from 33% in 1990. Forest clearing for agricultural expansion (Cropland) is the second largest driver of forest conversion, representing 35% of all forest area lost in 2014. Annual rates dropped from 42 kha in 1990 to 12 kha in 2014, 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 149 kha, accounting for 12% of total forest conversion areas over the reporting period. Hydroelectric development occurs mainly in the Taiga Shield East and the Boreal Shield East.

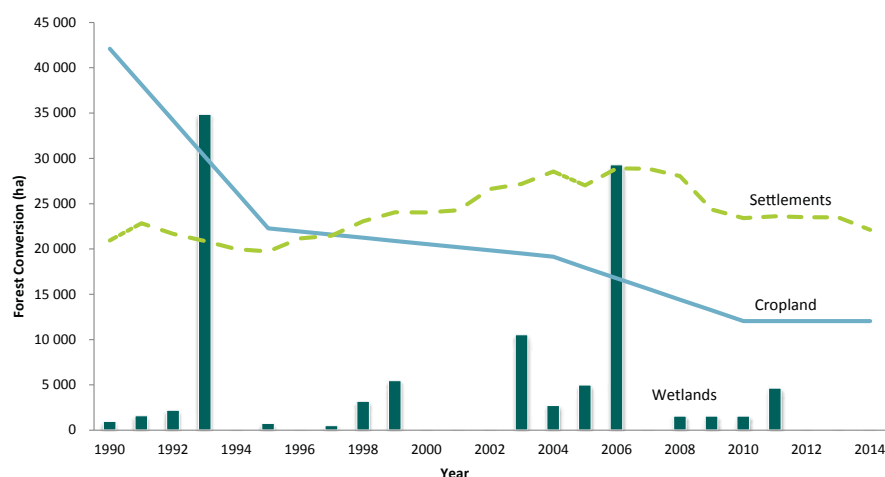
### 2.3.4.3. Cropland (2014 GHG Removals, 8.4 Mt)

The Cropland category includes the effect of agricultural practices on CO<sub>2</sub> emissions from, and removals by, arable soils and the immediate and long-term impacts of forest and grassland conversion to cropland. The trend shows a steady decline in emissions from Cropland, notably in the period 1990–2006, from a net source of 10.5 Mt in 1990 to a net sink of 9.9 Mt in 2006, a total change of 20 Mt. This trend is a result of changes in agricultural land management practices in western Canada that conserve carbon in soils, such as the extensive adoption of conservation tillage practices (≈17 million hectares of cropland since 1990) and an 81% reduction in summerfallow by 2014. Since 2006, net removals have gradually declined to 8.4 Mt, due to the soil carbon approaching equilibrium and an increase in the conversion of perennial to annual crops. A decline in emissions from the conversion of Forest Land to Cropland has also contributed to this trend (see Section 2.3.4.2).

### 2.3.4.4. Other LULUCF Sources/Sinks (2014 GHG emissions, 7.8 Mt)

Other LULUCF sources/sinks comprise Settlements, Wetlands and Grassland, which contribute 3.7 Mt, 3.4 Mt and 0.7 Mt, respectively, to the net emissions of 7.8 Mt reported in 2014, down from 11 Mt in 1990. The Settlements category includes the growth of urban trees (annual removals of 2.5 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 conversion to Settlements and flooded land can be found in Section 2.3.4.2.

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



2.3.5. Waste Sector  
(2014 GHG Emissions, 29 Mt)

The Waste Sector includes GHG emissions from the treatment and disposal of wastes. Emissions from the Waste Sector contributed 29 Mt (3.9%) to Canada's total emissions in 2014, compared with 26 Mt (4.2%) in 1990, an increase of approximately 2.5 Mt or 9.6% (Figure 2–22 and Table 2–11). Over the same period, total national GHG emissions grew by 20% and the population grew by 28%. Of the total emissions of 29 Mt from this sector in 2014, Solid Waste Disposal, which includes municipal solid waste (MSW) landfills and wood waste landfills, accounted for 26 Mt (or 91% 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 1.0 Mt, 1.1 Mt and 0.56 Mt, respectively.

2.3.5.1. Solid Waste Disposal  
(2014 GHG Emissions, 26 Mt)

Emissions from Solid Waste Disposal were estimated for two solid waste emission sources: MSW (22 Mt in 2014) and wood waste landfills (4 Mt in 2014). The CH<sub>4</sub> 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 76% of the emissions from this sector.

Methane emissions from MSW landfills increased 13% between 1990 and 2014. Of the 33 Mt CO<sub>2</sub> eq of CH<sub>4</sub> generated by MSW landfills in 2014, only 22 Mt (or 66% 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<sub>4</sub> increased from 20% of the generated emissions in 1990 to 34% in 2014. Of the total amount of CH<sub>4</sub> collected in 2014, 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<sub>4</sub> emissions from MSW landfills to 9% 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 2014, due to a plateauing of the number of active landfills and of the quantities of landfill gas collected (Figure 2–23).

Figure 2–22 Trends in Canadian GHG Emissions from Waste (1990–2014)

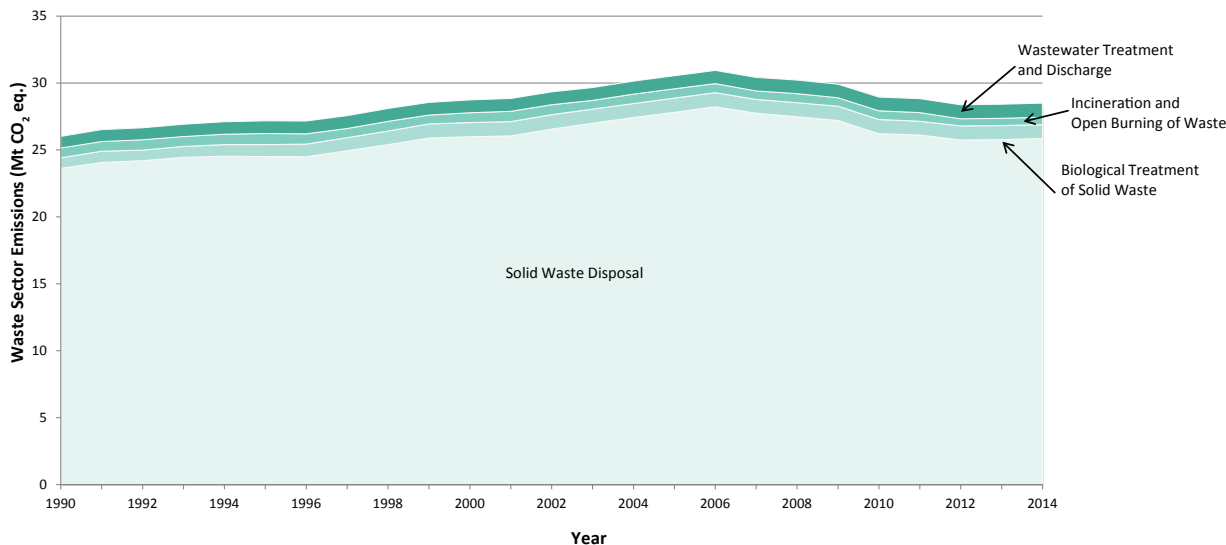


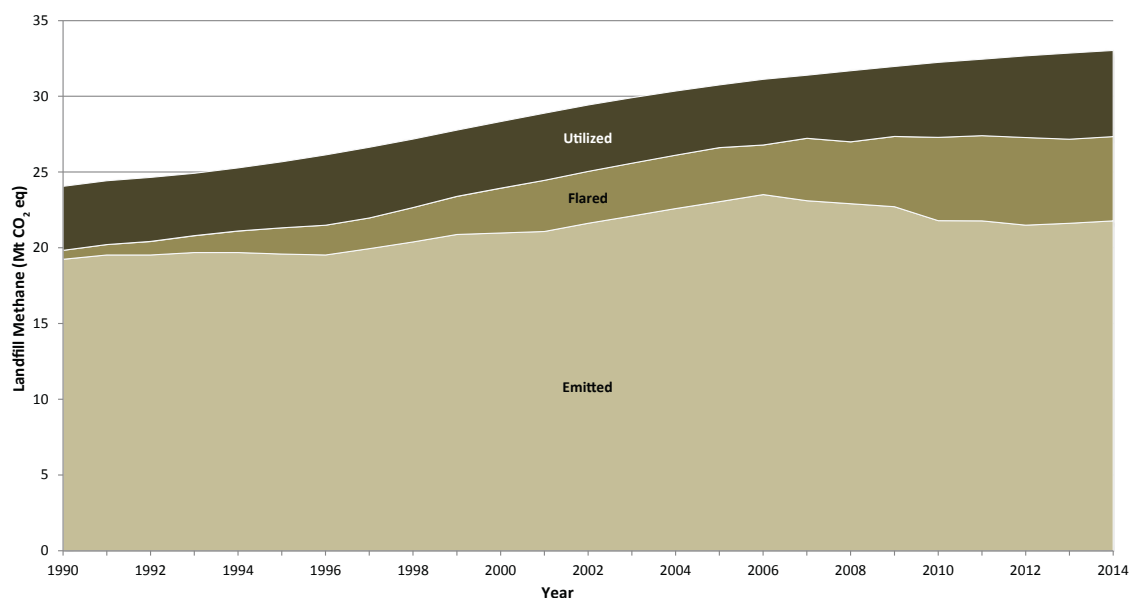
Table 2–11 GHG Emissions from Waste, Selected Years

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)								Change (%)
	1990	2005	2009	2010	2011	2012	2013	2014	1990–2014
Waste Sector	26	31	30	29	29	28	28	29	9.6%
Solid Waste Disposal	24	28	27	26	26	26	26	26	9.5%
Biological Treatment of Solid Waste	0.79	1.05	1.06	1.06	1.03	1.05	1.04	1.03	30%
Wastewater Treatment and Discharge	0.87	0.98	1.02	1.03	1.04	1.04	1.05	1.06	22%
Incineration and Open Burning of Waste	0.74	0.70	0.65	0.66	0.65	0.54	0.55	0.56	-24%

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 (2014 GHG Emissions, 2.6 Mt)

Over the 1990–2014 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 30% and 22%, respectively, while emissions from Incineration and Open Burning emissions decreased by 24% (Figure 2-22 and Table 2-11). The growth in Wastewater Treatment and Discharge emissions reflects the increase in the Canadian population (28%). 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 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 useful 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 economic sectors: Oil and Gas, Electricity, Transportation, Emissions-

Intensive and Trade-Exposed Industries,<sup>11</sup> 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. This reallocation 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 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.

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

<sup>11</sup> The emissions intensive trade exposed industry sector represents emissions arising from mining activities other than oil and gas, i.e. smelting and refining, pulp and paper, iron and steel, cement, lime and gypsum, and chemicals and fertilizers.

machinery or mining trucks would be reflected in the economic sector estimates for Agriculture or Mining and Extraction.

Annex 10 contains a series of tables which show the distribution of emissions allocated on the basis of the economic sector from which they originate for all years in the time series (1990–2014) and the relationship between economic and IPCC categories or sectors. Each economic sector includes 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 Emissions-Intensive and Trade-Exposed Industry Sector represents emissions arising from 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.

### 2.4.1. Emission Trends by Economic Sector

#### Oil and Gas

In 2014, the Oil and Gas sector produced the largest share of GHG emissions in Canada (26%). Between 1990 and 2014, emissions from this sector increased by 85 Mt. The majority of this increase (52 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 2014 due to a lower global demand for petroleum products and to the gradual exhaustion of traditional natural gas and oil resources in Canada (see text box below).

#### Transportation

Canada's Transportation sector is the second-largest contributor to Canada's GHG emissions, representing 23% of total emissions in 2014. Between 1990 and 2005 emissions rose by 41 Mt (32%), but since then, emissions from this sector have leveled off. Section 2.3 discusses the main drivers of emissions trends associated with passenger and freight transport.

#### Electricity

In 2014, 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. Section 2.3 discusses the main drivers of emissions trends associated with electricity generation.

#### Emissions-Intensive and Trade-Exposed Industries

The Emissions Intensive Trade Exposed 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 12 Mt between 2005 and 2014.

#### 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. Since 1990, emissions have increased from 73 Mt to 87 Mt (19%).

#### Agriculture and Waste & Other

In general, emissions from the Agriculture sector have continued a slow upward trend throughout the reporting period, while emissions from the Waste and Other sector have remained relatively stable.



## 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 2014, the largest contributor to O&G emissions was the Oil Sands category (68 Mt, or 35%) followed by Natural Gas Production and Processing (57 Mt, or 29%), Conventional Oil Production (36 Mt, or 18%) 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

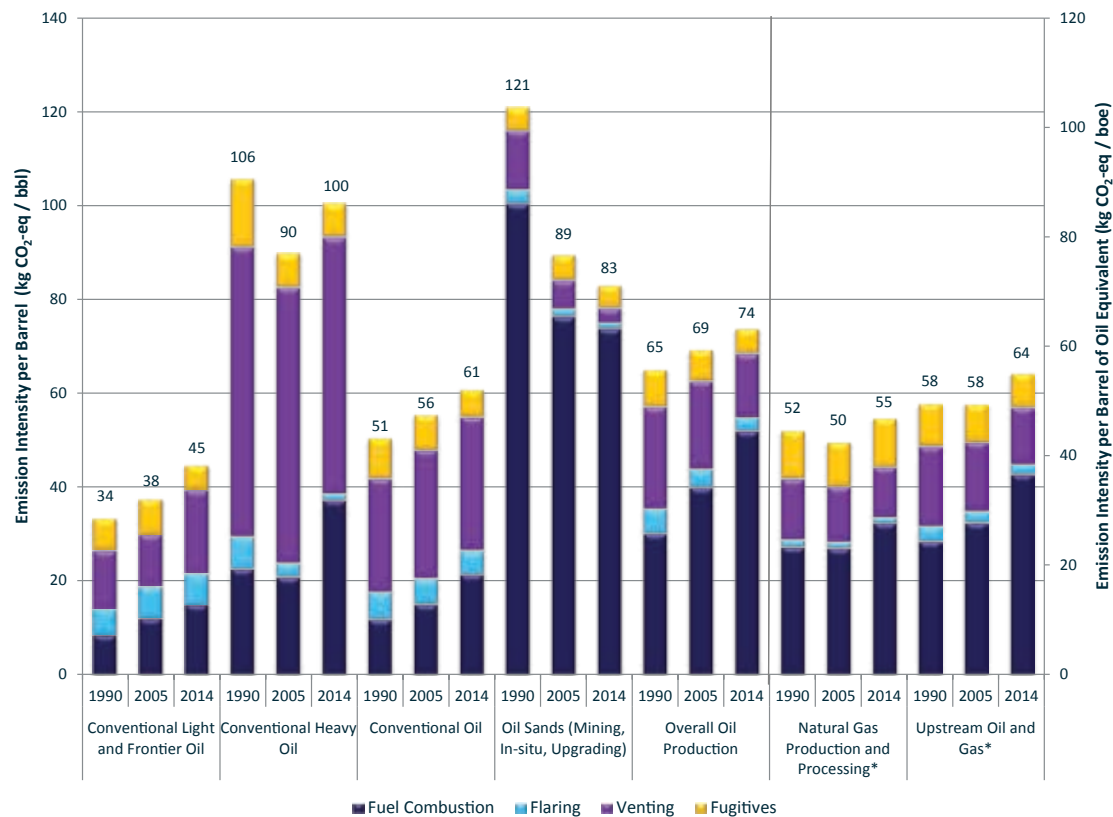
From 1990 to 2014, the production of total crude oil increased by 135% (Statistics Canada 2015b). The increase was driven almost entirely by Canada's oil sands operations, where total output (non-upgraded bitumen and synthetic crude oil production) has increased by almost 560%, with most of the growth occurring from 1996 onward (AER 2015). Consistent with the production increases, emissions from total crude oil production increased by 64 Mt (about 160%), with oil sands alone increasing by 53 Mt (345%).

### Production Characteristics (Emission Intensity)

The emission intensity of overall oil production in Canada increased by about 11% between 1990 and 2014, from 65 to 74 kg CO<sub>2</sub> 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 (121 kg CO<sub>2</sub> eq per barrel) until about 2005 (89 kg CO<sub>2</sub> eq per barrel), and since that time has remained fairly static. The initial decline in emission intensity was due to technological innovation, equipment turnover and increased reliability across operations.

Figure 2–24 Emission Intensity by Source Type for Oil and Gas (2005 and 2014)



Notes:  
Intensities are based on total subsector emissions and relevant production amounts. They represent overall averages, not facility intensities.  
\*Natural Gas Production and Processing and Upstream oil and Gas Emission intensities calculated on barrel of oil equivalent (boe) basis. Boe calculated by converting natural gas and crude oil production volumes to energy basis and then dividing by energy content of light crude oil (38.5 TJ/10<sup>3</sup> m<sup>3</sup>).  
1 barrel (bbl) = 0.159 m<sup>3</sup>

Table 2-12 Details of Trends in GHG Emissions by Economic Sector<sup>1</sup>

	1990	2000	2005	2010	2011	2012	2013	2014
<i>Mt CO<sub>2</sub> eq</i>								
<b>NATIONAL GHG TOTAL</b>	<b>613</b>	<b>747</b>	<b>696</b>	<b>706</b>	<b>710</b>	<b>718</b>	<b>731</b>	<b>732</b>
<b>Oil and Gas</b>	<b>107</b>	<b>159</b>	<b>160</b>	<b>162</b>	<b>164</b>	<b>176</b>	<b>187</b>	<b>192</b>
Upstream Oil and Gas	88	136	137	140	143	153	164	170
Natural Gas Production and Processing	36	58	52	51	50	53	57	57
Conventional Oil Production	24	31	29	29	30	32	35	36
Conventional Light Oil Production	12	12	12	12	14	15	16	17
Conventional Heavy Oil Production	12	17	15	15	15	15	16	17
Frontier Oil Production	0*	2	2	2	2	2	2	2
Oil Sands (Mining, In-situ, Upgrading)	15	34	48	53	55	60	64	68
Mining and Extraction	4	10	13	15	15	16	16	18
In-situ	3	8	15	19	20	24	26	30
Upgrading	8	16	20	19	20	21	21	20
Oil and Natural Gas Transmission	12	12	8	7	7	8	8	10
Downstream Oil and Gas	20	23	23	22	21	23	23	23
Petroleum Refining	18	22	22	21	20	22	22	21
Natural Gas Distribution	2	1	1	1	1	1	1	1
<b>Electricity</b>	<b>95</b>	<b>118</b>	<b>94</b>	<b>95</b>	<b>87</b>	<b>83</b>	<b>80</b>	<b>78</b>
<b>Transportation</b>	<b>129</b>	<b>171</b>	<b>168</b>	<b>173</b>	<b>170</b>	<b>171</b>	<b>174</b>	<b>171</b>
Passenger Transport	83	97	96	97	95	95	98	95
Cars, Trucks and Motorcycles	74	88	88	89	87	87	89	86
Bus, Rail and Domestic Aviation	8	9	8	8	8	9	9	9
Freight Transport	36	62	65	67	67	69	69	68
Heavy Duty Trucks, Rail	30	55	57	60	61	62	63	62
Domestic Aviation and Marine	6	8	7	8	6	7	6	6
Other: Recreational, Commercial and Residential	10	11	7	8	9	8	7	9
<b>Emissions Intensive &amp; Trade Exposed Industries</b>	<b>95</b>	<b>88</b>	<b>72</b>	<b>74</b>	<b>79</b>	<b>79</b>	<b>77</b>	<b>76</b>
Mining	6	6	7	7	8	8	8	8
Smelting and Refining (Non Ferrous Metals)	17	14	12	11	11	10	11	10
Pulp and Paper	15	9	7	7	7	7	7	7
Iron and Steel	16	19	15	16	17	17	15	16
Cement	10	13	10	10	10	11	10	10
Lime & Gypsum	3	3	2	3	3	3	2	3
Chemicals & Fertilizers	29	23	20	21	23	24	24	24
<b>Buildings</b>	<b>73</b>	<b>85</b>	<b>83</b>	<b>81</b>	<b>86</b>	<b>84</b>	<b>85</b>	<b>87</b>
Service Industry	27	40	38	37	40	41	40	41
Residential	46	46	45	43	46	43	44	46
<b>Agriculture</b>	<b>57</b>	<b>70</b>	<b>67</b>	<b>68</b>	<b>69</b>	<b>70</b>	<b>73</b>	<b>73</b>
On Farm Fuel Use	7	9	9	11	13	12	13	14
Crop Production	16	17	19	19	19	21	24	22
Animal Production	33	45	39	37	37	37	37	37
<b>Waste &amp; Others</b>	<b>56</b>	<b>56</b>	<b>52</b>	<b>54</b>	<b>55</b>	<b>55</b>	<b>55</b>	<b>54</b>
Waste	26	29	31	29	29	28	28	29
Coal Production	-	-	-	-	-	-	-	-
Light Manufacturing, Construction & Forest Resources	0.2	0.1	0.2	0.2	0.4	0.3	0.2	0.3

Note:

Totals may not add up due to rounding.

Provincial/territorial GHG emissions allocated to IPCC sectors are provided in Annex11 of this report.

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<sub>2</sub>-eq

1. Please refer to Annex 10 for a fuller description of the relationship between these economic sectors and the IPCC sectors and categories. This Annex provides detailed tables showing the correspondence between emissions allocated to both breakdowns.

# Chapter 3

## Energy (CRF Sector 1)

### 3.1. Overview

In 2014, the Energy Sector accounted for 596 Mt (or 81%) of Canada's total greenhouse gas (GHG) emissions (Table 3–1). The Energy Sector includes all GHG (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) emissions from stationary and transport fuel combustion activities as well as fugitive emissions from the fossil fuel industry.<sup>1</sup>

Emissions resulting from stationary fuel combustion include, for example, the use of fossil fuels by the electricity generating industry, the oil and gas industry, the manufacturing and construction industry, and the residential and commercial sectors. Only CH<sub>4</sub> and N<sub>2</sub>O 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<sub>2</sub> 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 the consumption of transport fuels (e.g. gasoline and diesel fuel) by the mining industry, by the oil

and gas extraction industry, and by agriculture and forestry are also included under Other Transportation (Off-road). Emissions from international Aviation and Navigation bunker activities are reported as a memo item in the CRF tables.

Fugitive emissions associated with the fossil fuel industry are the intentional (e.g. venting) or 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, recalculation activities contributed to an increase of 1.9 Mt compared to last year's submitted value for 2013. The total change was due mainly to revised energy data. Revised energy data represents the final 2013 data which has (as per standard practice) been incorporated as an update to the preliminary data utilized in last year's inventory.<sup>2</sup> A summary of recalculations for all sectors is provided in Chapter 8.

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

Emission sources in the Fuel Combustion Activities subsector 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

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

2 Statistics Canada annually publishes a revised, final version of the previous year's (preliminary) energy data. Currently, energy data for 2014 represents preliminary data (which will be revised in 2017).

**Table 3–1 GHG Emissions from Energy, Selected Years**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2010	2011	2012	2013	2014
<b>Energy Sector</b>	<b>482 000</b>	<b>603 000</b>	<b>597 000</b>	<b>570 000</b>	<b>574 000</b>	<b>576 000</b>	<b>590 000</b>	<b>594 000</b>
<b>Fuel Combustion Activities (1.A)</b>	<b>433 000</b>	<b>534 000</b>	<b>536 000</b>	<b>516 000</b>	<b>518 000</b>	<b>519 000</b>	<b>532 000</b>	<b>534 000</b>
Energy Industries (1.A.1)	146 000	200 000	193 000	165 000	158 000	158 000	156 000	154 000
Manufacturing Industries and Construction (1.A.2) <sup>1</sup>	64 900	69 500	69 300	78 100	82 600	88 700	95 100	97 100
Transport (1.A.3)	148 000	181 000	195 000	199 000	199 000	198 000	204 000	203 000
Other Sectors (1.A.4)	74 600	82 800	79 600	73 500	79 200	73 800	76 600	80 500
<b>Fugitive Emissions from Fuels (1.B)</b>	<b>49 000</b>	<b>70 000</b>	<b>61 000</b>	<b>54 000</b>	<b>55 000</b>	<b>57 000</b>	<b>58 000</b>	<b>60 000</b>
<b>CO<sub>2</sub> Transport and Storage (1.C)</b>	<b>NO</b>	<b>0.09</b>	<b>0.09</b>	<b>0.09</b>	<b>0.09</b>	<b>0.09</b>	<b>0.09</b>	<b>0.1</b>

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 Occurring

0 value indicates emissions truncated due to rounding.

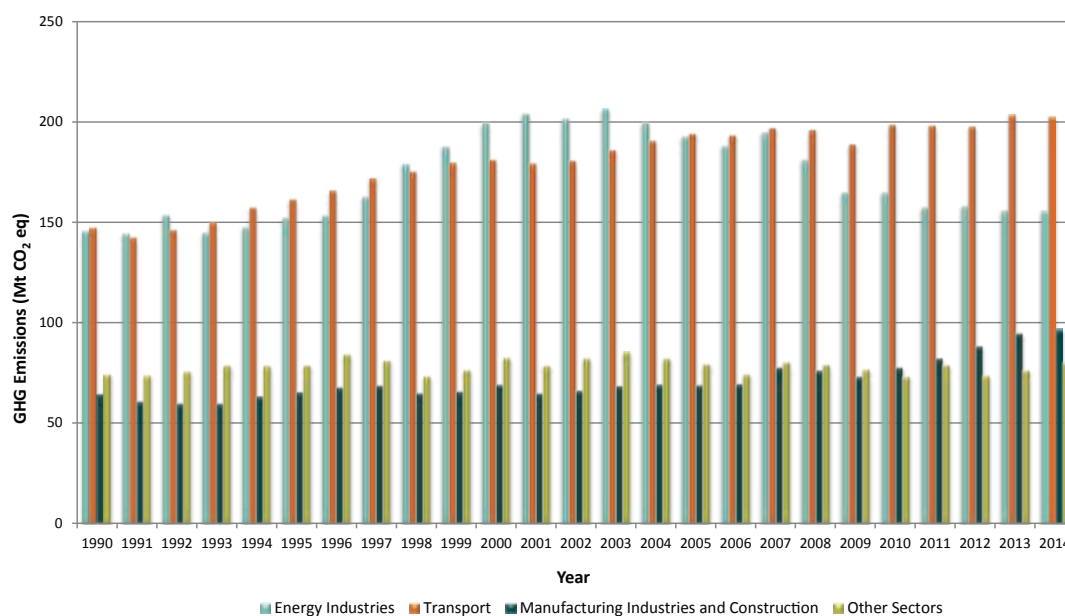
Table 3–2 GHG Emission Change due to Recalculation

IPCC Categories	1990	2000	2005	2009	2010	2011	2012	2013
1 Energy Sector	Overall GHG Emissions (Mt CO <sub>2</sub> eq)							
2015 Inventory Submission	485	606	601	563	573	576	577	588
2016 Inventory Submission	482	603	597	560	570	574	576	590
<b>Total change due to recalculations</b>	<b>-2.7</b>	<b>-2.9</b>	<b>-3.3</b>	<b>-3.1</b>	<b>-2.6</b>	<b>-2.4</b>	<b>-0.3</b>	<b>1.9</b>
1.A. Fuel Combustion	-2.7	-2.9	-3.0	-2.9	-2.4	-2.2	-0.2	2.2
1.A.1., 1.A.2. and 1.A.4. – Stationary Combustion	-2.6	-2.5	-2.3	-2.1	-1.6	-1.5	0.7	2.7
1.A.3. – Transport	-0.1	-0.4	-0.7	-0.8	-0.8	-0.7	-0.8	-0.5
1.B – Fugitive and 1.C – CO <sub>2</sub> Transport & Storage	-	0.0	-0.3	-0.2	-0.2	-0.2	-0.1	-0.3

Note:

Totals may not add up due to rounding.

Figure 3–1 GHG Emissions from Fuel Combustion, 1990–2014



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 Intergovernmental Panel on Climate Change (IPCC) Tier 2 approach, with country-specific emission factors and parameters.

In 2013, about 537 Mt (73%) of Canada's GHG emissions were from the combustion of fossil fuels (Table 3–1). Overall GHG emissions from Fuel Combustion Activities have increased by 24% since 1990. Between 1990 and 2014, emissions from the Stationary Combustion Sources subsector (i.e. Energy Industries (1.A.1), Manufacturing Industries and Construction (1.A.2) and Other Sectors ((1.A.4)) and the Transport category increased by about 17% (48.3 Mt) and 38% (56.2 Mt), respectively (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.

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

Emissions (Table 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* (RES-D) (Statistics Canada 2003– ) 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 NIR 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 RES-D (Statistics Canada 199– ). 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

Emissions from fuel use in the Energy Sector are those related to the combustion of fuels for generating heat or work. In addition to being combusted for energy production, fossil fuels are also consumed for non-energy purposes. Non-energy uses of fossil fuels include application as waxes, solvents, lubricants and feedstocks (including the manufacturing of fertilizers, rubber, plastics and synthetic fibres). Emissions from the non-energy use of fossil fuels have been included in the Industrial Processes and Product Use Sector (Chapter 4 of this report), whereas emissions from the use of fossil fuels associated with flaring activities by the oil and gas industry are included in the Fugitive category (section 3.3. of the present chapter).

Refer to the Industrial Processes and Product Use chapter (Chapter 4) for a discussion of the use of feedstocks and the nonenergy use of fossil fuels and the methodological issues associated with calculating emissions from this source.

## 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 Production, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries.

In 2014, the Energy Industries category accounted for 156 Mt (over 21%) of Canada's total GHG emissions, with a 7% increase in total GHG emissions since 1990. The Public Electricity and Heat Production subcategory accounted for 56% (88 Mt) of the GHG

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2010	2011	2012	2013	2014
International Aviation	6 200	9 300	10 100	9 400	9 500	10 900	11 400	11 700
Domestic Aviation	7 200	7 700	7 600	6 500	6 200	7 300	7 500	7 400
<b>Total</b>	<b>13 300</b>	<b>17 000</b>	<b>17 800</b>	<b>15 900</b>	<b>15 700</b>	<b>18 200</b>	<b>18 900</b>	<b>19 000</b>

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 <sub>2</sub> eq)							
	1990	2000	2005	2010	2011	2012	2013	2014
International Navigation	3 100	3 100	3 100	2 400	1 700	1 400	1 500	1 300
Domestic Navigation	4 800	4 900	6 400	6 800	5 600	5 600	5 100	4 700
<b>Total</b>	<b>7 900</b>	<b>8 100</b>	<b>9 400</b>	<b>9 100</b>	<b>7 300</b>	<b>7 000</b>	<b>6 600</b>	<b>6 000</b>

Note: Totals may not add up due to rounding.

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2010	2011	2012	2013	2014
Public Electricity and Heat Production	94 500	131 000	124 000	102 000	94 500	91 500	87 800	85 500
Petroleum Refining	17 100	17 300	20 200	18 100	17 600	18 700	18 000	16 800
Manufacture of Solid Fuels and Other Energy Industries <sup>1</sup>	34 300	51 100	48 700	45 100	45 700	48 100	50 500	51 300
<b>Energy Industries TOTAL (1.A.1)</b>	<b>146 000</b>	<b>200 000</b>	<b>193 000</b>	<b>165 000</b>	<b>158 000</b>	<b>158 000</b>	<b>156 000</b>	<b>154 000</b>

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.

emissions from Energy Industries, while the Petroleum Refining and Manufacture of Solid Fuels and Other Energy Industries subcategories contributed 10.7% (16.8 Mt) and 32.9% (51.3 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 production, 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 (e.g. an oil and gas facility burning natural gas that it produced or a coal mine burning coal that it produced), while emissions from the consumption of purchased fuels by the same industries are included in Other – Mining (excluding fuels) and Quarrying under Manufacturing Industries and Construction category, and in Pipeline Transport and Other Transportation (Off-Road) under the Other Transportation subcategory. Emissions are allocated in this way because fuel consumption data at a lower level of disaggregation are not available. 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 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 Production (CRF Category 1.A.1.a)

The Public Electricity and Heat Production subcategory includes the GHG emissions associated with the production of electricity and heat from the combustion of fuel in public utility thermal power plants. The estimated GHG emissions from this subcategory do not include emissions from industrial generation; rather, these emissions have been allocated to specific industrial sectors.

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<sub>2</sub> 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 in the Manufacturing Industries and Construction–Mining (excluding fuels) and Quarrying subcategory, whereas emissions associated with pipeline transmission and with the use of transport fuels (such as gasoline and diesel) in off-road applications in the mining and the oil and gas mining and extraction industry are reported under Other Off-Road (CRF Category 1.A.3.e.ii). This breakdown is dictated by limitations of the fuel data in Statistics Canada’s national energy balance, 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 Production (CRF Category 1.A.1.a)

The 2006 IPCC Guidelines require the Public Electricity and Heat Production subcategory to include GHG emissions generated from producers whose main activity is the generation of electricity and heat for public use. GHG emissions from producers that are generating electricity and heat as a supporting activity rather than as their primary purpose (i.e. industrial generation) are allocated to the industry that produces the energy under the appropriate industrial category within the Energy Sector, regardless of whether the energy is for sale or for internal use. Statistics Canada fuel-use data in the RESD do distinguish industrial electricity generation data, but aggregate the data into one category titled Industrial Electricity Generation. The GHG emissions from industrial electricity generation were reallocated to their respective industrial subcategories using the RESD input data. The methodology is described in greater detail in Annex 3.1.

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) divide the Public Electricity and Heat Production 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 do not distinguish based on these

subcategories, but aggregate the data 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<sub>4</sub> and N<sub>2</sub>O from the combustion of biomass were reallocated to their respective categories using the RESD input data. CO<sub>2</sub> 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.

## 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 for more details.

### 3.2.4.3. Uncertainties and Time-Series Consistency

The estimated uncertainty range for the Energy Industries category is  $\pm 7\%$  for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O combined and  $\pm 7\%$  for CO<sub>2</sub> 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<sub>2</sub> emission factors for non-marketable fuels, such as still gas, petroleum coke and catalytic coke, have a greater impact on the uncertainty estimate than the CO<sub>2</sub> factors for commercial fuels. Coal CO<sub>2</sub> emission factors were developed using statistical methods and 95% confidence intervals.

The estimated uncertainty for CH<sub>4</sub> (±21%) and N<sub>2</sub>O (±39%) emissions for the Energy Industries category is influenced by the uncertainty associated with the emission factors (ICF Consulting 2004). Additional expert elicitation is required to improve the CH<sub>4</sub> and N<sub>2</sub>O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by ICF Consulting, since insufficient time was available to have these assumptions reviewed by industry experts. 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 84% of the 2014 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 insitu bitumen extraction industries. The uncertainty for this fuel is influenced by the CO<sub>2</sub> (±6%) and CH<sub>4</sub> (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.

#### 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. As detailed below, revised activity data and emission factors contributed to improved emission estimates from (stationary) fuel combustion. The emissions reported for 2013 have increased by 1.9 Mt CO<sub>2</sub>eq over the previous submission, as a result of these emission factor and activity data updates.

*Activity Data:* Revisions to the following activity data resulted in recalculation:

- 2013 RESD data, for all fuel types were revised by Statistics Canada, and estimates were recalculated accordingly.

*Emission factors:* Revisions to the following emission factors resulted in recalculations to the entire time series (unless specified):

- Revised CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emission factors for residential firewood, based on the 2006 IPCC Guidelines.
- Revised 2013 CO<sub>2</sub> emission factor for still gas and petroleum coke based on updated industry data (CIEEDAC 2015).
- New emission factors for CH<sub>4</sub> for still gas and motor gasoline based on the 2006 IPCC Guidelines.

#### 3.2.4.6. Planned Improvements

Environment 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, an analysis is currently underway to evaluate and assess the availability of regional (provincial and territorial) natural gas energy conversion factors from 1990 onward, to properly 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 the development of carbon dioxide emission factors in energy units, following ERT recommendations.

In addition, work is under way to investigate the possibility of developing a bottom-up inventory for the Public Electricity and Heat Production 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.

### 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 2014, the Manufacturing Industries and Construction category accounted for 97.1 Mt (13.1%) of Canada's total GHG emissions, with a 49.6% (32.2 Mt) increase in overall emissions since 1990 (refer to Table 3–6 for more details). Within the Manufacturing Industries and Construction category, 65.7 Mt (67.7%) of the GHG emissions are from the Other subcategory, which is made up of mining, construction and other manufacturing activities. This

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2010	2011	2012	2013	2014
Iron and Steel	4 950	6 210	5 550	4 440	5 270	5 480	5 560	6 100
Non-ferrous Metals	3 320	3 590	3 620	2 990	3 310	2 930	3 070	2 870
Chemicals	8 260	10 820	8 320	9 910	11 110	10 960	11 580	12 060
Pulp, Paper and Print	14 600	12 600	8 700	6 000	6 300	6 000	6 300	6 300
Food Processing, Beverages and Tobacco <sup>1</sup>	IE	IE	IE	IE	IE	IE	IE	IE
Non-metallic minerals	3 960	4 630	5 430	4 070	4 300	4 010	3 840	4 060
Other	29 900	31 600	37 700	50 700	52 400	59 300	64 800	65 700
Mining <sup>2</sup>	6 800	12 240	19 120	35 350	36 420	42 880	48 310	50 010
Construction	1 880	1 080	1 450	1 510	1 350	1 370	1 280	1 290
Other Manufacturing	21 200	18 200	17 100	13 900	14 600	15 100	15 200	14 400
<b>Manufacturing Industries and Construction TOTAL (1.A.2)</b>	<b>64 900</b>	<b>69 500</b>	<b>69 300</b>	<b>78 100</b>	<b>82 600</b>	<b>88 700</b>	<b>95 100</b>	<b>97 100</b>

Note:

- Note that Food Processing, Beverages and Tobacco emissions are included under Other Manufacturing.
- 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.

subcategory is followed (in order of decreasing contributions) by Chemicals (12.1 Mt, 12.4%), Pulp, Paper and Print (6.3 Mt, 6.5%), Iron and Steel (6.1 Mt, 6.3%), Non-metallic Minerals (4.1 Mt, 4.2%); and Non-ferrous Metals (2.9 Mt, 3%) subcategories. GHG emissions from Food Processing, Beverages and Tobacco are included in the Other 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 the 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, 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 the Transport category (Section 3.2.6, Transport (CRF Category 1.A.3)). CH<sub>4</sub> and N<sub>2</sub>O emissions from the combustion of biomass were also included in the relevant subcategory of Manufacturing Industries and Construction. CO<sub>2</sub> 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 manufacturing all the coal-based metallurgical coke produced in Canada. All 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). As such, 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. Due to the nature of fuel consumption reporting by the iron and steel industry, determining the amount of coke oven gas lost as fugitive emissions through flaring is not feasible. However, Statistics Canada reports that the amount of fuel flared is included in the energy statistics, indicating that 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.

### 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. Consumption of diesel associated with on-site off-road vehicles in mining (which also includes oil and gas mining and extraction use of diesel) have been allocated to Other Off-Road (CRF category 1.A.3.e.ii).

#### 3.2.5.3. Uncertainties and Time-Series Consistency

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

The underlying fuel quantities and CO<sub>2</sub> emission factors have low uncertainty because they are predominantly commercial fuels, which have consistent properties and a more accurate tracking of quantity purchased for consumption. Coal CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF Consulting study (ICF Consulting 2004), since these assumptions were not reviewed by industry experts owing to a lack of available time in the study's preparation.

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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O 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

Revised emission factors and 2013 RESD data contributed to recalculations and improved accuracy of the emission for the Manufacturing Industries and Construction category. Refer to Section 3.2.4.5, Recalculations, for more details.

#### 3.2.5.6. Planned Improvements

Environment 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, current Statistics Canada fuel-use data does not disaggregate this source to a specific 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 203 Mt, accounting for 28% 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 131% (27.2 Mt) for LDGTs, 218% (0.4 Mt) and 142% (28.0 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 17.4 Mt since 1990. Emissions from the Transport category have increased 37% and have contributed the equivalent of 44% of the total overall growth in emissions observed in Canada.

**Table 3–7 Transport GHG Contribution**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2010	2011	2012	2013	2014
Domestic Aviation	7 200	7 700	7 600	6 500	6 200	7 300	7 500	7 400
Road Transportation	99 500	121 000	136 000	142 000	140 000	141 000	144 000	140 000
Light-duty Gasoline Vehicles	50 200	45 200	44 100	40 500	38 200	36 900	37 300	34 300
Light-duty Gasoline Trucks	20 800	35 500	41 500	45 500	45 100	46 000	48 500	47 900
Heavy-duty Gasoline Vehicles	5 890	7 330	7 160	7 900	7 510	7 810	8 220	7 910
Motorcycles	76.6	83.6	130	163	161	166	167	161
Light-duty Diesel Vehicles	479	494	522	624	686	758	850	847
Light-duty Diesel Trucks	200	384	405	479	479	501	597	636
Heavy-duty Diesel Vehicles	19 700	30 900	41 800	46 300	46 800	47 700	48 100	47 700
Propane & Natural Gas Vehicles	2 200	1 100	730	780	820	880	720	790
Railways	6 900	6 600	6 600	6 600	7 500	7 600	7 300	7 500
Domestic Navigation	4 800	4 900	6 400	6 800	5 600	5 600	5 100	4 700
Other Transportation	29 000	41 000	38 000	37 000	39 000	37 000	39 000	43 000
Off-road Gasoline	5 300	5 500	6 100	5 200	4 800	4 500	4 300	6 300
Off-road Diesel	17 000	24 000	21 000	26 000	29 000	27 000	28 000	29 000
Pipeline transport	6 910	11 300	10 200	5 720	5 650	5 730	6 720	7 890
<b>Transport TOTAL (1.A.3.)</b>	<b>148 000</b>	<b>181 000</b>	<b>195 000</b>	<b>199 000</b>	<b>199 000</b>	<b>198 000</b>	<b>204 000</b>	<b>203 000</b>

Note: Totals may not add up due to rounding.

### 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:

- 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 Canada's Mobile Greenhouse Gas Emission Model (MGEM) 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 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 Off-Road (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 2003–...). The majority of aircraft fuel sales reported in the RESD represent 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 (except for propane and natural gas vehicles, for which an IPCC Tier 2 method is followed for CO<sub>2</sub> emissions and an IPCC Tier 1 for CH<sub>4</sub> and N<sub>2</sub>O



emissions), as outlined in IPCC (2006). MGEM disaggregates vehicle data and calculates emissions of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O from all mobile sources except pipelines.

### 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<sub>2</sub> emissions and an IPCC Tier 1 methodology for CH<sub>4</sub> and N<sub>2</sub>O emissions (IPCC 2006). Emission estimates are performed within MGEM. Fuel sales data from the RESD (Statistics Canada 1990– ) reported under railways are multiplied by country-specific emission factors.

### 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<sub>2</sub> emissions and an IPCC Tier 1 for CH<sub>4</sub>, and N<sub>2</sub>O emissions (IPCC 2006), and emission estimates are performed within MGEM. 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<sup>3</sup> 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.

### 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. Non-road or off-road

transport<sup>4</sup> (ground, non-rail vehicles and equipment) includes GHG emissions resulting from both gasoline and diesel fuel combustion. Vehicles in this subcategory include farm tractors, logging skidders, construction vehicles and mobile mining vehicles, as well as off-road recreational vehicles. Equipment in this sub-category includes residential and commercial lawn and garden combustion machines, generators, pumps and portable heating devices.

Industry uses a considerable amount of diesel fuel in non-road vehicles. The mining and construction industries (including coal, oil and natural gas drilling and extraction activities) both operate significant numbers of heavy non-road vehicles and are the largest diesel fuel users in the group.

Off-road emissions are calculated using an IPCC Tier 2 approach (IPCC 2006). For these estimates, emissions are based on country-specific emission factors and total fuel consumed.

### 3.2.6.3. Uncertainties and Time-Series Consistency

The Transport category employs 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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> and N<sub>2</sub>O emission factor uncertainties have been updated to better reflect the improvements made by implementing AGEM. A number of on-road CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> and N<sub>2</sub>O 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

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

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

navigation, railways and other transportation, specifically the subcategory off-road diesel.

## Transport

The overall uncertainty of the 2014 estimates for the Transport category (not including pipelines) was estimated to be  $\pm 3.4\%$ . The uncertainty for Transport fuel combustion CO<sub>2</sub> emissions was  $\pm 0.4\%$ , whereas the uncertainty ranges for CH<sub>4</sub> and N<sub>2</sub>O emissions were two to three orders of magnitude greater than that of CO<sub>2</sub>, similar to the case of stationary fuel combustion sources. Hence, the overall uncertainty for the Transport category reflects the predominance of CO<sub>2</sub> in total GHG emissions.

## 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 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  $\pm 1\%$ , driven primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO<sub>2</sub> emissions. Conversely, the high uncertainties associated with CH<sub>4</sub> and N<sub>2</sub>O emissions, as well as biofuel activity data, did not significantly influence the analysis due to their comparatively minor contributions to the inventory.

## Emissions from Railways

The uncertainty associated with emissions from rail transport was estimated to be  $\pm 21\%$ . The greatest influence was exerted by the high N<sub>2</sub>O emission factor uncertainty ( $-50\%$  to  $+200\%$ ), whereas the relatively low uncertainties in diesel fuel activity data and CO<sub>2</sub> 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  $\pm 3\%$ . The high N<sub>2</sub>O emission factor uncertainty ( $-40\%$  to  $+140\%$ ) represented the largest contribution to uncertainty, while CO<sub>2</sub> 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<sub>4</sub> emission uncertainty for pipeline transport ranges from  $\pm 40\%$ . 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  $\pm 18\%$ . Consistent with the inventory estimation methodology for this source subcategory, off-road diesel fuel consumption is calculated from the on-road diesel fuel consumption residual, and likewise for offroad gasoline consumption. Consequently, activity data uncertainties from road transportation were used in the off-road uncertainty analysis and did not contribute substantially to the results mentioned above since they were relatively low. Of greater influence was the N<sub>2</sub>O emission uncertainty for gasoline ( $-90\%$  to  $+900\%$ ) and diesel fuel ( $-50\%$  to  $+200\%$ ). Approximately 17% 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. The QC activities are documented and archived in paper and electronic form.

In addition, certain verification steps were performed during the model preparation stage. Since MGEM 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 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. The interdepartmental collaboration is currently focusing on a detailed survey of on-road vehicle activity.

### 3.2.6.5. Recalculations

Transportation estimates were revised for the 1990–2013 period. Revised activity data and emission factor updates for railways, navigation and off-road diesel all contributed to recalculations in



the Transport category, the net impact of which is summarized in Table 3–2.

More specifically, the changes in the Transport category can be described as the following:

*Activity Data:*

1. The fuel-use data were revised for 2013 based on Statistics Canada data, and estimates were recalculated accordingly. Refer also to Section 3.2.4.5.
2. Biofuel consumption data were revised for 2013.
3. On-road vehicle populations have been updated for years 2005–2013 except for motorcycles, which were revised for the entire time series. Please see Annex 3.1, section A.3.1.4.2.1 for more information.
4. Kilometre accumulation rates for light and heavy vehicles have been revised affecting the entire time series. Please see Annex 3.1, section A.3.1.4.2.1 for more information.

*Emission Factors:*

Emission factors for CH<sub>4</sub> and N<sub>2</sub>O have been revised for railways, navigation and off-road diesel to comply with the new default emission factors provided in the 2006 IPCC Guidelines (IPCC 2006). For further documentation on emission factors, refer to Annex 6.

### 3.2.6.6. Planned Improvements

Planned improvements have been identified for the Transport category. Current high priorities include the development of a bottom-up Tier 3 methodology for off-road emission estimates using the NONROAD model and the replacement of the transportation model (MGEM) with the Motor Vehicle Emission Simulator (MOVES) for on-road emission estimation.

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 is being considered in order to make use of higher resolution data and to align model methodologies with other emission inventories produced by Environment Canada. For example, adoption of NONROAD will allow Canada to estimate emissions for off-road activities in construction and residential sectors, which is not currently possible with MGEM.

While Canada has made progress towards the implementation of MOVES and NONROAD, various challenges along the way have postponed the implementation of both models. Canada continues to work towards their implementation and will report on its progress in the next inventory submission.

Based on 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. 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. GHG emissions from the use of transportation fuels in these subcategories are allocated to Transport (Section 3.2.6).

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<sub>2</sub> as well as CH<sub>4</sub> and N<sub>2</sub>O 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 is a small source of emissions in the Commercial/Institutional subcategory. Emissions from CH<sub>4</sub> and N<sub>2</sub>O were included in the subcategory estimates, while CO<sub>2</sub> emissions were reported separately in the CRF tables as memo items and were not included in Energy Sector totals.

In 2014, the Other Sectors category contributed 80.5 Mt (10.9%) of Canada's total GHG emissions, with an overall growth of about

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

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2010	2011	2012	2013	2014
<b>Other Sectors TOTAL (1.A.4)</b>	<b>74 600</b>	<b>82 800</b>	<b>79 600</b>	<b>73 500</b>	<b>79 200</b>	<b>73 800</b>	<b>76 600</b>	<b>80 500</b>
Commercial/Institutional	25 800	33 100	32 100	28 200	30 100	28 200	29 400	31 300
Commercial and Other Institutional	23 900	30 800	30 000	26 300	28 200	26 400	27 700	29 600
Public Administration	1 990	2 300	2 070	1 820	1 920	1 760	1 630	1 670
Residential	46 300	47 200	45 400	42 500	45 600	42 100	43 600	45 600
Agriculture/Forestry/Fishing	2 410	2 570	2 110	2 900	3 460	3 560	3 580	3 680
Forestry	58	77	159	189	136	137	168	158
Agriculture	2 350	2 490	1 950	2 710	3 320	3 420	3 410	3 530

Note: Totals may not add up due to rounding.

8% (6.0 Mt) since 1990. Within the Other Sectors category, the Residential subcategory contributed emissions of about 45.6 Mt (56.6%), followed by the Commercial/Institutional subcategory, with emissions of 31.3 Mt (or 38.8%). Since 1990, GHG emissions have grown by 21% in the Commercial/Institutional subcategory, while GHG emissions in the Residential subcategory have declined by about 1.6%. 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 according to the methodology described in Annex 3.1, which is considered to be 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), are based on volumes collected for the Waste Sector. CH<sub>4</sub> and N<sub>2</sub>O emissions from the combustion of LFG are included, while CO<sub>2</sub> emissions are excluded from totals, but reported separately in the UNFCCC CRF tables as a memo item.

#### 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, although CO<sub>2</sub> emissions are not accounted for in the national residential GHG total (but reported as a memo item), the CH<sub>4</sub> and N<sub>2</sub>O emissions are reported here.

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

This subcategory includes emissions from stationary fuel combustion in the agricultural and forestry industries. However, emission estimates are included for the agriculture and forestry portion only. Fishery emissions are currently under either the Transport category or the Other Manufacturing (i.e. food processing) subcategory. Mobile emissions associated with this subcategory were not disaggregated and are included as off-road or marine emissions reported under Transport (Section 3.2.6). Emissions from on-site machinery operation and heating are based on fuel-use data reported as agriculture and forestry in the RESD.

### 3.2.7.3. Uncertainties and Time-Series Consistency

The estimated uncertainty range for the Other Sectors category is  $\pm 6\%$  for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O combined and  $\pm 2\%$  for CO<sub>2</sub> alone.

The underlying fossil fuel quantities and non-biomass CO<sub>2</sub> emission factors have low uncertainties, since they are predominantly commercial fuels that have consistent properties and can be accurately tracked, as compared to residential biomass information. The overall non-CO<sub>2</sub> emissions uncertainty is 12% for the Residential subcategory due to higher uncertainty associated with biomass emission factors (CH<sub>4</sub> with -90% to +1500% and N<sub>2</sub>O with -65% to +1000%) as compared to fossil-fuel-based CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> and N<sub>2</sub>O 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 2013 RESD data contributed to recalculations and improved accuracy of the emissions for the Other Sectors category. Refer to Section 3.2.4.5, Recalculations, for more details.

### 3.2.7.6. Planned Improvements

Environment 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 57-003-X). This is a small source; emissions were <100 kt CO<sub>2</sub> eq in 2014.

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

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

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 2014, the Fugitive Emissions from Fuels category accounted for about 60 Mt (8.1%) of Canada's total GHG emissions, with 22% growth in emissions since 1990. Between 1990 and 2014, fugitive emissions from oil and natural gas increased 27% to 58 Mt, and those from coal decreased by approximately 1 Mt from 3 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.

**Table 3–9 Fugitive GHG Contribution**

GHG Source Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Solid Fuels—Coal Mining (1.B.1)	3 000	2 000	1 000	1 000	1 000	1 000	2 000	1 000
a. Coal Mining and Handling	3 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
i. Abandoned Underground Mines	200	500	200	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
a. Oil <sup>1</sup>	5 000	6 500	6 400	6 000	6 200	6 800	7 200	7 500
b. Natural Gas <sup>1</sup>	13 000	18 000	14 000	12 000	12 000	12 000	12 000	13 000
c. Venting and Flaring <sup>2</sup>	27 600	43 700	39 300	34 700	35 900	37 000	37 400	37 500
i. Venting	23 000	38 000	34 000	30 000	31 000	32 000	32 000	32 000
ii. Flaring	4 600	5 700	5 300	4 700	4 900	5 000	5 400	5 500
CO <sub>2</sub> Transport and Storage (1.C) <sup>3,4</sup>	-	0.09	0.09	0.09	0.09	0.09	0.09	0.1
<b>Fugitive Emissions from Fuels (1.B)</b>	<b>49 000</b>	<b>70 000</b>	<b>61 000</b>	<b>54 000</b>	<b>55 000</b>	<b>57 000</b>	<b>58 000</b>	<b>60 000</b>

Notes:

1. All other fugitives except venting and flaring.

2. Both oil and gas activities.

- Indicates no emissions.

0 values indicate emissions truncated due to rounding.

Totals may not add up due to rounding.

### 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<sub>4</sub> from within the deposit. Post-mining activities such as preparation, transportation, storage and final processing prior to combustion also release CH<sub>4</sub>.

#### 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 54 kt CO<sub>2</sub> eq in 2014, while emissions from the two active underground mines were estimated at only 108 kt CO<sub>2</sub> 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 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<sub>4</sub>, CO<sub>2</sub>, 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<sub>4</sub>) emissions were measured remotely using a ground-based mobile plume transect system (MPTS) for area sources and tracer tests for volume and point sources (Cheminfo Services and Clearstone Engineering 2014). Data from this field testing was used to modify the CH<sub>4</sub> 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 necessary 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

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<sub>4</sub> 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<sub>4</sub> 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

No recalculations were undertaken.

### Abandoned Underground Mines

Emissions were revised to reflect the confirmed flooding of abandoned mines in Nova Scotia.

#### 3.3.1.6. Planned Improvements

### Coal Mining and Handling

New uncertainty estimates will be developed based on the recently completed study.

### 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 linecleaning 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<sup>3</sup>). 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/m<sup>3</sup>. 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<sub>4</sub> 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<sub>2</sub>S) 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<sub>2</sub> 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<sub>4</sub> 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 and 2006–2010 were provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2012 onwards are estimated using length of natural gas transmission pipeline and amounts of natural gas transported. 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<sub>2</sub>S 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 2015) and the National Energy Board's (NEB 1998–2014) 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 (2015) 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 distribu-

tion 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 and 2006–2010 were provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2012 onwards are estimated using length of natural gas distribution pipeline and amounts of natural gas transported. 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 2014 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 2014 oil sands/bitumen fugitive emission estimates has been estimated to be  $\pm 6.1\%$ , on the basis of a study conducted on 2006.<sup>5</sup> An IPCC Good Practice Guidance Tier 1 uncertainty assessment was conducted for each oil sands

<sup>5</sup> Some changes have occurred in the industry since that time, but uncertainty has not been reassessed.

**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
<b>Total</b>	<b>-10.4 to + 10.5</b>	<b>-18.6 to +29.6</b>	<b>-16.4 to +17.8</b>	<b>± 52.6</b>	<b>-20.0 to +18.2</b>

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 uncertainties 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<sub>2</sub> 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

**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
<b>Overall</b>	<b>±6.1</b>

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 1990–2013 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.

These improvements have increased the transparency, accuracy and representativeness of fugitive emission estimates at the sectoral and subsectoral levels.

**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

### 3.3.2.6. Planned Improvements

*Oil Sands/Bitumen:* In the long term, a comprehensive study to update the bitumen study (CAPP 2006) is planned with the goal of improving emission estimates from oil sands mining and extraction, in-situ production 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 expert review team (ERT) reviews.

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

Carbon dioxide transport and storage involves the capture of anthropogenic CO<sub>2</sub> and its transport to a storage facility.

While two CO<sub>2</sub> pipelines exist in Canada, they are associated with the use of carbon dioxide in an enhanced oil recovery (EOR) process. All CO<sub>2</sub> 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<sub>2</sub> – 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<sub>2</sub> 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<sub>2</sub>. 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<sub>2</sub>/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 required for the first year of reporting.

#### 3.4.1.6. Planned Improvements

Environment Canada is monitoring the construction of additional CO<sub>2</sub> pipelines in Alberta and will incorporate these into emissions estimates as they come on-line.

## 3.5. Other Issues

### 3.5.1. CO<sub>2</sub> Emissions from Transport Biomass

As per the UNFCCC reporting guidelines, CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O 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)<sup>6</sup> of 24.12 TJ/ML, 52.14% carbon content and 789.2 kg/m<sup>3</sup> 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 offroad as a whole) as per the percentage of total gasoline. In lieu of developing specific emission factors for CH<sub>4</sub> and N<sub>2</sub>O for ethanol, the representative gasoline emission factor was applied as per mode and technology class. CO<sub>2</sub> emission factors used are those based on true chemical characteristics mentioned previously and a 100% oxidation rate.

<sup>6</sup> 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	2000	2005	2010	2011	2012	2013	2014
Ethanol Consumed (ML)	7	227	267	1 874	2 753	2 876	2 661	2 829

**Table 3-14 Biodiesel Used for Transport in Canada**

Year	1990	2000	2005	2010	2011	2012	2013	2014
Biodiesel Consumed (ML)	0	0	4	394	583	621	648	565

### 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)<sup>7</sup> used is 35.18 TJ/ML, with a 76.5% carbon content and 882 kg/m<sup>3</sup> 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<sub>4</sub> and N<sub>2</sub>O for biodiesel, the representative fossil fuel-based diesel emission factor was applied as per mode and technology class. CO<sub>2</sub> emission factors used are those based on true chemical characteristics mentioned previously and a 100% oxidation rate.

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

In Canada, CO<sub>2</sub> captured during coal gasification 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<sub>2</sub> being trapped in the voids previously occupied by hydrocarbon molecules. This process is commonly known as geological storage of CO<sub>2</sub>.

CO<sub>2</sub> 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 (U.S.) is transported via pipeline to the field. In addition, starting in late

2014 some CO<sub>2</sub> was transported to the Weyburn site from SaskPower's Boundary Dam coal-fired power station. This fresh supply and CO<sub>2</sub> recovered from previous flooding cycles are combined and injected into the reservoir. Currently about 2.8 Mt per year of CO<sub>2</sub> is injected at the Weyburn-Midale operations.<sup>7</sup> From 2000 to 2014, the Weyburn site injected over 28 Mt of fresh CO<sub>2</sub> purchased from the Dakota gasification plant with an injection rate of 7000 t of CO<sub>2</sub> per day (PTRC 2011). Since 2005, the Midale site has injected more than 2 Mt of fresh CO<sub>2</sub>, with an injection rate of 1800 t of CO<sub>2</sub> per day (PTRC 2004).

In addition to being a CO<sub>2</sub> EOR operation, Weyburn is also the site of a full-scale geological CO<sub>2</sub> storage research program led by the International Energy Agency's (IEA) Greenhouse Gas Research and Development Programme (IEAGHG) with the support of various industries, research organizations and governments. Modelling and simulation results from the first phase (from 2000 to 2004) of the IEAGHG's CO<sub>2</sub> monitoring and storage project, managed by the Petroleum Technology Research Centre (PTRC), indicates that over 98% of CO<sub>2</sub> 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 PTRC website focused on developing a best practice manual for future projects on the geological storage of CO<sub>2</sub>, 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.

<sup>7</sup> CO<sub>2</sub> Injected Data for Weyburn and Midale. Operational information provided in a presentation by F. Mourits, IEA GHG Weyburn-Midale CO<sub>2</sub> Monitoring and Storage Project, Natural Resources Canada. January 2010.

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

Canada exports a large proportion of its produced fossil fuel resources, mostly to the United States. In 2014, Canada exported approximately 64% (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 2014, emissions associated with the production of oil and gas for exports have increased by approximately 270%, coinciding with an increase of approximately 215% in total exported oil and gas (Table 3–15). Over the same period, oil exports have increased at a rate 2.5 times greater than the growth in domestic production, while the emissions associated with those exports have grown by almost 400% (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). For natural gas, emissions associated with exports have doubled, coinciding with an increase of almost 100% in natural gas exports (almost twice the rate of growth of natural gas production) (Table 3–17).<sup>8</sup>

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<sup>9</sup> from Canada's oil sands has been consistently increasing (Table 3–19). In 2014, production was over six times higher than in 1990, while exports were eight times higher than in 1990. Whereas exports have grown eight-fold, the emissions associated with these exports are only five and a half times larger, reflecting improved efficiencies in extracting oil sands products.

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

<sup>9</sup> 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
Domestic Production (PJ)	7 958	12 170	13 092	12 804	13 409	13 868	14 387	15 192
Energy Exported (PJ)	3 068	7 068	7 870	8 256	8 583	8 909	9 256	9 691
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	31.5	71.1	86.5	90.4	95.3	104.1	111.3	116.4

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

Crude Oil Trends	1990	2000	2005	2010	2011	2012	2013	2014
Domestic Production (PJ)	3 774	5 108	5 899	6 797	7 347	7 863	8 336	8 885
Energy Exported (PJ)	1 531	3 222	3 804	4 582	5 020	5 516	6 088	6 695
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	19.5	39.4	53.9	62.3	68.4	77.3	85.4	92.4

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

<b>Natural Gas Trends</b>	<b>1990</b>	<b>2000</b>	<b>2005</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>
Domestic Production (PJ)	4 184	7 062	7 192	6 007	6 062	6 006	6 051	6 306
Energy Exported (PJ)	1 537	3 846	4 066	3 673	3 563	3 393	3 169	2 996
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	12.0	31.7	32.6	28.2	26.9	26.8	25.9	24.0

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

<b>Crude Oil Trends</b>	<b>1990</b>	<b>2000</b>	<b>2005</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>
Domestic Production (PJ)	2 973	3 590	3 459	3 184	3 378	3 451	3 583	3 597
Energy Exported (PJ)	1 112	2 433	2 293	2 315	2 608	2 622	3 227	3 345
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	11.4	26.4	33.0	26.4	29.5	30.6	35.4	39.3

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

<b>Crude Oil Trends</b>	<b>1990</b>	<b>2000</b>	<b>2005</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>
Domestic Production (PJ)	801	1 519	2 441	3 613	3 968	4 411	4 754	5 288
Energy Exported (PJ)	418	789	1 511	2 268	2 412	2 894	2 861	3 350
Emissions Associated with Gross Exports (Mt CO <sub>2</sub> eq.)	8.1	13.0	20.9	35.9	38.9	46.6	50.0	53.1



# 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<sub>6</sub>) and nitrogen trifluoride (NF<sub>3</sub>); 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 Mt to the 2014 national GHG inventory (Table 4–1), compared with 55.9 Mt in 1990. The 2014 IPPU emissions represented 7% of total Canadian GHG emissions in 2014. The contributing factors of the long-term and short-term trends in this sector are discussed in Chapter 2.

In line with the principle of continuous improvement and in response to comments made by the expert review teams (ERTs) on previous submissions, this submission has incorporated improvements to activity data, emission factors, methods and allocation of emissions. Detailed explanations for the changes in estimates as a result of these improvements are described in the “Category-Specific Recalculations” sections of this chapter and are summarized in Table 4–2.

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

Greenhouse Gas Category	GHG Emissions (kt CO <sub>2</sub> eq)							
	1990	2000	2005	2010	2011	2012	2013	2014
<b>INDUSTRIAL PROCESSES AND PRODUCT USE</b>	<b>55 900</b>	<b>53 500</b>	<b>58 300</b>	<b>50 500</b>	<b>51 400</b>	<b>55 800</b>	<b>52 700</b>	<b>51 000</b>
Mineral Products	8 400	10 000	10 000	7 800	7 900	8 500	7 700	7 800
Cement Production	5 800	7 200	7 600	6 000	6 100	6 600	6 000	6 000
Lime Production	1 760	1 870	1 710	1 370	1 430	1 450	1 360	1 430
Mineral Product Use	910	910	910	410	450	440	380	380
Chemical Industry	17 300	8 610	9 470	5 470	6 090	6 440	6 400	5 990
Ammonia Production	2 770	2 960	2 710	2 490	2 880	3 000	2 950	2 540
Nitric Acid Production	970	1 200	1 200	1 100	1 100	1 100	990	1 000
Adipic Acid Production	10 000	870	2 500	-	-	-	-	-
Petrochemical and Carbon Black Production	3 300	3 600	3 000	1 900	2 100	2 300	2 500	2 400
Metal Production	23 800	23 400	20 200	16 200	17 100	16 900	14 800	14 700
Iron and Steel Production	10 500	11 800	10 300	9 170	10 100	10 200	8 040	8 600
Aluminum Production	10 300	8 890	8 680	6 870	6 810	6 470	6 530	5 840
SF <sub>6</sub> Used in Magnesium Smelters and Casters	2 960	2 660	1 230	183	183	248	213	229
Production and Consumption of Halocarbons, SF <sub>6</sub> and NF <sub>3</sub>	980	3 400	5 700	7 500	8 000	8 300	8 600	9 000
Non-Energy Products from Fuels and Solvent Use	5 000	7 500	12 000	13 000	12 000	15 000	15 000	13 000
Other Product Manufacture and Use	370	630	530	430	410	510	530	440

Note: Totals may not add up due to rounding.



Table 4-2 Impact of Recalculations from Revisions and Improvements

Greenhouse Gas Categories	GHG Emissions or Change in Emissions <sup>1</sup> (Mt CO <sub>2</sub> eq), Selected Years						
	1990	2000	2005	2010	2011	2012	2013
<b>INDUSTRIAL PROCESSES AND PRODUCT USE</b>							
Current (2016) submission	55.9	53.5	58.3	50.5	51.4	55.8	52.7
Previous (2015) submission	55.1	53.4	58.8	50.7	50.9	55.0	52.2
Net change in emissions	+0.8	+0.1	-0.5	-0.2	+0.6	+0.7	+0.5
<b>Mineral Products</b>							
Current (2016) submission	8.4	10.0	10.2	7.8	7.9	8.5	7.7
Previous (2015) submission	8.7	10.2	10.3	8.0	8.2	8.8	8.1
Net change in emissions	-0.3	-0.3	-0.1	-0.1	-0.2	-0.3	-0.4
<b>Chemical Industry<sup>2</sup></b>							
Current (2016) submission	17.3	8.6	9.5	5.5	6.1	6.4	6.4
Previous (2015) submission	14.2	5.1	6.5	3.6	4.1	4.2	4.5
Net change in emissions	+3.1	+3.5	+2.9	+1.9	+2.0	+2.3	+1.9
<b>Metal Production</b>							
Current (2016) submission	23.8	23.4	20.2	16.2	17.1	16.9	14.8
Previous (2015) submission	23.5	23.1	20.1	16.1	16.9	16.6	14.5
Net change in emissions	+0.3	+0.3	+0.1	+0.1	+0.2	+0.3	+0.3
<b>Production and Consumption of Halocarbons, SF<sub>6</sub> and NF<sub>3</sub><sup>2</sup></b>							
Current (2016) submission	1.0	3.4	5.7	7.5	8.0	8.3	8.6
Previous (2015) submission	1.2	3.8	5.4	5.9	6.1	6.4	6.6
Net change in emissions	-0.2	-0.4	+0.2	+1.5	+1.9	+1.9	+1.9
<b>Non-Energy Products from Fuels and Solvent Use<sup>2</sup></b>							
Current (2016) submission	5.0	7.5	12.1	13.1	11.9	15.2	14.7
Previous (2015) submission	7.4	10.8	16.0	16.9	15.5	18.8	18.2
Net change in emissions	-2.3	-3.2	-3.9	-3.8	-3.5	-3.6	-3.5
<b>Other Product Manufacture and Use</b>							
Current (2016) submission	0.4	0.6	0.5	0.4	0.4	0.5	0.5
Previous (2015) submission	0.2	0.4	0.4	0.2	0.3	0.3	0.3
Net change in emissions	+0.2	+0.2	+0.2	+0.2	+0.2	+0.2	+0.2

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), and Chemical Industry (specifically petrochemical production).

## 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 2005-2014b). 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.

In 2014, the category accounted for 6.0 Mt (or 0.8%) of Canada's total emissions, with about a 3.5%-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 here.

### 4.2.2. Methodological Issues

CO<sub>2</sub> emissions from cement production were calculated using a Tier 2 method (Equation 4-1) that incorporates country-specific emission factors.

**Equation 4-1:**

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

where:

$EF_{cl}$	=	annual emission factor based on clinker production, 0.5270 kt CO <sub>2</sub> /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 (1.013)
$EF_{toc}$	=	emission factor for CO <sub>2</sub> emissions from organic carbon in the raw feed, 0.0115 kt CO <sub>2</sub> /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 publically 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 (2002–2013) and 1990 (CAC, 2013). These same quantities have been estimated for the remaining reporting years (1991–2001 and 2014). The CAC receives plant-based data from its member companies in accordance with the quantification method published under the umbrella of the Cement Sustainability Initiative of the World Business Council for Sustainable Development (WBCSD), CO<sub>2</sub> Emissions Inventory Protocol, Version 2.0.

The calcination CO<sub>2</sub> emission factor ( $EF_{cl}$ ) varies from year to year and is based on the available data for years 1990, 2000, and 2002–2013. For the unknown data years (1991–1999, 2001), an average is taken from the years before and after the unknown data point. The correction factor for CKD/by-pass dust is calculated by the CAC to be 1.013 and is based on CKD data from years 1990, 2000, and 2002–2013.

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 2002–2013. These assumptions, combined with the molecular weight ratios of CO<sub>2</sub> to C (44.01/12.01), result in the organic carbon emission factor ( $EF_{toc}$ ) of 0.0115 (kt CO<sub>2</sub>/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 1997–2014 were obtained from Statistics Canada (Statistics Canada 1990–2004; Statistics Canada 2005–2014a).

Refer to Annex 3.3 for additional information on methodological issues.

Provincial/territorial emissions are estimated based on clinker capacity of cement plants across Canada. The source of 1990–2006 data was the Canadian Minerals Yearbook (NRCan 1990–2006). In subsequent years (2007–2013), information was

provided directly by Natural Resources Canada via personal communication.<sup>1</sup> Capacity data was not available for 2014 and was therefore 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 based on 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. Also considered was the error associated with the non-response rate of the Statistics Canada survey for clinker production data. The Tier 1 uncertainty associated with the CO<sub>2</sub> estimate for clinker production was ±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.

### 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

There have been no recalculations for this category.

### 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

<sup>1</sup> Panagapko D. 2008-2014. Personal communications (emails to Environment Canada and Climate Change, last email dated September 16, 2014).

for all inventory years. There is no information on hydraulic lime production in Canada; its proportion of lime production is therefore assumed to be zero.

Emissions from the regeneration of lime from spent pulping liquors at pulp mills are not accounted for in the IPPU Sector. The CO<sub>2</sub> emissions associated with the use of natural limestone for lime production in the pulp and paper industry is accountable and is 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<sub>2</sub> 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 based on the information on Canadian lime compositions collected from the Canadian Lime Institute<sup>2</sup> 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) for the period up to and including the year 2006. In subsequent years, information was provided directly by Natural Resources Canada via personal communication. The most recent lime production data are preliminary and subject to revision in subsequent publications.

Canadian lime plants are classified into three types based on their final products: dolomitic lime only, high-calcium lime only, and both high-calcium and dolomitic lime. In the absence of disaggregated data on the breakdown of lime types, an 85/15 value for highcalcium/dolomitic lime was used for lime plants producing both high-calcium and dolomitic lime, resulting in the breakdown provided in Table 4–3. National CO<sub>2</sub> 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 28.25%.<sup>3</sup> The water content of hydrated lime is deducted from national lime production to calculate the amount of “dry” lime production, which is broken down into the two lime types: high calcium and dolomitic. Corresponding emission factors are then applied.

Provincial CO<sub>2</sub> emissions are derived from national emissions based on the calcining capacity of each province/territory.

The decline in the share of dolomitic lime between 1999 and 2000 is the result of changes at two Ontario plants in that period.

**Table 4–3 Split between Dolomitic and High-Calcium Lime Production in Canada (1990–2014)**

Year	% Split	
	Dolomitic Lime	High-Calcium Lime
1990–1992	14%	86%
1993–1999	16%	84%
2000–2002	8%	92%
2003–2008	9%	91%
2009–2014	7%	93%

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.<sup>4</sup> 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 has been 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 the percentage split between the two types of lime. The uncertainty associated with the category as a whole was evaluated at  $\pm 8.2\%$ , 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 activity data sources have changed over the time series from the Canadian Lime Institute to data collected by 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 elaborated 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).

<sup>2</sup> Kenefick W. 2008. Personal communication (email from Kenefick W to Shen A, Environment and Climate Change Canada, dated October 7, 2008). Canadian Lime Institute.

<sup>3</sup> Kenefick W. 2008. Personal communication (email from Kenefick W to Shen A, Environment and Climate Change Canada, dated October 22, 2008). Canadian Lime Institute.

<sup>4</sup> Panagapko D. 2013. Personal communication (email to Edalatmanesh M, Environment Canada and Climate Change, dated November 6, 2013).

### 4.3.5. Category-Specific Recalculations

Updates to the activity data for 2013 resulted in a small (42 kt) upward recalculation of emissions for that year.

### 4.3.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

## 4.4. Mineral Product Use (CRF Categories 2.A.3 and 2.A.4)

### 4.4.1. Category Description

The categories discussed here, 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 2014, the aggregate category accounted for 0.4 Mt (or 0.05%) of Canada’s total GHG emissions, with a decrease of about 58% in total emissions since 1990. Limestone and Dolomite Use accounted for 47% of the Mineral Product Use emissions, whereas Non-metallurgical Magnesia Production, Other Uses of Soda Ash, and Glass Production each contributed 24%, 16%, and 13% of emissions, respectively.

#### Glass Production (CRF Category 2.A.3)

The CO<sub>2</sub> emissions associated with soda ash and limestone consumed in Canadian glass production are included in this category. For the full time series, soda ash has been the predominant source of CO<sub>2</sub> emissions from glass production.

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

Second to glass production, soda ash is used in the production of chemicals, in soaps and detergents, pulp and paper, and in 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 in different periods during the years 1990–2008. Two of the facilities closed in 1991 and 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 as makeup lime, and other chemical uses, such as wastewater treatment and flue gas desulphurization (FGD).

### 4.4.2. Methodological Issues

#### Glass Production (CRF Category 2.A.3)

National CO<sub>2</sub> 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.<sup>5</sup>

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

National CO<sub>2</sub> emissions are calculated using a Tier 1 method that applies the stoichiometry-based emission factor of 415 g CO<sub>2</sub>/kg soda ash to the national consumption data, assuming 100% purity of soda ash used in Canada.

Soda ash consumption data were estimated based on soda ash production, import and export data.

Import and export data were obtained from Global Trade Information Services (GTIS 1995–2006, 2007–2009) and Statistics Canada’s Canadian International Merchandise Trade Database (Statistics Canada 2010–2014). The trade data for the years 1990–1994 were assumed to be the average of the 1995–2000 trade data, since GTIS does not report trade data before 1995. The total quantities of soda ash used were distributed by application type, based on the U.S. pattern of soda ash consumption: glass, chemical, soaps and detergents, pulp and paper, flue gas desulphurization, and others. Likewise, provincial emissions were estimated by

<sup>5</sup> 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.

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<sub>2</sub> process emissions from the use of magnesite in magnesia production. The method applies an emission factor of 522 g CO<sub>2</sub>/kg magnesite, based on the stoichiometric carbon available in the magnesite, and assumes that magnesite is 97% pure (AMEC 2006). The emission factor is multiplied by facility-specific activity data to produce provincial and national CO<sub>2</sub> 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 were back-calculated from the amount of magnesia produced, which was 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.<sup>6</sup> The activity data for 2006 and 2007 were 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 (1990–2014) and its annual activity data are sourced from British Columbia's Ministry of Energy and Mines (BC Geological Survey, 2014).

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

A Tier 2 method is used to estimate CO<sub>2</sub> 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<sub>2</sub> per kilogram of pure limestone used, and adjusted to consider a purity fraction of 95% (Derry Michener Booth and Wahl 1989). The Canadian emission factor is therefore 418 g CO<sub>2</sub>/kg of limestone used (AMEC 2006).

<sup>6</sup> 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.B.3 Glass Production	2.A.4.d Other process uses of carbonates		
	High Calcium (kt)	Dolomite (kt)	High Calcium (kt)	High Calcium (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	446	191	0	31	47	349



An overall emission factor of 468 g CO<sub>2</sub>/kg of dolomite used was derived based on the emission factors for pure limestone (440 kg CO<sub>2</sub>/tonne) and magnesite (522 kg CO<sub>2</sub>/tonne) and on the assumption that dolomite is composed of approximately 58% CaCO<sub>3</sub> and 41% MgCO<sub>3</sub> (AMEC 2006).

For 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 were obtained from the *Canadian Minerals Yearbook* (NRCan 1990–2006). For subsequent years, information was 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 based on 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<sub>2</sub> emissions are estimated by multiplying the quantities of limestone and dolomite consumed by the corresponding emission factors. The emissions are then 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 was assumed to be 100% emissive and 100% composed of limestone and has been duly accounted for. Dolomite is usually less appropriate than limestone for most industrial applications, and most dolomite that is mined is crushed and sieved to be utilized as aggregate in concrete or asphalt (Bliss et al. 2008). Other markets of dolomite, such as glassmaking and agricultural use, are excluded from Canada’s “other chemical uses” subcategory.

Based on Canadian information,<sup>7</sup> only limestone is used for FGD processes in Canadian coal power plants.

Provincial emission estimates were 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 were used (i.e. pulp and paper, non-ferrous metal, glass and chemical sectors).

### 4.4.3. Uncertainties and Time-Series Consistency

#### Glass Production (CRF Category 2.A.3)

The Tier 1 uncertainty assessment of the Glass Production category considers uncertainties associated with the consumption data, emission factors, and assumptions for soda ash and

limestone used in glass production. The overall uncertainty associated with the 2014 estimate is ±10.2%.

The same emission factors were 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 ±10.2% to ±13.8%.

The same emission factor was 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 has been 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 ±5% to ±8%, with data on the use of magnesite being the largest contributor.

The same emission factor was consistently applied over the 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% to ±38%, with activity data on chemical uses being the largest contributor to the uncertainty estimate.

The same emission factors were 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 was 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.

<sup>7</sup> Cook S. 2013. Personal communication to Edalatmanesh M, Environment and Climate Change Canada, November 18, 2013. Canadian Electricity Association.

### 4.4.5. Category-Specific Recalculations

The 2013 emission estimate for Limestone and Dolomite Use was recalculated downward (by 70 kt) as a result of an update in the preliminary activity data.

Note that the previous 2015 submission did not report emissions for CRF category 2.A.3, Glass Production, and in order to do so, some emissions have been re-allocated. More specifically:

- Emissions from the use of limestone for glass production have been re-allocated from CRF category 2.A.4.d Other (Limestone and Dolomite Use) to CRF category 2.A.3 Glass Production; and
- Emissions from the use of soda ash for glass production have been re-allocated from CRF category 2.A.4.b, Other Uses of Soda Ash, to CRF category 2.A.3, Glass Production.

Similarly, emissions from the use of limestone and dolomite in iron and steel furnaces have been re-allocated from CRF category 2.A.4.d, Other (Limestone and Dolomite Use), to CRF category 2.C.1, Iron and Steel Production.

These re-allocations have impacted the entire time series (1990–2013).

### 4.4.6. Category-Specific Planned Improvements

Organic carbon contained in raw materials used in the production of ceramics is a source of CO<sub>2</sub> emissions that is currently not estimated in Canada's inventory. It is therefore planned to conduct a study in order to estimate and report CO<sub>2</sub> emissions for CRF category 2.A.4.a, Ceramics, in future inventory submissions.

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

### 4.5.1. Category Description

The Ammonia Production category accounted for 2.5 Mt (0.35%) of Canada's emissions in 2014, and its level of emissions has decreased by 8.6% since 1990.

There are currently seven ammonia production plants operating in Canada, located in Alberta, Saskatchewan, Manitoba, and Ontario. Six of these plants use steam-methane reformers to produce ammonia; they also recover CO<sub>2</sub> emissions to produce urea. The seventh plant uses by-product hydrogen (purchased from a neighbouring chemical plant) to feed into the Haber-Bosch reaction and is therefore assumed to have negligible process-related CO<sub>2</sub> emissions.

### 4.5.2. Methodological Issues

The Ammonia Production category estimates CO<sub>2</sub> 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 2008–2014 were obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey (Statistics Canada 2008–2014). 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<sub>j</sub>) to determine the resulting CO<sub>2</sub> emissions generated. The amount of CO<sub>2</sub> 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<sub>2</sub> and that 5 kg of CO<sub>2</sub> are emitted per tonne of urea produced. The resulting recovery factor (RF<sub>CO2</sub>) is therefore 0.728 kg CO<sub>2</sub> / kg urea.

Equation 4-2: CO<sub>2</sub> Emissions from Ammonia Production

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

where:

$E_{CO_2}$	=	emissions of CO <sub>2</sub> , kt
$AP_i$	=	ammonia production of facility i, kt
$FF_i$	=	ammonia-to-feed fuel conversion factor of facility i, m <sup>3</sup> natural gas/ t NH <sub>3</sub>
$CC_j$	=	carbon content factor of the fuel in province j, kt CO <sub>2</sub> /m <sup>3</sup> of natural gas
$RF_{CO_2}$	=	factor for CO <sub>2</sub> recovered for urea production, 0.728 kg CO <sub>2</sub> / kg urea
$UP_i$	=	urea production of facility i, kt

Assuming a complete conversion of NH<sub>3</sub> and CO<sub>2</sub> to urea, the stoichiometric mass ratio of CO<sub>2</sub>:urea (0.733 tonnes CO<sub>2</sub> per tonne urea) is used to convert urea production to CO<sub>2</sub>, as recovered from ammonia process emission. Using a CO<sub>2</sub> release rate of 5 kg per tonne of urea production, the net emissions recovered (R<sub>CO2</sub>) is calculated at 0.728 tonnes CO<sub>2</sub>/ tonne urea.



Urea production data for years 2008 through 2014 were retrieved from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey. For the years 1990–2007, urea production was estimated based on 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 has been 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 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

Updates to the activity data for 2013 resulted in a downward recalculation of 531 kt for that year.

### 4.5.6. Category-Specific Planned Improvements

There are currently no improvements planned for estimating CO<sub>2</sub> 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 1.0 Mt (0.14%) of Canada's emissions in 2014, and the level of emissions was similar to that in 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<sub>x</sub>). In contrast, a "selective" catalytic reduction (SCR) uses ammonia, which selectively reacts only with nitrogen oxide (NO) and nitrogen dioxide (NO<sub>2</sub>) gases, and not with nitrous oxide (N<sub>2</sub>O). Hence, a higher N<sub>2</sub>O emission factor. Most Canadian plants (nine out of twelve) 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 T1, T2 and T3 methods were used in the estimation of N<sub>2</sub>O from nitric acid production, the pre-dominance being with T2, 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<sub>2</sub>O emissions from nitric acid production for 1990–2004 were gathered through a study

**Table 4-5 Nitric Acid Industry-Typical Emission Factors**

Type of Production Process Technology	Type of Emission Control Technology	Emission Factor (kg N <sub>2</sub> O/t HNO <sub>3</sub> )	Data Source
Dual Pressure	Extended Absorption "Type 1"	9.4	1992 letter from G. Collis <sup>1</sup>
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.

conducted for Environment Canada (Cheminfo Services 2006), those for 2005–2009 were obtained by Environment Canada from industry through a voluntary data submission process, and those for 2008–2014 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 based on 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 2005–2014, 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.

### 4.6.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been 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 associated with the category as a whole is evaluated at  $\pm 10\%$ , with the emission factors being the largest contributors. The uncertainty value is applicable to all years of the time series.

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

Nitric acid production is a 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 IPCC Good Practice Guidance (IPCC 2000).

### 4.6.5. Category-Specific Recalculations

There have been no recalculations for this category.

### 4.6.6. Category-Specific Planned Improvements

Installed control technologies will be reviewed for the next submission cycle.

## 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<sub>2</sub>O 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<sub>2</sub>O and CO<sub>2</sub> 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<sub>2</sub>O/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:**

$$\begin{aligned} \text{Total Emissions (t)} \\ &= \text{N}_2\text{O Emissions (t) with abator} \\ &+ \text{N}_2\text{O Emissions (t) without abator} \end{aligned}$$

**N<sub>2</sub>O Emissions with Abator:****Equation 4–4:**

$$\begin{aligned} \text{N}_2\text{O Emissions (t) with Abator} \\ &= (\text{Production(t)}) \times \left( \frac{0.3t \text{ N}_2\text{O}}{t \text{ adipic acid}} \right) \\ &\times (1 - \text{Destruction Efficiency}) \times (\text{Abatement Utilization Ratio}) \end{aligned}$$

where:

**Destruction Efficiency** = determined based on the difference between the amount of N<sub>2</sub>O entering the abatement unit and that leaving the unit. It is a monthly average calculated using values recorded by analyzers, 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<sub>2</sub>O goes through the abator divided by the total operating time.

**N<sub>2</sub>O Emissions without Abator:****Equation 4–6:**

$$\begin{aligned} \text{N}_2\text{O Emissions (t) without Abator} \\ &= (\text{Production(t)}) \times \left( \frac{0.3t \text{ N}_2\text{O}}{t \text{ adipic acid}} \right) \\ &\times (1 - \text{Abatement Utilization Ratio}) \end{aligned}$$

where:

**Abatement Utilization Ratio** = number of hours during which N<sub>2</sub>O goes through the abator divided by the total operating time.

It is important to note that the in-line continuous emission monitor has never been used to directly monitor net N<sub>2</sub>O emissions. This is because the analyzer is limited to accurately measuring relatively low concentrations of N<sub>2</sub>O only when the reactor is online and abating N<sub>2</sub>O gas. The analyzer is not capable of measuring the full range of N<sub>2</sub>O concentrations that could potentially exist in the stack. The N<sub>2</sub>O concentration can vary from a low nominal level of 0.3% when the stream leaves the abator to a high nominal level of 35–39% N<sub>2</sub>O in the unabated stream. When the abatement reactor is bypassed, there is no N<sub>2</sub>O abatement occurring, and the analyzer will not record N<sub>2</sub>O stack emissions (Cheminfo Services 2006).

The calculation technique used to estimate emissions for the 1990–1997 period is in accordance with the Tier 1 method of the 2006 IPCC Guidelines (IPCC 2006). For the period between 1998 and 2009, the estimation methods used for emissions with and

without the abator align with Tier 3 and Tier 2 methods (IPCC 2006).

### 4.7.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been 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 , two methods are applied in the time series: one for the period of time during which the plant operated *with* the emission abatement system and another for the period of time 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<sub>2</sub> emissions generated from the ash production process for the applicable reporting years (1990–2001). The net CO<sub>2</sub> emissions are assumed to be negligible because the CO<sub>2</sub> 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<sub>2</sub>). SiC and CaC<sub>2</sub> are no longer produced in Canada; the last of two SiC plants closed in 2002 and the only CaC<sub>2</sub> plant closed in 1992.

#### 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.

Process GHG (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) 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<sub>2</sub> and light hydrocarbons. Additional CH<sub>4</sub> emissions can occur in venting of process gases containing CH<sub>4</sub> from the methanol distillation train and methanol storage tanks and from fugitive emissions from equipment leaks (Cheminfo Services 2010).

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

There were five ethylene facilities in operation in Canada between 1990 and 2014, 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. One is the direct chlorination of ethylene in a vapour or liquid phase reaction using ethylene dibromide as catalyst. The second process is called oxychlorination.

In terms of emissions, the process off-gas that contains the chlorinated hydrocarbons is combusted within the plant prior to release, so any carbon in this off-gas is converted to CO<sub>2</sub>. The process CO<sub>2</sub> emissions from EDC production come from the side reaction of feedstock oxidation. The process CH<sub>4</sub> emissions would most likely come from light hydrocarbons from distillation operations that are not captured by a flare gas recovery system. These emissions are vented to the atmosphere (Cheminfo Services 2010).

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

Four facilities produced carbon black in Canada between 1990 and 2014, three of which are currently operating.

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

Three styrene facilities produced styrene in Canada between 1990 and 2014, one of which closed in 1998.

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

During the manufacture of HCFC-22, trifluoromethane (HFC-23 or CHF<sub>3</sub>) is generated as a byproduct (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).

There has been no known production of SF<sub>6</sub> 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<sub>4</sub> emissions from carbide production. A study was commissioned to identify and establish the production capacities of the three carbide production facilities in Canada. A time series of process CH<sub>4</sub> emissions was estimated for the two silicon carbide facilities from 1990 to 2001 and for one calcium carbide facility from 1990 to 1991, based on assumed capacity utilization and CH<sub>4</sub> emission factors. Only production capacity data (SiC and CaC<sub>2</sub>) during the time series were identified during the study. As such, the following equation was used to estimate total CH<sub>4</sub> emissions from carbide production:

Equation 4–8:

$$\text{Total CH}_4 \text{ emissions (t)} = \sum_y [(SiC \text{ capacity} \times \text{capacity utilization} \times \text{Emission Factor}_{SiC}) + (CaC_2 \text{ capacity} \times \text{capacity utilization} \times \text{Emission Factor}_{CaC_2})]$$

where:

y	=	companies
SiC or CaC <sub>2</sub> capacity	=	data collected from the industry, kt
Capacity utilization	=	based on Cheminfo Services' knowledge of the industry, %
Emission Factor <sub>SiC</sub>	=	11.6 kg CH <sub>4</sub> /t SiC (IPCC 2006)
Emission Factor <sub>CaC<sub>2</sub></sub>	=	4.8 kg CH <sub>4</sub> /t CaC <sub>2</sub> , derived from CH <sub>4</sub> emission factor for silicon carbide and the ratio of IPCC default Calcium Carbide CO <sub>2</sub> emission factor to IPCC default Silicon Carbide CO <sub>2</sub> emission factor (i.e. 11.6 (kg CH <sub>4</sub> /t SiC) * (1.09 tCO <sub>2</sub> /tCaC <sub>2</sub> / 2.62 tCO <sub>2</sub> /tSiC))

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

When available, CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, 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<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O. National methanol production values are taken from Camford's CPI Product Profile for 1990–1999 and estimated based on 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 the production period between 2011 and 2014 (Cheminfo Services 2015).

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

Two consulting studies were commissioned to evaluate CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emission sources in Canadian petrochemical production as well as the quantity of fuels consumed as feedstocks. The latter was required to differentiate the emissions associated with petrochemical production (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,<sup>8</sup> 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<sub>2</sub>O emission factors. The second study<sup>9</sup> examined the fuels consumed by Canadian ethylene producers over the entire time series (1990–2014) and derived facility-level emission factors for CO<sub>2</sub> and CH<sub>4</sub> on a year-by-year basis. The two emission factors change over time in step with changes to the feedstocks consumed in Canadian ethylene production.

National ethylene production data are taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. For 2008–2014, 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 based on the

<sup>8</sup> Cheminfo Services 2010

<sup>9</sup> Cheminfo Services 2015



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<sub>4</sub> emissions from EDC production for the years 1990–2009 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<sub>4</sub> emission estimates. The annual EDC production data come from the Canadian C<sub>2</sub>+ Petrochemical Report. The default process CH<sub>4</sub> emission factor for EDC as applied comes from Table 2-10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), under the name dichloroethylene. The Canadian C<sub>2</sub>+ 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 based on 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<sub>4</sub> 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<sub>4</sub> 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<sub>4</sub> and 0.032 kg/t for N<sub>2</sub>O were derived as weighted averages of the reported 2007–2009 data. One sector-wide process CH<sub>4</sub> emission factor was also calculated as a weighted average based on the same set of data reported by the two facilities (1.29 kg CH<sub>4</sub>/t product).

The sector-wide EF value is lower than the IPCC default value of 11 kg CH<sub>4</sub>/t product. It is suspected that the IPCC default EF, which is based on only one study, has included CH<sub>4</sub> from the combustion of fuel as well. The Canadian EF only includes the CH<sub>4</sub> that originates directly from the feed.

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 based on 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) based on a sector average growth rate for 1990–1994. The total sector production for each year of 1996–2006 is calculated by multiplying the sector average growth rate by the total sector production of the preceding year (starting from 1995). Production data for 2010–2014 are obtained from Statistics Canada's Industrial Chemicals and Synthetic Resins Survey.

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

Process CO<sub>2</sub> emissions can come from the combustion of the process off-gas (fuel gas) as fuel or from flaring of over-pressured process streams. Methane (CH<sub>4</sub>) 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<sub>4</sub> emission estimates. Annual styrene production data were retrieved from the Canadian C<sub>2</sub>+ Petrochemical Report. For the purpose of emission estimation at the provincial level, the annual styrene production is allocated to each plant based on capacity share. The default process CH<sub>4</sub> emission factor for styrene (4 kg/t) comes from Table 2-10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997). As the 2006 IPCC Guidelines do not cover styrene production under its petrochemicals section, a more recent emission factor cannot be found. 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 2012–2014 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.<sup>10</sup>

### 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) based on expert knowledge following the 2006 IPCC Guidelines.

Regarding the carbide capacity data, an uncertainty of  $\pm 5\%$  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  $\pm 16\%$  to  $\pm 27\%$  (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<sub>4</sub> emissions: 20%;
- reported process N<sub>2</sub>O emissions: 30%;
- reported process CO<sub>2</sub> emissions: 10%

The uncertainty associated with the category as a whole for the time series ranged from 7.4% to  $\pm 20\%$  for CH<sub>4</sub> emissions, from 10.76% to  $\pm 30\%$  for N<sub>2</sub>O emissions, and from 2.71% to  $\pm 10\%$  for CO<sub>2</sub> emissions.

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

A Tier 1 uncertainty assessment was performed by Cheminfo Services (2010, 2015) for the subcategory of Ethylene Production following the 2006 IPCC Guidelines.

In the Cheminfo Services (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided any uncertainty

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

- capacity data:  $\pm 5\%$ ;
- reported production data:  $\pm 2\%$ ;
- capacity share fractions used for allocation of national production data:  $\pm 10\%$ ;
- reported process CH<sub>4</sub> emissions:  $\pm 20\%$ ; and
- reported process N<sub>2</sub>O emissions:  $\pm 30\%$ .

The uncertainties for the time series range from  $\pm 7\%$  to  $\pm 12\%$  for CH<sub>4</sub> emission estimates, from  $\pm 12\%$  to  $\pm 21\%$  for N<sub>2</sub>O emission estimates, and from  $\pm 15\%$  to  $\pm 21\%$  for CO<sub>2</sub> 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  $\pm 21\%$  (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:  $\pm 5\%$ ;
- reported production data:  $\pm 2\%$ ;
- capacity share fractions used for allocation of national production data:  $\pm 10\%$ ;
- reported process CH<sub>4</sub> emissions:  $\pm 20\%$ ; and
- reported process N<sub>2</sub>O emissions:  $\pm 30\%$ .

The Tier 1 uncertainty associated with the CH<sub>4</sub> emission estimates ranges from  $\pm 9\%$  to  $\pm 11\%$ .

<sup>10</sup> 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.

### 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 the category as a whole for the time series was estimated at  $\pm 30\%$  (Cheminfo Services 2010).

### 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

Emission estimates associated with methanol production for the time period between 2011 and 2013 have been updated in light of new methanol production data (Cheminfo Services 2015, Methanex 2013).

The CO<sub>2</sub> emissions associated with ethylene and methanol production were previously included with the emissions associated with non-energy uses of fuels (CRF category 2.D). A recent study (Cheminfo Services 2015) has been used to disaggregate the quantity of fuels consumed in ethylene and methanol production from the fuels reported to Statistics Canada as "non-energy" consumption. The fuels consumed as feedstock include methane, natural gas liquids and petrochemical feedstocks. The recalculation has re-allocated fuel use from the Non-Energy Products from Fuels and Solvent Use (CRF category 2.D) to Petrochemical and Carbon Black Production (CRF category 2.B.8) and applied emission factors that are specific to the products from the pet-

rochemical industry. This resulted in an upward recalculation of emissions across the time series (1990–2013) for the Petrochemical Production category. In 2013, the volume of fuels withdrawn from CRF category 2.D, Non-Energy Products from Fuels and Solvent Use, resulted in a reduction of emissions for that category in the order of 3.5 Mt. The fuels were re-allocated to petrochemical production and the new emission estimates for CRF category 2.B.8, Petrochemical and Carbon Black Production, resulted in an upward recalculation of 2.4 Mt. For the full time series, recalculations in category 2.B.8 range between 1.7 Mt and 5.4 Mt. Although the magnitude of emissions have increased, the overall declining trend in petrochemical emissions from 1990 remains unchanged.

#### 4.9.6. Category-Specific Planned Improvements

Production of ethylene oxide is a source of CO<sub>2</sub> and CH<sub>4</sub> 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 8600 kt (1.2%) to Canada's total emissions in 2014, an 18% decrease since 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<sub>2</sub> emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron;
- CO<sub>2</sub> emissions during steel production, which occur to a much lesser extent (these come from the oxidation of carbon in crude iron and electrode consumption);

- CO<sub>2</sub> emissions given off by limestone flux in the blast furnace; and
- CH<sub>4</sub> 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<sub>met\_coke</sub>), and carbon content of pig iron.

CO<sub>2</sub> emissions from pig iron production were estimated using the following equation:

Equation 4–9:

$$E_{CO_2,PI} = (EF_{met\_coke} \times M_{met\_coke}) + (M_{ore} \cdot CC_{ore} - P_{PI} \cdot CC_{PI}) \times \left(\frac{44}{12}\right)$$

where:

E <sub>CO<sub>2</sub>,PI</sub>	=	process emissions from pig iron production, kt
EF <sub>met_coke</sub>	=	year-specific emission factors (t CO <sub>2</sub> / t metallurgical coke used) obtained from the Cheminfo Services (2010) study
M <sub>i</sub>	=	mass of i used or produced, kt; where i is metallurgical coke, ore
CC <sub>i</sub>	=	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 <sub>PI</sub>	=	production of pig iron, kt
44/12	=	ratio of the molecular weight of CO <sub>2</sub> 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* (RESO) (Statistics Canada 1990–2014). 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 2013–2014. The emission factors for coke use (EF<sub>met\_coke</sub>) 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 1990–2009. The emission factors were calculated as ratios of CO<sub>2</sub> emissions to coke consumption. No Canada-specific coke carbon content is available for 2010–2014; as a result, the 2009 coke carbon content is assumed for 2010–2014 (being a calcined product, coke is not expected to vary greatly with regard to its carbon content.)

The coke carbon contents were then applied to the set of coke use data provided by Statistics Canada. With respect to the carbon content of pig iron, the CSPA<sup>11</sup> provided an industry-average content value, which is kept confidential.

CO<sub>2</sub> emissions from steel production were estimated using the following equation:

Equation 4–10:

$$E_{CO_2,steel} = [CC_{iron} \cdot M_{iron} + CC_{scrap\ steel} \cdot M_{scrap\ steel} - CC_{BOF} \cdot M_{BOF} - CC_{EAF} \cdot M_{EAF}] \cdot \frac{44}{12} + EF_{EAF} \cdot P_{EAF} + EF_{BOF} \cdot P_{BOF}$$

where:

E <sub>CO<sub>2</sub>,steel</sub>	=	process emissions from steel production, kt
CC <sub>j</sub>	=	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 <sub>j</sub>	=	mass of j used, kt
44/12	=	ratio of the molecular weight of CO <sub>2</sub> to the molecular weight of carbon
EF <sub>k</sub>	=	emission factors (t CO <sub>2</sub> / t steel produced) obtained from the Canadian Steel Producers Association
P <sub>k</sub>	=	steel production by either EAF or BOF, kt

According to Equation 4-10, part of the CO<sub>2</sub> emitted from the steel production process is estimated based on the difference between the amount of carbon in the iron and in scrap steel used to make steel and the amount of carbon in the steel produced in basic oxygen furnaces and electric arc furnaces (EAFs). It should be noted that the amount of pig iron fed to steel furnaces (used in Equation 4-10) is not equal to the amount of total pig iron production (used in Equation 4-9). As part of the steel production process, emissions are also generated by the consumption of electrodes in EAFs and in the 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 the Canadian Steel Producers Association for 2013–2014. The values of the carbon contents and emission factors mentioned in Equation 4-10 were all provided by the CSPA.<sup>12</sup>

The methodology used to estimate CO<sub>2</sub> emissions from limestone used as a flux in iron and steel furnaces are described in Section 4.4.2.

11 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.

12 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.

CH<sub>4</sub> emissions were estimated based on the mass of metallurgical coke used (Statistics Canada 1990-2014) multiplied by an emission factor. The emission factor value for CH<sub>4</sub> emissions from coke use in the iron and steel industry is not presented in this report to protect the confidentiality of the data.

Data on metallurgical coke use at provincial/territorial levels from the Report on Energy Supply and Demand in Canada (RESO) (Statistics Canada 1990-2014) were used to derive the percentage of total reductant consumption attributed to each province and territory. CO<sub>2</sub> emissions at provincial/territorial levels were then estimated by multiplying the percentage derived by the national emission estimate.

It should be noted that RESO 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 nonenergy uses of petroleum coke. To avoid double counting, the CO<sub>2</sub> emissions from the consumption of electrodes in the steel production process in EAFs are therefore subtracted from the total non-energy emissions. It is assumed that there are no imported electrodes used for steel production in EAFs in Canada. If electrodes are imported, the portion of CO<sub>2</sub> generated by the imported electrodes needs to be subtracted from the emissions from electrode consumption before being subtracted from the total non-energy emissions.

### 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 uncertainty associated with the category as a whole for the time series is around  $\pm 5.5\%$ .

### 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 CO<sub>2</sub> emissions in this category. However, emissions from other CRF categories have been appropriately re-allocated to the Iron and Steel Production category, specifically CO<sub>2</sub> emissions from limestone used as flux in iron and steel furnaces and CH<sub>4</sub> emissions from metallurgical coke use. In the previous submission, these sources were reported under Mineral Products (with other limestone and dolomite use) and the Energy Sector, respectively. These re-allocations have resulted in an upward recalculation ranging from 45 kt to 506 kt across the time series (1990–2013) in the Iron and Steel category.

### 4.10.6. Category-Specific Planned Improvements

As noted earlier, a smaller part of the process CO<sub>2</sub> 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 RESO and due 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 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 RESO) used in iron and steel making is currently reported under the Non-energy Products from Fuels and Solvent Use category (Section 4.13). It is planned to allocate the aforementioned emissions to CRF category Iron and Steel Production.

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

### 4.11.1. Category Description

The Aluminium Production category accounted for 5840 kt (0.8%) of Canada's emissions in 2014, representing an overall decrease in emissions of 43% 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<sub>2</sub> emissions, primary aluminium smelting is a source of carbon tetrafluoride (CF<sub>4</sub>) and carbon hexafluoride

(C<sub>2</sub>F<sub>6</sub>), both of which are included in this submission. This submission also includes a small amount of SF<sub>6</sub> that is emitted from its use as cover gas as well as a degassing (purifying) agent at some aluminium plants that produce high magnesium-aluminium alloys.<sup>13</sup> The consumption of SF<sub>6</sub> is highly variable depending on whether any or both of these operations (SF<sub>6</sub> use as a cover gas and/or purifying agent) occur within a given year.

Aluminium plants are characterized by the type of anode technology employed. In general, older plants using Söderberg technology have higher emissions than newer plants, which usually use pre-baked anodes. The trend in the Canadian aluminium industry has been towards modernizing facilities and improving production efficiency. Of the 11 plants currently in operation, five use Söderberg technology either exclusively or in addition to newer technology.

### 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.<sup>14</sup> 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 the AAC. In addition to the smelter-specific emission estimates, information on the methodologies used by the aluminium producers to calculate CO<sub>2</sub>, PFC and SF<sub>6</sub> emissions and plant-specific production data for the time series were obtained from the AAC. According to the methodology documents supplied by the AAC, SF<sub>6</sub> emissions are equal to consumption in the aluminium industry.

Depending on data availability of each year in the time series, the estimation techniques applied vary between Tiers 1, 2 and 3, as described in Annex 3.3. 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<sub>2</sub>, PFCs and SF<sub>6</sub> are Tier 3 plant-level estimates using plant-specific parameters.<sup>15</sup>

<sup>13</sup> 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.

<sup>14</sup> <http://www.westernclimateinitiative.org/>.

<sup>15</sup> <http://www.env.gov.bc.ca/cas/mitigation/ggrcta/reporting-regulation/amendedquantificationmethods.html>.

### 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<sub>2</sub>, PFC and SF<sub>6</sub> emission estimates). It takes into account the uncertainties associated with all the parameters used to calculate the emissions. The *Aluminium Sector Greenhouse Gas Protocol* (IAI 2006) was the main source uncertainty values for parameters. The uncertainties for the CO<sub>2</sub>, PFC and SF<sub>6</sub> estimates are ±7%, ±9% and ±3%, respectively. For the CO<sub>2</sub> and PFC estimates, it should be noted that the uncertainty assessment is done for only one year of the time series (2006 for CO<sub>2</sub> and 2007 for PFC). It is expected that emission estimates of more recent years would have similar uncertainties, while older estimates would have higher uncertainties. For the SF<sub>6</sub> estimate, it is assumed that the uncertainty is the same as that of the Magnesium Casting category, since the method used to develop SF<sub>6</sub> emission estimates is the same for both Aluminium Production and Magnesium Casting.

### 4.11.4. Category-Specific QA/QC and Verification

CO<sub>2</sub> 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 minor corrections made in facility-reported CO<sub>2</sub> emissions for 2013, resulting in a downward recalculation of less than 200 kt CO<sub>2</sub>.

### 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<sub>6</sub> is emitted during magnesium production and casting, where it is used as a cover gas to prevent oxidation of the molten metals. SF<sub>6</sub> 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<sub>6</sub> and eventually eliminate the use of SF<sub>6</sub> as cover gas at its plant.<sup>16</sup> This research, as well as the use of substitute gas mixtures, produced significant reductions in SF<sub>6</sub> emissions in the mid- to late 1990s. For the years 2005–2007, Norsk Hydro's SF<sub>6</sub> 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<sub>6</sub> every year during the entire period. Some casters started using SF<sub>6</sub> towards the mid- or late 1990s, whereas others replaced it with an alternative gas, such as SO<sub>2</sub>. 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<sub>6</sub>. 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.

### 4.12.2. Methodological Issues

SF<sub>6</sub> emissions from magnesium production for 1999–2007 were directly reported by the companies (Norsk Hydro, Timminco Metals and Métallurgie Magnola Inc.) to Canada's National Pollutant Release Inventory (NPRI). Emission estimates used in this report are obtained from the NPRI's online database (Environment Canada 1990–2007). For previous years (i.e. 1990–1998), the data were provided voluntarily by the producers to Environment Canada through personal communication. Since there were no reported 2008 data for Timminco, its 2008 SF<sub>6</sub> value was estimated based on its 2007 data and on 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<sub>6</sub> emissions. Both companies reported that they had used the IPCC default method (emissions of SF<sub>6</sub> = consumption of SF<sub>6</sub>), as recommended in the IPCC Good Practice Guidance (IPCC 2000). However, they used different ways for estimating their SF<sub>6</sub> consumption. Norsk Hydro confirmed the use of the weight difference method,<sup>17</sup> based on measuring the weight of gas cylinders used at the facility at the time of purchase and at the time they were returned to suppliers

at the end of their usage. The accounting method was reported as being used by Timminco for estimating its SF<sub>6</sub> use.<sup>18</sup> In this method, accounting of delivered purchases and inventory changes of SF<sub>6</sub> used are recorded. The purchases must be the actual volumes received in the calendar period; therefore, beginning-of-year and end-of-year inventories are taken into account.

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<sub>6</sub> emissions from casting facilities assumes all SF<sub>6</sub> used as a cover gas is emitted to the atmosphere. To estimate SF<sub>6</sub> 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<sub>6</sub> data for only one year, it was assumed that their SF<sub>6</sub> use stayed constant during the other operating years at the level of the year for which the actual SF<sub>6</sub> data were obtained. For casters that had data for more than one year, linear interpolation between two data points was applied to estimate SF<sub>6</sub> 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<sub>6</sub> use stayed at the 2007 level. For 2009, communication was established with all seven companies. Two of the companies, for which magnesium casting operations had shut down in 2009, were not able to report their 2009 SF<sub>6</sub> use data, but provided reasonable assumptions that could be used to estimate the 2009 SF<sub>6</sub> use. SF<sub>6</sub> use data for 2009 were provided by the other five facilities. Due to the unavailability of data for a few facilities, the SF<sub>6</sub> emission and production values for these facilities for data years 2010–2014 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 as a Tier 3 type.

### 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<sub>6</sub> data reported by each facility. The uncertainty for the category as a whole was estimated at ±4.0%. It should be

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

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

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



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, based on the fact that the same emission estimation method (i.e. emissions = consumption of SF<sub>6</sub>) was applied to both categories of Magnesium Casting and Magnesium Production, it was assumed that the Magnesium Production category would have the same uncertainty (±4.0%) as the Magnesium Casting category.

The data source remains consistent over the time series. The methodology, which equates consumption of SF<sub>6</sub> as a cover gas by magnesium casters to emissions of SF<sub>6</sub>, 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 elaborated 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

Minor recalculations were made in the category of Magnesium Casting to reflect updated gross output forecast values for 2010–2013.

4.12.6. Category-Specific Planned Improvements

Efforts will be made to obtain up-to-date SF<sub>6</sub> 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<sub>2</sub> emissions. Also included in this category are emissions from the use of hydrocarbons (such as coal) as reductants for base metal smelting as well as petroleum-based solvents, cleaners and paint thinners.

The use of fossil fuels as feedstock or for other non-energy purposes is reported in an aggregated manner by Statistics Canada as “Non-Energy Use” for each individual fuel. In the event that CO<sub>2</sub> emissions resulting from non-energy fuel use are allocated to another category of the IPPU Sector (as is the case for Ammonia Production, Petrochemical Production, Iron and Steel Production, and Aluminium Production), those emissions are subtracted from the total emissions from this category to avoid double counting.

4.13.2. Methodological Issues

Emission factors for non-energy use of fuels were developed based on the total potential CO<sub>2</sub> emission rates and the IPCC 1996 Energy Sector’s default percentages of carbon stored in products (IPCC/OECD/IEA 1997). The total potential CO<sub>2</sub> emission factors were derived from the carbon emission factors shown in Jaques (1992), McCann (2000) and CIEEDAC (2006), which are EFs based on natural units of fuel; the IPCC provides for energy units-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 1990–2014) and the Annual Industrial Consumption of Energy Survey (ICE) (Statistics Canada 2014). It should be noted that the RESD/ICE data for any given year are

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

preliminary and subject to revisions in subsequent publications. These data were multiplied by the emission rates shown in Annex 3.3 to estimate CO<sub>2</sub> 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<sub>2</sub> 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 nonenergy use of fuels, based on the amount of carbon stored in the products resulting from the process. The CO<sub>2</sub> 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).

### 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  $\pm 21\%$ . 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

The emissions associated with fuels consumed in the production of ethylene and methanol were previously included in the category Non-Energy Products from Fuels and Solvent Use (CRF category 2.D). The fuels have been withdrawn from category 2.D and their associated emissions are now accounted for in Petrochemical Production (CRF category 2.B.8). In 2013, the volume of fuels withdrawn from CRF category 2.D resulted in a reduction of emissions in the order of 3.5 Mt and a corresponding increase in emissions of 2.4 Mt in CRF Category 2.B.8. For the full time series, the recalculated decreases in category 2.D range between 2.3 Mt and 4.3 Mt.

### 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, 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. For example, it is planned to report emissions from Lead and Zinc Production (currently aggregated in the Non-energy Products from Fuels and Solvent Use category) under the appropriate CRF categories 2.C.5 and 2.C.6. Refer to Chapter 8 for planned improvements for specific categories and Annex 3.3 for more information on methodological issues for the Non-energy Products from Fuels and Solvent Use category.

## 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<sub>6</sub> and NF<sub>3</sub> in semiconductor manufacturing, electrical environmental testing, gross leak testing and thermal shock testing. This category does not include emissions of SF<sub>6</sub> 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).

### 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).

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 4-11, was used to estimate PFC emissions from the semiconductor manufacturing industry:

## Equation 4–11:

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

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 <sub>4</sub> 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 2006 IPCC Guidelines.

As no information on emission control technologies for these processes in Canada was available, it was assumed that no emission control technologies were used. The heel (h) value was assumed to equal 0.1, as suggested in IPCC (2000).

### NF<sub>3</sub> Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

In 2013, Environment Canada commissioned a study to determine the extent of NF<sub>3</sub> usage in Canada, including a survey of all potential NF<sub>3</sub> gas suppliers as well as seven identified potential users (Cheminfo Services 2014). In the survey, only one user indicated usage of NF<sub>3</sub> 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<sub>3</sub> were used in 1986. All NF<sub>3</sub> 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<sub>3</sub> usage, as opposed to NF<sub>3</sub> 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<sub>4</sub> emission factors were also used to estimate CF<sub>4</sub> emissions from NF<sub>3</sub> usage with Tier 2a methods.

The identified user for 2013 was assumed to have utilized an equal amount from 2010–2014. The (unidentified) 2010 purchaser was assumed to have consumed its supply on an equal basis from 2010–2014. The 1986 data point was therefore linearly interpolated with the 2010 value, with emissions assumed constant since.

### SF<sub>6</sub> Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

The method applied to estimate SF<sub>6</sub> emissions from semiconductor manufacturing was similar to that used to calculate PFC and NF<sub>3</sub> emissions. However, there is no by-product CF<sub>4</sub> created during the use of SF<sub>6</sub> 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<sub>6</sub> gas distributors, Air Liquide and Praxair, was 12%.<sup>19</sup> 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<sub>6</sub> sales to semiconductor manufacturers in 2004–2009 were estimated by multiplying the total SF<sub>6</sub> import data (from Statistics Canada) by the sales distribution data (in %) received from SF<sub>6</sub> distributors (Cheminfo Services 2005a). No SF<sub>6</sub> sales data were collected for the 2010–2014 data years. The average proportion of SF<sub>6</sub> sold to the semiconductor manufacturing industry from 2004–2009 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 2012–2014 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<sub>6</sub> sold to the semiconductor industry.

Due to the two different sources of SF<sub>6</sub> data (i.e. Canadian gas suppliers for 1995–2003 and Statistics Canada for 2004–2009), there was a significant difference among these periods. To ensure a consistent trend over the entire time series, an overlap technique (IPCC 2006, Volume 1, Chapter 5) was applied for 1990–2003 (both data sources had SF<sub>6</sub> data for years 1998–2000).

It is noteworthy to mention that attempts were made to collect SF<sub>6</sub> 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

<sup>19</sup> 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.

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  $\pm 10\%$  to  $\pm 23\%$ .

The 2006 IPCC Guidelines show the relative error for Tier 2b etching with  $\text{NF}_3$  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  $\text{SF}_6$  emissions from semiconductor manufacturing ( $\pm 45\%$ ).

### 4.14.4. Category-Specific QA/QC and Verification

PFC,  $\text{NF}_3$ , and  $\text{SF}_6$  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

A correction was made to the PFC (i.e.  $\text{CF}_4$ ) emission estimates in the semiconductor manufacturing industry; this correction had a minor impact on the entire time series (downward recalculation of approximately 2.6 kt  $\text{CO}_2$  eq across the time series, 1990–2013). Although not a recalculation in emissions, there was also a correction made to  $\text{NF}_3$  consumption in the semiconductor manu-

facturing industry. This correction impacted the implied emission factor, making it constant for the entire time series.

As previously mentioned, to develop a more consistent time series, an overlap technique was applied to  $\text{SF}_6$  emissions from semiconductor manufacturing for 1990–2003; this resulted in a

downward recalculation of about 1 kt  $\text{CO}_2$  eq for each year during this period.

### 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 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 HFCs and PFCs (4.15 and 4.16, respectively). This section explains the Canadian context.

Hydrofluorocarbons (HFCs) are used in Canada in a variety of applications including refrigeration and air conditioning (AC), fire suppression, aerosols, solvent cleaning, and foam blowing.

Globally, before the Montreal Protocol ban on the production and use of CFCs came into effect in 1996, very few HFCs were produced and used. As such, Canadian emissions from HFC consumption were 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. All HFCs consumed in Canada are imported in bulk or in manufactured items and products (e.g. refrigerators). HFC consumption and hence the inventory in Canada begins in 1995 continuing through today (Table 4–7).

**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-134a	1995 onwards	HFC-245fa	2001 onwards
HFC-143a	1995 onwards	HFC-32	1995 onwards
HFC-152a	1995 onwards	HFC-365mfc	2008 onwards
HFC-227ea	1995 onwards	HFC-41	1999 & 2000
HFC-23	1995 onwards	HFC-4310mee	1998 onwards

### 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; an additional mandatory activity data collection took place in 2014, covering activities in the years 2008–2012. Note that the 1996 survey did not include information on imports and exports of manufactured items for the 1995 data year, and because the assumptions used for the derivation of this portion of the activity data could not be verified for this submission, the manufactured items were not included.

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

A 2014 mandatory survey of HFC bulk imports, exports and sales by HFC type and market segment form the foundation for the 2008 through 2012 bulk portion of the HFC inventory. A few additional reports that were received provided data to 2013 and 2014. 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 survey and have now been 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 changing practices brought about by provincial and federal HFC regulations and regulations and improvements achieved by industry in the design and manufacture of HFC-containing equipment.

The emission factors for 1995 to 1998 are from the IPCC 1996 revised guidelines (IPCC/OECD/IEA 1997). 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 starting in the 2010 data year, as it falls within the period from 2006, when all regulations were in place, to 2012, when the survey was performed. Emission factor values were interpolated between 1998 and 2010 to obtain annual values reflecting changes in practices brought about by regulations. All 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 the IPCC equation 7.1 (IPCC 2006, Volume 3) is used to suit the Canadian data as shown in Equation 4-12.

Equation 4-12:

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

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 the subcategories, such as residential/commercial refrigeration, stationary/mobile AC, 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  $\pm 34\%$  to  $\pm 50\%$ .

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). The only item of note was that further data mining of old survey responses is required to verify HFC 245fa quantities from 2001 to 2007.

### 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 the implementation of a new growth model for activity data using

surrogate variables. Specifically, the activity data were updated for HFC bulk and in-item imports for 2008 to 2012, 1995 in-item imports and exports were estimated based on the 1996 to 1999 survey data, and HFC 245fa activity data now includes the 2001 to 2010 period as well. Regarding emission factors, new country-specific emission factors were used for the "Other" refrigeration subcategory and fixed the conversion error related to percentages. Also, corrections were made to emission formulae for all subcategories (except for the refrigeration and air conditioning). Lastly, assembly emissions for refrigeration and air conditioning were removed as per the 2006 IPCC Guidelines, and estimates associated with the fire-extinguishing subcategory were recalculated to meet the guidelines. As a result of the recalculations, the 1990 to 2013 growth trend for this category changed from +660% to 880%.

### 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 2.F, PFCs)

### 4.16.1. Category Description

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

### 4.16.2. Methodological Issues

The IPCC Tier 2 methodology was used to estimate emissions from the consumption of PFCs for the years 1995–2014. 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 based on 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 2014 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 2011–2014 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 AC, and mobile AC systems, as well as leakage emissions for the same applications.

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 AC 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 AC 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.

**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

**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<sub>6</sub> in electrical equipment (CRF category 2.G.1), emissions of N<sub>2</sub>O from medical applications (CRF category 2.G.3.a), emissions of N<sub>2</sub>O 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<sub>2</sub> 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<sub>2</sub>O for commercial sales in Canada. It supplies N<sub>2</sub>O to two of the three primary N<sub>2</sub>O gas distributors that essentially account for the total commercial market in Canada. These companies sell cylinders of N<sub>2</sub>O to a relatively large number of sub-distributors. It is estimated that there may be 9000 to 12 000 final end-use customers for N<sub>2</sub>O in Canada, including dental offices, clinics, hospitals and laboratories (Cheminfo Services 2006).

N<sub>2</sub>O 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<sub>2</sub>O can be used include production of sodium azide (a chemical that is used to inflate automobile airbags), atomic absorption spectrometry and semiconductor manufacturing. According to the distributors that were surveyed during the recent study, approximately 82% of their N<sub>2</sub>O sales volume is used in dentistry/medical applications, 15% in food processing propellants and only 3% for the other uses (Cheminfo Services 2006).

Of all applications in which N<sub>2</sub>O can be used, only the two major types are emissive. When N<sub>2</sub>O is used as an anaesthetic, it is assumed that none of the N<sub>2</sub>O is metabolized (IPCC 2006). In other words, the used N<sub>2</sub>O quickly leaves the body in exhaled breath (i.e. is emitted) as a result of the poor solubility of N<sub>2</sub>O in

blood and tissues. When N<sub>2</sub>O is used as a propellant, only emissions coming from N<sub>2</sub>O used in whipped cream are estimated, because the amounts of N<sub>2</sub>O 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<sub>2</sub>O gas expands and whips the cream into foam. As none of the N<sub>2</sub>O 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.

### 4.17.2. Methodological Issues

#### SF<sub>6</sub> Emissions from Electrical Equipment (CRF Category 2.G.1)

In electric utilities, SF<sub>6</sub> is used as an insulating and arc-quenching medium in high-tension electrical equipment, such as electrical switchgear, stand-alone circuit breakers and gas-insulated substations. In Canada, SF<sub>6</sub> is primarily used in high-voltage circuit breakers and related equipment.

A modified Tier 3 method was used to estimate SF<sub>6</sub> emissions from electrical equipment in utilities for certain years (i.e. 2006–2014) of the time series, in place of the previous top-down approach (which assumed that all SF<sub>6</sub> purchased from gas distributors replaces SF<sub>6</sub> lost through leakage). The SF<sub>6</sub> emission estimates by province for 2006–2014 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<sub>6</sub> 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<sub>6</sub> injected into the equipment or contained in the cylinders. The national SF<sub>6</sub> estimate for each year of 2006–2014 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<sub>6</sub> 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 and Hydro Quebec for the years 1990–2005 because a systematic manner for taking inventory of the quantities of SF<sub>6</sub> from these organizations only started in the 2006 data year. Hence, the application of the Protocol was not possible. Surveys of SF<sub>6</sub> distributors were used to obtain usage data prior to the application of the Protocol. To resolve this issue of data availability and to ensure a consistent time series, an overlap technique (IPCC 2006, Volume 1, Chapter 5) was applied; in this case, the overlap was assessed between four sets of annual estimates (2006–2009) derived from the distributor surveys and obtained under the Protocol.

Emissions at provincial/territorial levels were estimated based on the national emission estimates (obtained from the use of the overlap approach) and the percent of provincial shares (based on the reported 2006–2009 data).

### **N<sub>2</sub>O Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF Category 2.G.3.b)**

N<sub>2</sub>O 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 equal domestic consumption.

The producer and distributors were surveyed to obtain sales data by market segment and qualitative information in order to establish the 2005 Canadian N<sub>2</sub>O sales pattern by application (Cheminco Services 2006). The sales patterns for 2006–2014 are assumed to be the same as the one for 2005. The amounts of N<sub>2</sub>O sold for anaesthetic and propellant purposes are calculated from the total domestic sales volume and their respective share of sales.

As of 2012, N<sub>2</sub>O import data are no longer available from Statistics Canada. Therefore, the 2012 to 2014 N<sub>2</sub>O import data were estimated based on a trend line built on the N<sub>2</sub>O imports of 2005 to 2011.

Provincial and territorial estimates were developed by distributing the national-level estimates based on provincial/territorial population data (Statistics Canada 2015).

### **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<sub>2</sub> 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<sub>x</sub> 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.<sup>20</sup>

### **4.17.3. Uncertainties and Time-Series Consistency**

A Tier 1 uncertainty assessment was performed for the category of SF<sub>6</sub> 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<sub>6</sub> 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 assess-

<sup>20</sup> Rideout G. 2014. Personal communication (email to McKibbin S. November 4, 2014). Pollution Inventories and Reporting Division, Environment and Climate Change Canada.

ment for PFC Consumption. The uncertainty associated with the category as a whole for the time series ranged from  $\pm 10\%$  to  $\pm 23\%$ .

A Tier 1 uncertainty assessment was performed for the categories of N<sub>2</sub>O 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  $\pm 19\%$ . 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<sub>2</sub> Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles. The overall uncertainty was found to be  $\pm 50\%$ .

#### 4.17.4. Category-Specific QA/QC and Verification

The categories of SF<sub>6</sub> Consumption in Electrical Equipment, N<sub>2</sub>O 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<sub>2</sub> 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 were made in these categories, namely updates to facility-reported SF<sub>6</sub> consumption in electrical equipment, updated N<sub>2</sub>O import data and updated activity data for CO<sub>2</sub> emissions from the use of urea in SCR vehicles.

#### 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

Emission sources from the Agriculture Sector include the enteric fermentation ( $\text{CH}_4$ ) and manure management ( $\text{N}_2\text{O}$  and  $\text{CH}_4$ ) categories from animal production and the agricultural soils ( $\text{N}_2\text{O}$ ) and field burning of crop residues ( $\text{CH}_4$  and  $\text{N}_2\text{O}$ ) categories for emissions that occur during crop production. Carbon dioxide emissions from lime and urea application are now reported in the Agriculture Sector; however,  $\text{CO}_2$  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).

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 animals are produced for commercial purposes, namely bison,<sup>1</sup> llamas, alpacas, horses, goats, elk, deer, wild boars, foxes, mink, rabbits, and mules and asses, but production is small.

Canadian agriculture is highly regionalized due to historic and climatic influences. Approximately 75% of beef cattle and more than 90% of wheat, barley and canola are produced on the Prairies in 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 2014.

Since 1990, cropping practices have changed in Canada, with canola production increasing from 3 Mt to 16 Mt, corn production from 7 Mt to 11 Mt, soybean production from 1.3 Mt to 6.0 Mt, and wheat production decreasing slightly from 32 Mt to 29 Mt. Synthetic nitrogen consumption has increased from 1.2 Mt N in 1990 to 2.5 Mt N in 2014, the area under summerfallow has decreased by 6.1 million hectares (Mha) and the regions using conservation tillage have increased by 17 Mha.

As a result of those changes, total greenhouse gas (GHG) emissions from the Canadian Agriculture Sector have increased from 49 Mt  $\text{CO}_2$  eq in 1990 to 59 Mt  $\text{CO}_2$  eq in 2014 (Table 5–1). This difference represents an increase of 21% from 1990, mainly due to higher populations of beef cattle and swine (12% and 28% increases, respectively), as well as an increase in the use of synthetic nitrogen fertilizers (107%).

Emissions of  $\text{CH}_4$  from livestock accounted for 26 Mt  $\text{CO}_2$  eq in 1990 and 29 Mt  $\text{CO}_2$  eq in 2014, and mean estimates lie within an uncertainty range of -16 to +20%. Over the time series of 1990 to 2014, mean  $\text{CH}_4$  emissions are estimated to have increased by 2.5 Mt  $\text{CO}_2$  eq, a 10% increase. The observed increase in emissions falls within an uncertainty range of 5% to 13%. Emissions of  $\text{N}_2\text{O}$  from agricultural soils and livestock accounted for 21 Mt  $\text{CO}_2$  eq in 1990 and 28 Mt  $\text{CO}_2$  eq in 2014; mean estimates lie within an uncertainty range of -27 to +29%. Over the time series, mean  $\text{N}_2\text{O}$  emissions increased by 6.4 Mt  $\text{CO}_2$  eq, an increase of 30%.

Emissions from the Agriculture Sector peaked in 2005, and decreased to 56 Mt  $\text{CO}_2$  eq in 2011, with reductions in emissions from animal production as major livestock populations decreased (see Enteric Fermentation and Manure Management source categories, Table 5–1). Since 2011, livestock populations have stabilized, while fertilizer emissions have increased. These trends, in combination with high crop production in recent years, have led emissions to increase from their low point in 2011.

In this submission, emissions were calculated as being 79 kt  $\text{CO}_2$  eq lower in 1990, 151 kt  $\text{CO}_2$  eq lower in 2005 and 126 kt  $\text{CO}_2$  eq lower in 2013 compared to the previous submission, for recalculations of 0.16%, 0.25% and 0.21%, respectively (Table 5–2). Some modifications were made to minor animal categories and liming, and error corrections were made to the spatial distributions of livestock, crop areas and tillage practices. These changes were due either to continuous inventory improvements (minor error corrections) or to Expert Review Team (ERT) recommendations (Table 5–3).

Rice is not produced in Canada and is not a source of  $\text{CH}_4$  emissions. Prescribed burning of savannas is not practiced in Canada. Finally, GHG emissions from on-farm fuel combustion are included in the Energy Sector (Chapter 3).

<sup>1</sup> 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.



Table 5-1 Short- and Long-Term Changes in GHG Emissions from the Agriculture Sector<sup>1</sup>

GHG Source Category			GHG Emissions (kt CO <sub>2</sub> eq)								
			1990	2000	2005	2010	2011	2012	2013	2014	
Agriculture TOTAL <sup>1</sup>			49,000	59,000	61,000	57,000	56,000	58,000	60,000	59,000	
Enteric Fermentation (CH <sub>4</sub> )			23,000	28,000	31,000	26,000	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	
	Beef Cattle <sup>2</sup>		18,000	23,000	26,000	21,000	20,000	20,000	20,000	20,000	
	Others <sup>3</sup>		730	1,100	1,300	1,100	1,100	1,100	1,100	1,100	
Manure Management			7,600	9,100	9,800	8,500	8,400	8,400	8,400	8,500	
	Dairy Cattle	CH <sub>4</sub>	980	880	850	820	820	810	840	840	
		N <sub>2</sub> O	560	450	420	390	390	380	380	380	
	Beef Cattle <sup>2</sup>	CH <sub>4</sub>	960	1,100	1,200	1,000	1,000	1,000	990	980	
		N <sub>2</sub> O	1,900	2,700	3,000	2,400	2,400	2,400	2,400	2,400	
	Swine	CH <sub>4</sub>	1,300	1,700	2,000	1,600	1,600	1,600	1,600	1,700	
		N <sub>2</sub> O	90	110	130	110	110	110	110	110	
	Poultry	CH <sub>4</sub>	160	190	190	190	190	190	190	190	
		N <sub>2</sub> O	430	530	540	560	560	560	560	560	
	Others <sup>4</sup>	CH <sub>4</sub>	40	50	60	60	60	60	60	60	
		N <sub>2</sub> O	90	150	180	160	160	160	160	160	
	Indirect Source of N <sub>2</sub> O		1,000	1,200	1,300	1,100	1,100	1,100	1,100	1,100	
	Agricultural Soils (N <sub>2</sub> O)			17,000	19,000	19,000	21,000	20,000	22,000	24,000	23,000
	Direct Sources			14,000	16,000	15,000	17,000	16,000	18,000	19,000	19,000
		Synthetic Nitrogen Fertilizers		5,700	7,400	6,800	8,400	8,800	10,000	11,000	11,000
Manure Applied as Fertilizers		1,700	2,000	2,100	1,800	1,800	1,800	1,800	1,800		
Crop Residue Decomposition		4,500	4,600	5,000	5,600	5,100	5,300	6,400	5,600		
Cultivation of Organic Soils		60	60	60	60	60	60	60	60		
Mineralization of Soil Organic Carbon		660	650	610	730	780	830	890	960		
Conservation Tillage <sup>5</sup>		-300	-760	-880	-990	-1,100	-1,300	-1,500	-1,400		
Summerfallow		1,400	1,100	790	520	480	470	460	370		
Irrigation		340	400	400	390	400	410	440	410		
Manure on Pasture, Range and Paddock		220	240	250	220	210	210	210	210		
Indirect Sources			3,000	3,700	3,700	3,900	3,900	4,300	4,600	4,500	
Crop Residue Burning (CH <sub>4</sub> & N <sub>2</sub> O)			230	130	50	30	30	40	50	50	
Lime and Urea Application (CO <sub>2</sub> )			1,200	1,600	1,400	1,800	2,000	2,300	2,600	2,500	

## 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, asses and mules.

4. Others, Manure Management, includes bison, goat, horse, lamb, llama/alpaca, sheep, fox, mink, rabbits, deer/elk, wild boars, asses and mules.

5. The negative values reflect a reduced N<sub>2</sub>O emission due to the adoption of conservation tillage.

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 2016 NIR**

		Recalculations (kt CO <sub>2</sub> eq )						
		1990	2000	2005	2010	2011	2012	2013
Previous submission (2015 NIR), kt CO <sub>2</sub> eq		49,000	59,000	62,000	57,000	56,000	58,000	60,000
Current submission (2016 NIR), kt CO <sub>2</sub> eq		49,000	59,000	61,000	57,000	56,000	58,000	60,000
Change due to ERT recommendation(s):								
Addition of Asses and Mules		4	4	5	5	5	5	5
Enteric Fermentation and Manure Management:	kt CO <sub>2</sub> eq	3	3	4	4	4	4	4
	%	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Agricultural Soils	kt CO <sub>2</sub> eq	1	1	1	1	1	1	1
	%	0.002	0.001	0.001	0.002	0.002	0.002	0.002
Emission factor correction to include a portion of dolomite contained in lime-stone data		8	9	4	4	5	7	7
CO <sub>2</sub> emissions from lime application:	kt CO <sub>2</sub> eq	8	9	4	4	5	7	7
	%	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Change due to continuous improvement or refinement:								
Recalculation of fur-bearing populations in considering life span of these animals		-120	-140	-170	-60	-30	-30	-20
Manure Management	kt CO <sub>2</sub> eq	-80	-90	-110	-40	-20	-20	-10
	%	-0.2	-0.1	-0.2	-0.1	-0.03	-0.03	-0.02
Agricultural Soils	kt CO <sub>2</sub> eq	-50	-50	-60	-20	-10	-10	-10
	%	-0.1	-0.1	-0.1	-0.04	-0.02	-0.02	-0.02
Error correction on livestock distribution, crop areas and tillage practices from the Census of Agriculture		50	60	40	-10	-40	-70	-90
Agricultural Soils:	kt CO <sub>2</sub> eq	50	60	40	-10	-40	-70	-90
	%	0.001	0.001	0.001	-0.0001	-0.001	-0.001	-0.002

**Table 5–3 Qualitative Summary of the Revisions to Methodologies, Corrections and Improvements Carried out for Canada's 2016 Submission**

Correction or Improvement	Recalculation Category	Years Affected
1. Correction to the implementation of 2006 Guidelines Emission Factor for fur bearing animals. Emission factors were applied to total numbers of fur-bearing animals in 2015 inventory, whereas they should have only been applied to breeding stock.	CH <sub>4</sub> emissions from manure management, and N <sub>2</sub> O emissions from direct and indirect emissions of manure management systems and agricultural soils	1990–2014
2. Addition of Assess and Mules based on previous ERT's recommendation	CH <sub>4</sub> emissions from enteric fermentation and manure management, and N <sub>2</sub> O emissions from direct and indirect emissions of manure management systems and agricultural soils	1990–2014
3. Minor error corrections to the spatial distribution of livestock distribution, crop areas and tillage practices	N <sub>2</sub> O 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 <sub>2</sub> emissions from agricultural use of limestone	1990–2014
5. Minor correction to beef cattle weight time series	CH <sub>4</sub> emissions from enteric fermentation	1990–2014

## 5.2. Enteric Fermentation (CRF Category 3.A)

### 5.2.1. Source Category Description

Methane (CH<sub>4</sub>) 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<sub>4</sub> is produced as a by-product. This process results in an accumulation of CH<sub>4</sub> in the rumen that

is emitted by eructation and exhalation. Some CH<sub>4</sub> is released later in the digestive process by flatulence, but this accounts for less than 5% of total emissions. Large ruminant animals, such as cattle, generate the most CH<sub>4</sub>.

In Canada, animal production varies from region to region. In western Canada, beef cattle production dominates, combining 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<sub>4</sub> 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<sub>4</sub> emissions are calculated, by province, by multiplying the animal population of a given category/subcategory by its corresponding regionally derived emission factor.

For cattle, CH<sub>4</sub> emission factors are estimated using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodology, based on the equations provided 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 1990–2014 time period are reflected in a 20% increase in CH<sub>4</sub> emission factors from this animal category. As milk production increases, the requirement of energy for lactation (NEL) becomes greater and requires increased food consumption. In beef cattle, changes in mature body weight influence maintenance and growth energy (NEm and NEg) 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 21%. Since finishing animals have a lower emission factor, the overall emission factor for the Non-dairy Cattle category has decreased from its peak in 2005.

For non-cattle animal categories, CH<sub>4</sub> emissions from 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 2014, uncertainty ranges from the 2012 analysis are applied to new emission estimates.

The uncertainty range for CH<sub>4</sub> emissions from enteric fermentation was similar in 1990 and 2014, and mean estimates lie within a range of -17 to +22% (Table 5–4). Over the time series of 1990 to 2014, mean emissions are estimated to have increased by 2.4 Mt CO<sub>2</sub> eq, an 11% 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 the methane conversion rate (Y<sub>m</sub>) and the factor associated with the estimation of the net energy of maintenance (C<sub>fi</sub>) (Karimi-Zindashty et al. 2012).

The methodology and parameter data used in the calculation of emission factors are consistent throughout the entire time series (1990–2014), 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 real milk production for the entire Canadian herd from 1990 to 1998 was calculated based

**Table 5–4 Uncertainty in Estimates of Emissions of CH<sub>4</sub> from Enteric Fermentation**

Animal Category	Uncertainty Source	Mean Value <sup>1</sup>	2.5% Prob <sup>2</sup>	97.5% Prob
Dairy Cattle	Population (1000 head)	954	907 (-5.2%)	1 006 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)	155	130 (-16%)	188 (+21%)
	Emissions (Mt CO <sub>2</sub> eq)	3.7	3.1 (-17%)	4.5 (22%)
Non-dairy Cattle	Population (1000 head)	11956	11 741 (-1.8%)	12 183 (+1.9%)
	Tier 2 Emission Factor (kg/head/year)	69	56 (-19%)	84 (+22%)
	Emissions (Mt CO <sub>2</sub> eq)	20	16 (-19%)	25 (+25%)
Other Animals	Emissions (Mt CO <sub>2</sub> eq)	1.1	0.9 (-18%)	1.3 (+17%)
Total Emissions	Emissions (Mt CO <sub>2</sub> eq) 1990	23	19 (-17%)	28 (+22%)
	2014	25	21 (-17%)	31 (+22%)
	Trend 1990–2014	2.7 (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 2014.

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 2014.

**Table 5–5 Recalculations of Estimates of Emissions and Their Impact on Emission Trend and Total Agricultural Emissions from Enteric Fermentation, Manure Management CH<sub>4</sub> and Manure Management N<sub>2</sub>O**

Emission Source	Year	Submission Year	Category Emissions (kt CO <sub>2</sub> eq)	Change in Emissions (kt CO <sub>2</sub> eq)	Relative Change Category Emissions (%)	Old Trend (%)	New Trend (%)
Enteric Fermentation	1990	2015	22838	-18	-0.1	Long term (1990 - 2013)	
		2016	22820			10	10
	2005	2015	31382	-26	-0.1	Short term (2005 - 2013)	
		2016	31355			-20	-20
	2013	2015	25234	-19	-0.1	Long term (1990 - 2013)	
		2016	25215			5.5	6.0
Manure Management CH <sub>4</sub>	1990	2015	3507	-16	-0.5	Long term (1990 - 2013)	
		2016	3491			5.5	6.0
	2005	2015	4312	-25	-0.6	Short term (2005 - 2013)	
		2016	4287			-14	-14
	2013	2015	3701	-1	0.0	Long term (1990 - 2013)	
		2016	3701			15	17
Manure Management - Direct N <sub>2</sub> O	1990	2015	3132	-57	-1.8	Long term (1990 - 2013)	
		2016	3075			15	17
	2005	2015	4302	-75	-1.7	Short term (2005 - 2013)	
		2016	4228			-16	-15
	2013	2015	3604	-11	-0.3	Long term (1990 - 2013)	
		2016	3593			14	14
Manure Management - Indirect N <sub>2</sub> O	1990	2015	989	-4	-0.4	Long term (1990 - 2013)	
		2016	985			14	14
	2005	2015	1319	-5	-0.4	Short term (2005 - 2013)	
		2016	1314			-14	-14
	2013	2015	1128	-1	-0.1	Long term (1990 - 2013)	
		2016	1127			-14	-14

on 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 1%, Table 5–5). The addition of mules and asses increased Enteric Fermentation estimates by 2 to 3 kt through the time series, but a very minor adjustment to the beef cattle weight time series decreased emissions by 20 to 30 kt, eliminating the impact of the addition of the new animal category.

### 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 live-stock, 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.

## 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 biodigestors. No manure is burned as fuel.

Both CH<sub>4</sub> and N<sub>2</sub>O are emitted during handling and storage of livestock manure. The magnitude of emissions depends 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<sub>4</sub> emissions

but relatively low N<sub>2</sub>O emissions, whereas well-aerated systems generate high N<sub>2</sub>O emissions but relatively low CH<sub>4</sub> emissions.

Manure management practices vary regionally 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. Feed-lot 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. Fur-bearing animals also produce solid manure.

### 5.3.1. CH<sub>4</sub> 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<sub>2</sub>. However, if little oxygen is present, carbon is reduced, resulting in the production of CH<sub>4</sub>. The quantity of CH<sub>4</sub> produced depends on manure characteristics and 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 based on 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<sub>4</sub> producing potential (B<sub>0</sub>) and CH<sub>4</sub> 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 2014 (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<sub>2</sub> eq from manure management CH<sub>4</sub> emissions from Canadian livestock in 2014 lies within an uncertainty range of -32% to +27% (Table 5–6). The emission estimate from manure management in 1990, 3.5 Mt CO<sub>2</sub> eq, has a slightly larger uncertainty range, -33% to +38%, due to greater uncertainty associated with the type of manure management systems in 1990. The estimate of a 5.5% increase in mean emissions between 1990 and 2014 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 methane conversion factor (MCF) that was applied to all regions of Canada and all animal types and the maximum methane production capacity (B<sub>0</sub>) (Karimi-Zindashty et al. 2012).

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2014), 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 Guide-

**Table 5–6 Uncertainty in Estimates of Emissions of CH<sub>4</sub> from Manure Management**

Animal Category	Uncertainty Source		Mean Value <sup>1</sup>	2.5% Prob. <sup>2</sup>	97.5% Prob
Dairy Cattle	Population (1000 head)		954	905 (-5.2%)	1 004 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		35.0	13 (-60%)	53 (+50%)
	Emissions (Mt CO <sub>2</sub> eq)		0.84	0.33 (-61%)	1.3 (+50%)
Non-dairy Cattle	Population (1000 head)		11,956	11 741 (-1.8%)	12 183 (+1.9%)
	Tier 2 Emission Factor (kg/head/year)		3.3	2.2 (-34%)	5.3 (+62%)
	Emissions (Mt CO <sub>2</sub> eq)		0.98	0.65 (-34%)	1.6 (+65%)
Swine	Population (1000 head)		12,860	12 512 (-2.7%)	13 207 (+2.7%)
	Tier 2 Emission Factor (kg/head/year)		5.1	2.5 (-51%)	7.2 (+43%)
	Emissions (Mt CO <sub>2</sub> eq)		1.6	0.80 (-51%)	2.3 (+44%)
Other Animals	Emissions (Mt CO <sub>2</sub> eq)		0.24	0.16 (-35%)	0.28 (+15%)
Total Emissions	Emissions (Mt CO <sub>2</sub> eq)	1990	3.5	2.3 (-33%)	4.8 (+38%)
		2014	3.7	2.5 (-32%)	4.7 (+27%)
	Trend	1990–2014	0.19 (5.5%)	-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 2014.

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 2014.



lines. The activity data and methodologies are documented and archived in both paper and electronic form. The IPCC Tier 2 CH<sub>4</sub> emission factors for manure management practices by all animal categories derived from Marinier et al. (2004) have been reviewed by independent experts (Patni and Desjardins 2004). These documents have been archived in 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 from manure management (Table 5–5) were also minor. The implementation of fur-bearing animal emission estimates in the 2015 submission was reviewed, resulting in a reevaluation of how emission factors were applied to animal populations. Based on a review of the sources of IPCC methodologies, it was apparent that emission factors were applicable to breeding stock rather than total animal populations. An alternate data source was identified for mink and fox populations that provided estimates of annual breeding stock on fur-farms, and rabbit numbers were revised based on average annual kit production. As a result, emission estimates were revised downward by a maximum of 26 kt CO<sub>2</sub> eq in 2006. This decrease in emissions was slightly offset by the implementation of the category of mules and asses, which added 0.2 kt CO<sub>2</sub> eq to the total.

### 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<sub>2</sub>O Emissions from Manure Management (CRF Category 3.B (b))

### 5.3.2.1. Source Category Description

The production of N<sub>2</sub>O during storage and treatment of animal waste occurs during nitrification and denitrification of nitrogen contained in the manure. Nitrification is the oxidation of ammonium (NH<sub>4</sub><sup>+</sup>) to nitrate (NO<sub>3</sub><sup>-</sup>), and denitrification is the reduction of NO<sub>3</sub><sup>-</sup> to N<sub>2</sub>O or N<sub>2</sub>. Manure from the Non-dairy Cattle, Sheep and Lamb, Goat and Horses, Deer and Elk, Mules and Asses, 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<sub>2</sub>O. Nitrous oxide emissions from manure excreted on pasture, range and paddock by grazing animals are reported separately (see Section 5.4.1.4).

### 5.3.2.2. Methodological Issues

Emissions of N<sub>2</sub>O 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<sub>4</sub> 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<sub>3</sub> and NO<sub>x</sub> 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<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O from agricultural sources (Karimi-Zindashty et al. 2014). For N<sub>2</sub>O emissions from manure management, the uncertainty in the parameters defined in the Tier



1 methodology of the 2006 IPCC Guidelines and all uncertainty in AWMS systems, animal populations and characterizations were identical to those used in the analysis of enteric fermentation and manure management CH<sub>4</sub> 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<sub>2</sub>O emissions of 3.6 Mt CO<sub>2</sub> eq from manure management in 2014 lies within an uncertainty range of 2.1 Mt CO<sub>2</sub> eq (-43%) to 5.4 Mt CO<sub>2</sub> 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<sub>2</sub>O model, the initial uncertainty analysis was limited to providing sound estimates of uncertainty for emission source categories and a basic sensitivity analysis. A complete analysis of the trend uncertainty has not yet been completed, due to limitations in software capabilities.

The same methodology, emission factors and data sources are used for the entire time series (1990–2014).

#### 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<sub>2</sub>O emission database.

There have been very few published data on N<sub>2</sub>O 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

The inclusion of a new animal category, Mules and Asses, resulted in a small increase in N<sub>2</sub>O emission estimates from manure management. This small increase in emissions was, however, more than offset by a downward adjustment of nitrogen excretion by fur-bearing animals (Table 5–5) associated with the changes described in Section 5.3.1.5 i.e. applying N excretion rates to breeding stock rather than total animal populations. The net impact of these changes is a reduction in emissions of 57 kt CO<sub>2</sub> eq in 1990, 75 kt CO<sub>2</sub> eq in 2005 and 11 kt CO<sub>2</sub> eq in 2013, with a relative change of less than 2% (Table 5–5). These recalculations also altered the long-term emission trend from 15% to 17%, and the short-term emission trend from -16% to -15%.

#### 5.3.2.6. Planned Improvements

Data from direct measurements of N<sub>2</sub>O emissions from manure management in Canada are scarce. Recent scientific advances in

analytical techniques allow direct measurements of N<sub>2</sub>O emissions from point sources. However, it will likely take several years before N<sub>2</sub>O emissions can be reliably measured and verified for various manure management systems in Canada.

As noted in Section 5.3.1.6, 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<sub>2</sub>O Emissions from Manure Management (CRF Category 3.B (c))

#### 5.3.3.1. Source Category Description

The production of N<sub>2</sub>O from manure management can also occur indirectly through NH<sub>3</sub> volatilization and leaching of N during storage and handling of animal manure. A fraction of the nitrogen in manure that is stored is transported off-site through volatilization in the form of NH<sub>3</sub> and NO<sub>x</sub> and subsequent redeposition. Furthermore, solid manure exposed to rainfall will be prone to loss of N through leaching, erosion 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<sub>2</sub>O.

#### 5.3.3.2. Methodological Issues

Indirect emissions of N<sub>2</sub>O from manure management are estimated separately for NH<sub>3</sub> 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<sub>3</sub> and NO<sub>x</sub> 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<sub>2</sub>O from NH<sub>3</sub> 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<sub>2</sub>O from manure management. Most uncertain quantities associated with livestock populations, manure N excretion rates, AWMS, frac-

tions of N leaching and  $\text{NH}_3$  volatilization along with indirect  $\text{N}_2\text{O}$  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 (1990–2014).

#### 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 the indirect  $\text{N}_2\text{O}$  emissions from the Manure Management source category occurred because of the inclusion of mules and asses and the modification of N excretion by fur-bearing animals (Table 5–5) 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  $\text{NH}_3$  volatilization. The net impact of the recalculations resulted in a small decrease in emissions of 4 kt  $\text{CO}_2$  eq in 1990, 5 kt  $\text{CO}_2$  eq in 2005 and 1 kt  $\text{CO}_2$  eq in 2013, with a relative change of less than 0.5%. 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  $\text{NH}_3$  volatilization and N leaching by livestock categories and AWMS for dairy, beef cattle and swine, for implementation over the medium term.

### 5.4. $\text{N}_2\text{O}$ Emissions from Agricultural Soils (CRF Category 3.D)

Emissions of  $\text{N}_2\text{O}$  from agricultural soils consist of direct and indirect emissions. The emissions of  $\text{N}_2\text{O}$  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 synthetic fertilizer and manure as  $\text{NH}_3$  and  $\text{NO}_x$  and its subsequent deposition off-site; and ii) leaching and runoff of synthetic fertilizer, manure and crop residue N. Changes in crop rotations and management practices, such as summerfallow, tillage and irrigation, can also affect direct  $\text{N}_2\text{O}$  emissions by altering mineralization of organic nitrogen, nitrification and denitrification.

### 5.4.1. Direct $\text{N}_2\text{O}$ Emissions from Soils (CRF Category 3.D.1)

Direct sources of  $\text{N}_2\text{O}$  from soils include the application of synthetic nitrogen fertilizers and animal manure, crop residue decomposition, losses of soil organic matter through mineralization and cultivation of histosols. In addition, Canada also reports three country-specific sources of emissions/removals: tillage practices, summerfallow and irrigation. Emissions/removals from these sources are estimated similarly based on nitrogen inputs from the application of synthetic nitrogen fertilizers and animal manure and crop residue nitrogen.

#### 5.4.1.1. Synthetic Nitrogen Fertilizers

##### 5.4.1.1.1. Source Category Description

Synthetic fertilizers add large quantities of nitrogen to agricultural soils. This added nitrogen undergoes transformations, such as nitrification and denitrification, which can release  $\text{N}_2\text{O}$ . 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  $\text{N}_2\text{O}$  emissions from synthetic nitrogen fertilizer application on agricultural soils, which takes into account moisture regimes and topographic conditions. Emissions of  $\text{N}_2\text{O}$  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 synthetic 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  $\text{N}_2\text{O}$  from agricultural sources noted in Section 5.3.2.3, included all direct and indirect emissions from soils (Table 5–6). For  $\text{N}_2\text{O}$  emissions from fertilizer, the analysis considered the uncertainty in the parameters defined in the country-specific methodology (Rochette et al. 2008b) used to develop  $\text{N}_2\text{O}$  emission factors, the uncertainty in provincial fertilizer sales, and the uncertainty in crop areas and production at the ecodistrict level.

The estimate of  $\text{N}_2\text{O}$  emissions of 11 Mt  $\text{CO}_2$  eq from application of fertilizers on agricultural soils in 2014 lies within an uncertainty range of 7 Mt  $\text{CO}_2$  eq (–35%) to 15 Mt  $\text{CO}_2$  eq (+43%) (Table 5–1).

**Table 5–7 Uncertainty Estimates for Emissions of N<sub>2</sub>O from Manure Management and Agricultural Soils**

Emission Source		Mean Value <sup>1</sup>	2.5% Prob. <sup>2</sup>	97.5% Prob
		Mt CO <sub>2</sub> eq		
Manure Management	Direct Emissions	3.6	2.1 (-43%)	5.4 (+51%)
	Indirect Emissions	1.1	0.5 (-60%)	1.9 (+70%)
Agricultural Soils (N <sub>2</sub> O)		23	15 (-36%)	35 (+52%)
Direct Sources		19	14 (-28%)	25 (+34%)
	Synthetic Nitrogen Fertilizers	11	7.0 (-35%)	15 (+43%)
	Manure Applied as Fertilizers	1.7	1.2 (-33%)	2.5 (+41%)
	Crop Residue Decomposition	5.6	3.7 (-35%)	8.1 (+45%)
	Cultivation of Organic Soils	0.06	0.01 (-79%)	0.12 (+96%)
	Mineralization of Soil Organic Carbon	0.96	0.6 (-35%)	1.4 (+45%)
	Manure on Pasture, Range and Paddock	0.21	0.1 (-60%)	0.4 (+75%)
	Soil N Mineralization/Immobilization	-0.65	-0.4 (-44%)	-1.0 (+55%)
Indirect Sources		4.5	1.8 (-60%)	7.7 (+70%)
	Atmospheric Deposition	1.7	0.4 (-75%)	3.6 (110%)
	Leaching and Runoff	2.7	0.5 (-80%)	5.4 (100%)

Notes:

1. Mean value reported from database.

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

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 (1990–2014).

#### 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 synthetic nitrogen fertilizer consumption data, the Pollutant Inventories and Reporting Division of Environment and Climate Change Canada carries out its own Tier 2 QC checks through historical records and consultations with regional and provincial agricultural industries.

Emissions of N<sub>2</sub>O associated with synthetic 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

The change in the amount of manure N applied as fertilizers resulting from the inclusion of mules and asses and the

modifications to N excretion from fur-bearing animals noted in Sections 5.3.1.5 and 5.3.2.5 resulted in redistribution of synthetic N fertilizers among ecodistricts. There were also revisions to field crop areas because of corrections to the implementation of data from the *Census of Agriculture*. These crop area recalculations modified the distribution of fertilizer N among ecodistricts.

Total recalculations resulted in an increase of 0.7 kt CO<sub>2</sub> eq in 1990, 2.1 kt CO<sub>2</sub> eq in 2005 and 6.5 kt CO<sub>2</sub> eq in 2013, with a relative change of less than 0.1% (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<sub>2</sub>O 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<sub>2</sub>O emissions from agricultural soils in Canada and to re-evaluate the empirical relationship between N<sub>2</sub>O emission factors and growing season precipitation and evapotranspiration.

#### 5.4.1.2. Manure Applied as Fertilizer

##### 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<sub>2</sub>O emissions. Emissions from this category include all manure managed by drylot, liquid and other animal waste management systems.

**Table 5–8 Recalculations of Estimates of N<sub>2</sub>O Emissions and their Impact on Emission Trend from Fertilizer Application, Manure Spreading, Crop Residue Decomposition and Animal Manure on Pasture, Range and Paddock**

Emission Source	Year	Submission Year	Category Emissions (kt CO <sub>2</sub> eq)	Change in Emissions (kt CO <sub>2</sub> eq)	Relative Change Category Emissions (%)	Old Trend (%)	New Trend (%)
Synthetic Nitrogen Fertilizers	1990	2015	5655	0.7	0.01	Long term (1990 - 2013)	
		2016	5656			89	89
	2005	2015	6765	2.1	0.03	Short term (2005 - 2013)	
		2016	6767				
	2013	2015	10707	6.5	0.06	58	58
		2016	10713				
Manure Applied as Fertilizers	1990	2015	1754	-35.1	-2.00	Long term (1990 - 2013)	
		2016	1719			3.2	4.9
	2005	2015	2150	-47.2	-2.19	Short term (2005 - 2013)	
		2016	2103				
	2013	2015	1810	-7.3	-0.41	-16	-14
		2016	1803				
Crop Residue Decomposition	1990	2015	4523	1.0	0.02	Long term (1990 - 2013)	
		2016	4524			41	42
	2005	2015	4978	1.6	0.03	Short term (2005 - 2013)	
		2016	4979				
	2013	2015	6400	2.0	0.03	29	29
		2016	6402				
Animal Manure on Pasture, Range and Paddock	1990	2015	216	0.1	0.06	Long term (1990 - 2013)	
		2016	216			-4.4	-4.4
	2005	2015	251	0.1	0.04	Short term (2005 - 2013)	
		2016	251				
	2013	2015	206	0.1	0.07	-18	-18
		2016	206				
Mineralization of Soil Organic Carbon Associated with Cropland Management Practices	1990	2015	661	1.7	0.25	Long term (1990 - 2013)	
		2016	662			35	35
	2005	2015	613	1.3	0.21	Short term (2005 - 2013)	
		2016	615				
	2013	2015	891	1.5	0.17	45	45
		2016	893				

#### 5.4.1.2.2. Methodological Issues

Like the methodology used to estimate emissions from synthetic nitrogen fertilizers, the method used to estimate N<sub>2</sub>O 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 manure deposited on pasture, range and paddock from 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<sub>2</sub>O 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<sub>2</sub>O emission factors, as noted in Section 5.4.1.1.3.

The estimate of N<sub>2</sub>O emissions of 1.8 Mt CO<sub>2</sub> eq from manure spreading of Canadian livestock wastes in 2014 lies within an uncertainty range of 1.2 Mt CO<sub>2</sub> eq (-33%) to 2.6 Mt CO<sub>2</sub> 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<sub>2</sub>O emission factors, animal N excretion rates, and emission factor modifiers for texture (RF<sub>TEXTURE</sub>) and tillage (RF<sub>TILL</sub>).

The same methodology and emission factors are used for the entire time series (1990–2014).

#### 5.4.1.2.4. QA/QC and Verification

This category has undergone Tier 1 QC checks as described in the QA/QC plan (see Section 1.3, Chapter 1) in a manner consistent

with the 2006 IPCC Guidelines. The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

#### 5.4.1.2.5. Recalculations

The amount of manure N applied as fertilizers was recalculated because of the inclusion of asses and mules and the modifications to N excretion from fur-bearing animals as noted in Sections 5.3.1.5 and 5.3.2.5.

Total recalculations resulted in a decrease of 35 kt CO<sub>2</sub> eq in 1990, 47 kt CO<sub>2</sub> eq in 2005 and 7 kt CO<sub>2</sub> eq in 2013, with a relative change of -2%, -2.2% and -0.4%, respectively (Table 5–8). These recalculations increased the long-term emission trend from 3% to 5% and the short-term emission trend from -16% to -14%.

#### 5.4.1.2.6. Planned Improvements

Through a compilation of soil N<sub>2</sub>O flux data from published literature, Canada aims to differentiate N<sub>2</sub>O 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 Residue Decomposition (CRF Category 3.D.3)

#### 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<sub>2</sub>O production.

#### 5.4.1.3.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of 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 synthetic fertilizer nitrogen application based on moisture regimes and topographic conditions.

#### 5.4.1.3.3. Uncertainties and Time-Series Consistency

For N<sub>2</sub>O 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<sub>2</sub>O emission factors as noted in Section 5.4.1.1.3.

The estimate of N<sub>2</sub>O emissions of 5.6 Mt CO<sub>2</sub> eq from crop residue decomposition in 2014 lies within an uncertainty range of 3.7 Mt CO<sub>2</sub> eq (-35%) to 8.1 Mt CO<sub>2</sub> 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<sub>2</sub>O emission factors and emission factor modifiers for texture (RF<sub>TEXTURE</sub>) and tillage (RF<sub>TILL</sub>).

The same methodology and emission factors are used for the entire time series (1990–2014).

#### 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<sub>2</sub>O emissions from decomposition of crop residues were mainly due to changes in the spatial distribution of crops due to corrections to the implementation of data from the *Census of Agriculture* noted in Section 5.4.1.1.5 and, as a result, in the distribution of N in crop residue among ecodistricts.

Total recalculations consisted of an increase of 1 kt CO<sub>2</sub> eq in 1990, 1.6 kt CO<sub>2</sub> eq in 2005 and 2 kt CO<sub>2</sub> eq in 2013, with a relative change of less than 0.1%. These small recalculations did not affect any long- or short-term emission trends.

#### 5.4.1.3.6. Planned Improvements

Through a compilation of soil N<sub>2</sub>O flux data from published literature, Canada aims to differentiate N<sub>2</sub>O 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. Manure on Pasture, Range and Paddock (CRF Category 3.D.4)

#### 5.4.1.4.1. Source Category Description

When manure is excreted on pasture, range and paddock by grazing animals, nitrogen in the manure undergoes transformations, such as ammonification, nitrification and denitrification. During these transformation processes, N<sub>2</sub>O can be emitted.



#### 5.4.1.4.2. Methodological Issues

N<sub>2</sub>O emissions from manure excreted by grazing animals are calculated using a country-specific IPCC Tier 2 method that was derived from field flux measurements (Rochette et al. 2014; Lemke et al. 2012). Details of these new emission factors can be found in Annex 3.4, Section A3.4.5. Emissions are calculated for each animal category by multiplying the number of grazing animals for that category by the appropriate nitrogen excretion rate and by the fraction of manure nitrogen available for conversion to N<sub>2</sub>O.

#### 5.4.1.4.3. Uncertainties and Time-Series Consistency

The uncertainty of the new estimates of N<sub>2</sub>O emissions associated with animal manure on pasture, range and paddock 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<sub>4</sub> from enteric fermentation and manure management defined in Sections 5.2.3 and 5.3.1.3.

Under these assumptions, the estimate of N<sub>2</sub>O emissions of 0.21 Mt CO<sub>2</sub> eq from pasturing Canadian livestock in 2014 lies within an uncertainty range of 0.1 Mt CO<sub>2</sub> eq (-60%) to 0.4 Mt CO<sub>2</sub> eq (+75%) (Table 5-1).

The same methodology and emission factors are used for the entire time series (1990–2014).

#### 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 inclusion of mules and asses resulted in a small increase in the amount of manure N deposited on pasture, range and paddock, and as a result, recalculations show a small increase in emissions of 0.1 kt CO<sub>2</sub> eq in 1990, 2005 and 2013, with a relative change of less than 0.1%. These small recalculations did not affect any long- or short-term emission trends.

#### 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 of Soil Organic Carbon Associated with Cropland Management Practices (CRF Category 3.D.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<sub>2</sub>O during either nitrification or denitrification. As a result, this N must be taken into account for its contribution to soil N<sub>2</sub>O emissions.

#### 5.4.1.5.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of 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 2014 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<sub>2</sub>O 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<sub>2</sub>O emission factors (EF<sub>BASE</sub>) are the same as those used for the estimation of emissions from synthetic 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 intensive tillage (IT), reduced tillage (RT) and no tillage (NT) in this year's submission. A review of the implementation of Earth observation-based crop areas in the 2015 NIR resulted in the identification of errors in the distribution of tillage areas on the agricultural landbase. As a result of this error correction, IT increased by 0.95 Mha in 1990 and decreased by 2.1 Mha in 2013, RT decreased by 0.81 Mha in 1990 and increased by 0.56 Mha in 2013, and NT decreased by 0.14 Mha in 1990 and increased by 1.5 Mha in 2013. The changes to crop areas noted in Section 5.4.1.1.5 also had small impacts on emissions from this source.

These changes resulted in an increase in emissions of 1.7 kt CO<sub>2</sub> eq in 1990, 1.3 kt CO<sub>2</sub> eq in 2005 and 1.5 kt CO<sub>2</sub> eq in 2013, with a relative change of less than 0.3%. These recalculations did not have any impact on the long-term or short-term emission trend.

#### 5.4.1.5.6. Planned Improvements

Through a compilation of soil N<sub>2</sub>O flux data from published literature, Canada aims to differentiate N<sub>2</sub>O 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.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<sub>2</sub>O production (Mosier et al. 1998).

#### 5.4.1.6.2. Methodological Issues

The IPCC Tier 1 methodology is used to estimate N<sub>2</sub>O emissions from cultivated organic soils. Emissions of N<sub>2</sub>O are calculated by multiplying the area of cultivated histosols by the IPCC default emission factor.

Areas of cultivated histosols at a provincial level are not surveyed in the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada have resulted in an estimated area of 16 kha of cultivated organic soils in Canada, a constant level for the period 1990–2014 (Liang et al. 2004a).

#### 5.4.1.6.3. Uncertainties and Time Series Consistency

For N<sub>2</sub>O 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<sub>2</sub>O emissions of 0.06 Mt CO<sub>2</sub> eq from organic soils in 2014 lies within an uncertainty range of 0.01 Mt CO<sub>2</sub> eq (-79%) to 0.12 Mt CO<sub>2</sub> 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 (1990–2014).

#### 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<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O production, including decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content (McConkey et al. 1996, 2003; Liang et al. 2004b). As a result, compared with conventional tillage, conservation tillage (i.e. RT and NT) generally reduces N<sub>2</sub>O emissions for the Prairies (Malhi and Lemke 2007), but increases N<sub>2</sub>O 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<sub>2</sub>O emissions resulting from the adoption of NT and RT are estimated through modifications of emission factors for synthetic 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<sub>2</sub>O fluxes on NT or RT to mean N<sub>2</sub>O fluxes on IT ( $N_{2O_{NT}}/N_{2O_{IT}}$ ), represents the effect of NT or RT on N<sub>2</sub>O emissions (see Annex 3.4).

### 5.4.1.7.3. Uncertainties and Time-Series Consistency

For N<sub>2</sub>O 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<sub>2</sub>O emission factors as noted in Section 5.4.1.1.3.

The estimate of N<sub>2</sub>O emission reductions of -1.4 Mt CO<sub>2</sub> eq from conservation tillage practices in 2014 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 (1990–2014).

### 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

Tillage practice calculations are dependent on all soil emission calculations, and recalculations are a function of all factors identified in previous sections, including modifications to N excretion by livestock noted in Section 5.3.3.5. Notably, in this year's submission, there were changes in the areas of IT, RT and

**Table 5–9 Recalculations of Estimates of N<sub>2</sub>O Emissions and Their Impact on Emission Trend from Conservation Tillage Practices, Summerfallow and Irrigation**

Emission Source	Year	Submission Year	Category Emissions (kt CO <sub>2</sub> eq)	Change in Emissions (kt CO <sub>2</sub> eq)	Relative Change Category Emissions (%)	Old Trend (%)	New Trend (%)
Conservation Tillage Practices	1990	2015	-356	51.3	-14.4	Long term (1990 - 2013)	
		2016	-305			305	404
	2005	2015	-924	39.0	-4.2	Short term (2005 - 2013)	
		2016	-885				
	2013	2015	-1442	-93.5	6.5	56	74
		2016	-1536				
Summerfallow	1990	2015	1362	0.1	0.0	Long term (1990 - 2013)	
		2016	1362			-66	-66
	2005	2015	793	0.1	0.0	Short term (2005 - 2013)	
		2016	793				
	2013	2015	462	0.3	0.1	-42	-42
		2016	462				
Irrigation	1990	2015	340	-1.3	-0.4	Long term (1990 - 2013)	
		2016	338			31	29
	2005	2015	406	-7.6	-1.9	Short term (2005 - 2013)	
		2016	398				
	2013	2015	446	-9.8	-2.2	10	9
		2016	436				

NT because of an error correction in implementing the Earth observation-based crop areas in the 2015 NIR, as noted in Section 5.4.1.5.5.

These changes resulted in an increase in emissions of 51 kt CO<sub>2</sub> eq in 1990 and 39 kt CO<sub>2</sub> eq in 2005 and a decrease in emissions of 94 kt CO<sub>2</sub> eq in 2013, with a relative change of -14%, -4% and +7%, respectively. These recalculations increased the long-term emission reduction due to tillage implementation from 305% to 404% and the short-term emission reduction trend from 56% to 74% (Table 5–9).

#### 5.4.1.7.6. Planned Improvements

Through a compilation of soil N<sub>2</sub>O flux data from published literature, Canada aims to update the method for estimating the impact of tillage practices on soil N<sub>2</sub>O 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<sub>2</sub>O Emissions Resulting from Summerfallowing

#### 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<sub>2</sub>O emissions. Summerfallow (SF) is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several soil factors may stimulate N<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O emissions because no crops are grown or fertilizer applied could lead to underestimating total N<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O emission factors as noted in Section 5.4.1.1.3.

The estimate of N<sub>2</sub>O emissions of 0.37 Mt CO<sub>2</sub> eq from summerfallow land in 2014 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<sub>TILL</sub>).

The same methodology and emission factors are used for the entire time series (1990–2014).

#### 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

Emissions from summerfallow are dependent on all soil emission calculations, and recalculations are a function of all factors defined in previous sections, including modifications to N excretion by livestock noted in Section 5.3.3.5. There were also very minor changes to summerfallow area because of corrections to the implementation of *Census of Agriculture* data noted in Section 5.4.1.1.5, ranging from -7 ha to +489 ha per year nationally.

These changes resulted in a very small increase in emissions of less than 1 kt throughout the time series and did not change the long- or short-term trend for this emission source category (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<sub>2</sub>O 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<sub>2</sub>O emissions is not derived from additional nitrogen input but rather reflects changes in soil conditions that affect N<sub>2</sub>O emissions. Higher soil water content under irrigation increases the potential for N<sub>2</sub>O emissions through increased 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<sub>2</sub>O 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<sub>2</sub>O emissions from agricultural soils was estimated using an EF<sub>BASE</sub> estimated at a P/PE = 1 (precipitation/potential evapotranspiration, EF<sub>BASE</sub> = 0.017 N<sub>2</sub>O-N/kg N) for the irrigated areas of a given ecodistrict. To improve the transparency, the effect of irrigation on soil N<sub>2</sub>O emissions is also reported separately from other source categories.

#### 5.4.1.9.3. Uncertainties and Time-Series Consistency

For N<sub>2</sub>O 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<sub>2</sub>O emission factors as noted in Section 5.4.1.1.3.

The estimate of N<sub>2</sub>O emissions of 0.41 Mt CO<sub>2</sub> eq from irrigated land in 2014 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 (1990–2014).

#### 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 estimated using all soil emission calculations, and recalculations are a function of all factors discussed in previous sections, including modifications to N excretion by livestock noted in Section 5.3.3.5. There were also very minor changes to irrigated areas because of corrections to the implementation of Census of Agriculture data noted in Section 5.4.1.1.5, ranging from -10 ha to +246 ha per year nationally.

These changes resulted in a decrease in emissions of 1.3 kt CO<sub>2</sub> eq in 1990, 7.6 kt CO<sub>2</sub> eq in 2005 and 9.8 kt CO<sub>2</sub> eq in 2013, with a relative change of -0.4%, -1.9% and -2.2, respectively. These recalculations decreased the long-term emission trend from an increase in emissions of 31% to an increase of 29% and the short-term emission trend from 10% 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 Emissions of N<sub>2</sub>O from Agricultural Soils (CRF Category 4.D.3)

A fraction of the nitrogen from both synthetic fertilizer and manure that are applied to agricultural fields is transported off-site through volatilization in the form of NH<sub>3</sub> and NO<sub>x</sub> and subsequent redeposition or leaching, erosion 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<sub>2</sub>O.

### 5.4.2.1. Volatilization and Redeposition of Nitrogen

#### 5.4.2.1.1. Source Category Description

When synthetic fertilizer or manure is applied to cropland, a portion of the nitrogen is lost through volatilization in the form of NH<sub>3</sub> or NO<sub>x</sub>, which can be redeposited elsewhere and undergo further transformation, resulting in N<sub>2</sub>O 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<sub>2</sub>O emissions from volatilization and redeposition of NH<sub>3</sub> and NO<sub>x</sub>. Leached or volatilized N may not be available for the process of nitrification and denitrification for many years, particularly in the case of N leaching into groundwater. Even though Indirect Soil N<sub>2</sub>O Emissions from Agricultural Soils are a key source category for level and trend assessments for Canada, there are difficulties in defining the duration and boundaries for this source of emissions because no standardized method for deriving the IPCC Tier 2 emission factors is provided by the IPCC Guidelines.

The IPCC Tier 1 methodology is used to estimate indirect N<sub>2</sub>O emissions due to volatilization and redeposition of nitrogen from synthetic N fertilizers and animal manure. The amount of synthetic fertilizer and manure nitrogen is multiplied by the fraction of N that is volatilized as NH<sub>3</sub>-N and NO<sub>x</sub>-N and then by an emission factor. The amount of nitrogen applied is obtained from yearly fertilizer sales data, which are available from Statistics Canada, and from the amounts of manure nitrogen excreted by animals (see Annex 3.4). The amount of nitrogen that volatilizes is assumed to be 10% of the total amount of synthetic fertilizer applied and 20% of the applied manure nitrogen to cropland (IPCC 2006). The default IPCC emission factor, 0.01 kg N<sub>2</sub>O-N/kg N, is used to derive the N<sub>2</sub>O emission estimate (IPCC 2006).

5.4.2.1.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N<sub>2</sub>O emissions from volatilization and redeposition 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<sub>3</sub> and total N.

The estimate of N<sub>2</sub>O emissions of 1.7 Mt CO<sub>2</sub> eq from volatilization and redeposition in 2014 lies within an uncertainty range of 0.4 Mt CO<sub>2</sub> eq (75%) to 3.6 Mt CO<sub>2</sub> 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 (1990–2014).

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

Changes to livestock N excretion discussed in Section 5.3.2.5 resulted in a small decrease of less than 0.5% in overall emissions from total N volatilized from agricultural soils (Table 5–10). These recalculations resulted in a small increase of 1% in the long- or short-term trend based on total NH<sub>3</sub> volatilization (Table 5–10).

5.4.2.1.6. Planned Improvements

The quantity of ammonia emissions from synthetic nitrogen fertilizer application depends on several factors, including crop types (annual or perennial crop), soil chemical properties, soil temperature, and form and method of nitrogen application. An empirical model is being developed to derive ammonia emission factors based on type of N fertilizers, degree of incorporation into soil, crop type, soil cation exchange capacity and pH, to be implemented over the short to medium-term.

Table 5–10 Recalculations of Estimates of N<sub>2</sub>O Emissions and Their Impact on Emission Trend from Indirect Emissions of Agricultural Soils, Volatilization and Redeposition and Leaching, Erosion and Runoff

Emission Source	Year	Submission Year	Category Emissions (kt CO <sub>2</sub> eq)	Change in Emissions (kt CO <sub>2</sub> eq)	Relative Change Category Emissions (%)	Old Trend (%)	New Trend (%)
Indirect Emissions, Volatilization and Redeposition	1990	2015	1068	-4.7	-0.44	Long term (1990 - 2013)	
		2016	1064			65	66
	2005	2015	1442	-6.2	-0.43	Short term (2005 - 2013)	
		2016	1436				
	2013	2015	1765	-0.8	-0.04	22	23
		2016	1765				
Indirect Emissions, Leaching, Erosion and Runoff	1990	2015	1924	-4.8	-0.25	Long term (1990 - 2013)	
		2016	1919			48	49
	2005	2015	2234	-6.6	-0.29	Short term (2005 - 2013)	
		2016	2228				
	2013	2015	2855	-0.3	-0.01	28	28
		2016	2855				



## 5.4.2.2. Leaching, Erosion, and Runoff

### 5.4.2.2.1. Source Category Description

When synthetic fertilizer, manure and crop residue are added to cropland, a portion of the nitrogen from these sources is lost through leaching, erosion 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<sub>2</sub>O emissions off-site.

### 5.4.2.2.2. Methodological Issues

There are few published scientific data that determine N<sub>2</sub>O emissions from leaching, erosion and runoff in Canada. As in the case of N<sub>2</sub>O emissions from volatilization and redeposition of NH<sub>3</sub> and NO<sub>x</sub>, this source is poorly defined because no standardized method for deriving the IPCC Tier 2 emission factors is provided by the IPCC Guidelines.

A modified IPCC Tier 1 methodology is used to estimate indirect N<sub>2</sub>O emissions from leaching, runoff and erosion of fertilizers, manure and crop residue nitrogen from agricultural soils. Indirect N<sub>2</sub>O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using FRAC<sub>LEACH</sub> multiplied by the amount of synthetic fertilizer nitrogen, non-volatilized manure nitrogen and crop residue nitrogen and by an emission factor of 0.0075 kg N<sub>2</sub>O-N/kg N (IPCC 2006).

The default value for the fraction of nitrogen that is lost through leaching and runoff (FRAC<sub>LEACH</sub>) in the Revised 1996 Guidelines is 0.3; however, FRAC<sub>LEACH</sub> can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC 2006), such as in the Prairie region of Canada. Accordingly, it is assumed that FRAC<sub>LEACH</sub> would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with no moisture deficit during the growing season (May through October), the maximum FRAC<sub>LEACH</sub> value of 0.3 recommended by the 2006 IPCC Guidelines is assigned. The minimum FRAC<sub>LEACH</sub> value of 0.05 is assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts, FRAC<sub>LEACH</sub> is estimated by the linear extrapolation of the two end-points described above.

### 5.4.2.2.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N<sub>2</sub>O emissions from leaching, erosion and runoff of N 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<sub>2</sub>O emissions of 2.7 Mt CO<sub>2</sub> eq from leaching, erosion and runoff of N in 2014 lies within an uncertainty range of 0.5 Mt CO<sub>2</sub> eq (-80%) to 5.4 Mt CO<sub>2</sub> 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%–2.5%).

The same methodology and emission factors are used for the entire time series (1990–2014).

### 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

Estimates of indirect emissions from leaching, erosion and runoff were mainly affected by changes to livestock N excretion discussed in Section 5.3.2.5. Total recalculations consisted of a decrease of 4.8 kt CO<sub>2</sub> eq in 1990, 6.6 kt CO<sub>2</sub> eq in 2005 and 0.3 kt CO<sub>2</sub> eq in 2013 (Table 5–10). These recalculations had little impact on the long- or short-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<sub>4</sub> and N<sub>2</sub>O Emissions from Field Burning of Agricultural Residues (CRF Category 4.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<sub>4</sub>, CO, NO<sub>x</sub> and N<sub>2</sub>O (IPCC 2006).

### 5.5.2. Methodological Issues

There are no published data on emissions of N<sub>2</sub>O and CH<sub>4</sub> from field burning of agricultural residues in Canada. Thus, the IPCC



default emission factors and parameters from the 2006 IPCC Guidelines were used for estimating emissions.

A complete time series of activity data on the type and percent of each crop residue subject to field burning was developed based on Statistics Canada's *Farm Environmental Management Survey* (FEMS)<sup>2</sup> and on expert consultations (Coote et al. 2008).

Crop-specific parameters required for estimating the amount of crop residue burned, such as moisture content of the crop product and ratio of above-ground crop residue to crop product, were obtained from Janzen et al. (2003) and are consistent with the values used to estimate emissions from crop residue decomposition.

### 5.5.3. Uncertainties and Time-Series Consistency

The uncertainties associated with CH<sub>4</sub> and N<sub>2</sub>O emissions from field burning of agricultural residues were determined using an IPCC Tier 1 method (IPCC 2006).

The uncertainties associated with CH<sub>4</sub> and N<sub>2</sub>O emissions from field burning of agricultural residues are the amount of field crop residues burned and emission factors. The uncertainty in the amount of crop residues burned is estimated, based on the area of specific seeded crop, to be  $\pm 50\%$  (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:  $\pm 40\%$  for CH<sub>4</sub> and  $\pm 48\%$  for N<sub>2</sub>O (IPCC 2006). The level uncertainties for CH<sub>4</sub> and N<sub>2</sub>O emission estimates were estimated to be  $\pm 64\%$  and  $\pm 69\%$ , respectively.

### 5.5.4. QA/QC and Verification

CH<sub>4</sub> and N<sub>2</sub>O 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.

<sup>2</sup> <http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5044&lang=en&db=imdb&adm=8&dis=2#a4>

## 5.6. CO<sub>2</sub> Emissions from Lime Application (CRF Category 3.G)

### 5.6.1. Source Category Description

In Canada, limestone is often used in the production of certain crops, such as alfalfa, to neutralize acidic soils, increase the availability of soil nutrients, particularly phosphorus, reduce the toxicity of heavy metals, such as aluminium, and improve the crop growth environment. During this neutralization process, CO<sub>2</sub> is released in bicarbonate equilibrium reactions that occur in the soil. The rate of release will vary with soil conditions and the compounds applied.

### 5.6.2. Methodological Issues

Emissions associated with the use of lime were calculated from the amount of the lime applied annually—specifically, the respective stoichiometric relationships that describe the breakdown of limestone into CO<sub>2</sub> and other minerals. 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  $\pm 30\%$ . 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  $0.34 \pm 0.22$  Mt CO<sub>2</sub> eq for the level uncertainty.

The same methodology is used for the entire time series of emission estimates (1990–2014).

### 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 collected and published data on agricultural use of lime in its *Canadian Minerals Yearbook* from 1990 to 2006. For more recent years, this information is only available on request (D. Panagapko, Natural Resources Canada, personal

communication). Liming data collected by Natural Resources Canada includes estimates of quantities of the mineral dolomite in addition to limestone, though it is reported as a single value. The proportion of dolomite is estimated to be 24% based on the data collected from 1998 to 2002 by the Canadian Fertilizer Institute. The average fraction of dolomite in these data was then used to weigh the liming material emission factor. Therefore, the liming material data are multiplied by an emission factor of 12.24%, rather than 12%, to provide emission estimates.

The impact of these recalculations was an increase in emissions of 7.6 kt CO<sub>2</sub> eq for 1990, 3.6 kt CO<sub>2</sub> eq for 2005 and 6.6 kt CO<sub>2</sub> eq for 2013.

### 5.6.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source.

## 5.7. CO<sub>2</sub> Emissions from Urea Fertilization (CRF Category 3.H)

### 5.7.1. Source Category Description

When urea (CO(NH<sub>2</sub>)<sub>2</sub>) or urea-based nitrogen fertilizers is applied to a soil to augment crop production, CO<sub>2</sub> is released on hydrolysis of the urea. According to the 2006 IPCC Guidelines, the quantity of CO<sub>2</sub> 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<sub>2</sub>)<sub>2</sub>.

### 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<sub>2</sub> 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 2.2 ± 1.1 Mt CO<sub>2</sub> eq for the level uncertainty.

The same methodology and data sources are used for the entire time series of emission estimates (1990–2014).

### 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, Canada's managed lands and the harvested wood products (HWP) derived from these lands, as well as those associated with land-use change. The assessment includes emissions and removals of CO<sub>2</sub>, additional emissions of CH<sub>4</sub>, N<sub>2</sub>O and CO due to wildfires and controlled burning, and N<sub>2</sub>O released following Land conversion to Cropland. All emissions from and removals by the LULUCF Sector are excluded from the national totals.

In 2014, the estimated net GHG flux in the LULUCF Sector, calculated as the sum of CO<sub>2</sub><sup>1</sup> emissions and removals and non-CO<sub>2</sub> emissions, amounted to emissions of 72 Mt. If these were included in the national totals, they would increase the total Canadian GHG emissions by 9.8%. Table 6–1 provides the net flux estimates for 1990, 2000, 2005 and recent years in the major LULUCF Sector categories and subcategories.

In view of the high interannual variability displayed by some categories and its effect on the sectoral trends, the reader is cautioned against interpreting the figures in Table 6–1 as trends. 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 except 1995, when the net flux was positive (emissions), due to exceptionally high emissions from wildfires. Years with lower net removals have increased in frequency in the latter part of the time series, reflecting the ongoing impact of insect disturbances in western Canada. The interannual variability in emission and removal estimates is high, fluctuating between -272 Mt (1992) and 9 Mt (1995) (see Figure 6–2). These fluctuations are mainly due to interannual variability in areas

1 Unless otherwise indicated, all emissions and removals are in CO<sub>2</sub> equivalents.

**Table 6–1 LULUCF: Sector Net GHG Flux Estimates, Selected Years**

Sectoral Category	Net GHG Flux (kt CO <sub>2</sub> eq) <sup>2</sup>							
	1990	2000	2005	2010	2011	2012	2013	2014
<b>Land Use, Land-Use Change and Forestry TOTAL<sup>1</sup></b>	<b>-87 000</b>	<b>-82 000</b>	<b>510</b>	<b>55 000</b>	<b>69 000</b>	<b>41 000</b>	<b>-30 000</b>	<b>72 000</b>
a. Forest Land	-250 000	-250 000	-150 000	-83 000	-71 000	-100 000	-170 000	-64 000
Forest Land remaining Forest Land	-250 000	-250 000	-150 000	-82 000	-70 000	-99 000	-170 000	-63 000
Land converted to Forest Land	-1 000	-980	-920	-740	-700	-650	-590	-550
b. Cropland	10 000	-2 000	-8 600	-9 400	-9 400	-9 200	-8 900	-8 400
Cropland remaining Cropland	630	-7 300	-13 000	-13 000	-12 000	-12 000	-12 000	-11 000
Land converted to Cropland	9 800	5 300	4 300	3 300	3 000	3 000	2 900	3 000
c. Grassland	640	1 000	850	320	630	1 600	680	680
Grassland remaining Grassland	640	1 000	850	320	630	1 600	680	680
Land converted to Grassland	NO	NO	NO	NO	NO	NO	NO	NO
d. Wetlands	5 900	4 300	4 300	3 900	3 700	3 700	3 600	3 400
Wetlands remaining Wetlands	1 200	2 400	2 200	2 300	2 200	2 300	2 300	2 300
Land converted to Wetlands	4 700	1 900	2 100	1 600	1 500	1 400	1 300	1 100
e. Settlements	4 300	3 500	4 000	3 800	3 900	3 900	3 900	3 700
Settlements remaining Settlements	-2 500	-2 500	-2 500	-2 500	-2 500	-2 500	-2 500	-2 500
Land converted to Settlements	6 800	6 100	6 500	6 400	6 500	6 500	6 500	6 300
f. Other Land	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO
g. Harvested Wood Products	140 000	160 000	150 000	140 000	140 000	140 000	140 000	140 000
Forest Conversion <sup>3</sup>	19 000	14 000	14 000	13 000	13 000	12 000	12 000	12 000

Notes:

1. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

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

3. Not a reporting category, it overlaps with the subcategories of Land converted to Cropland, Land converted to Wetlands and Land converted to Settlements.

NE = Not estimated, NO = Not Occurring

Table 6–2 Summary of Recalculations in the LULUCF Sector

Sectoral Category		1990	2000	2005	2010	2011	2012	2013
<b>Land Use, Land-use Change and Forestry TOTAL<sup>1</sup></b>		<b>kt</b>	<b>310</b>	<b>-5 000</b>	<b>-16 000</b>	<b>-27 000</b>	<b>-13 000</b>	<b>-19 000</b>
		<b>%</b>	<b>-0.4%</b>	<b>6.5%</b>	<b>-97%</b>	<b>-33%</b>	<b>-16%</b>	<b>-32%</b>
<b>a. Forest Land</b>		<b>kt</b>	<b>2 200</b>	<b>3 400</b>	<b>-9 300</b>	<b>-18 000</b>	<b>-2 000</b>	<b>-5 700</b>
		<b>%</b>	<b>-0.9%</b>	<b>-1.4%</b>	<b>6.5%</b>	<b>28%</b>	<b>2.9%</b>	<b>6.0%</b>
	Forest Land remaining Forest Land	<b>kt</b>	<b>2 200</b>	<b>3 400</b>	<b>-9 300</b>	<b>-18 000</b>	<b>-2 000</b>	<b>-5 700</b>
		<b>%</b>	<b>-0.9%</b>	<b>-1.4%</b>	<b>6.5%</b>	<b>28%</b>	<b>2.9%</b>	<b>6.1%</b>
	Land converted to Forest Land	<b>kt</b>	<b>.0 0</b>	<b>.0 0</b>	<b>.0 0</b>	<b>.0 0</b>	<b>.0 0</b>	<b>.0 0</b>
		<b>%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>
<b>b. Cropland</b>		<b>kt</b>	<b>140</b>	<b>80</b>	<b>- 140</b>	<b>-1 000</b>	<b>-1 400</b>	<b>-1 400</b>
		<b>%</b>	<b>1.3%</b>	<b>-3.8%</b>	<b>1.6%</b>	<b>12%</b>	<b>17%</b>	<b>18%</b>
	Cropland remaining Cropland	<b>kt</b>	<b>150</b>	<b>- 1.0</b>	<b>- 120</b>	<b>- 550</b>	<b>- 680</b>	<b>- 770</b>
		<b>%</b>	<b>32%</b>	<b>0.0%</b>	<b>1.0%</b>	<b>4.5%</b>	<b>5.8%</b>	<b>6.7%</b>
	Land converted to Cropland	<b>kt</b>	<b>- 16</b>	<b>81</b>	<b>- 16</b>	<b>- 480</b>	<b>- 670</b>	<b>- 660</b>
		<b>%</b>	<b>-0.2%</b>	<b>1.5%</b>	<b>-0.4%</b>	<b>-13%</b>	<b>-18%</b>	<b>-18%</b>
<b>c. Grassland</b>		<b>kt</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>-</b>	<b>0.0</b>	<b>-</b>
		<b>%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>-</b>	<b>0.0%</b>	<b>-</b>
	Grassland remaining Grassland	<b>kt</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>-</b>	<b>0.0</b>	<b>-</b>
		<b>%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>-</b>	<b>0.0%</b>	<b>-</b>
		<b>kt</b>	<b>- 38</b>	<b>- 34</b>	<b>24</b>	<b>- 40</b>	<b>- 27</b>	<b>- 27</b>
		<b>%</b>	<b>-0.6%</b>	<b>-0.8%</b>	<b>0.6%</b>	<b>-1.0%</b>	<b>-0.7%</b>	<b>-0.7%</b>
<b>d. Wetlands</b>		<b>kt</b>	<b>- 61</b>	<b>- 34.0</b>	<b>- 31</b>	<b>- 28</b>	<b>- 28</b>	<b>- 27</b>
		<b>%</b>	<b>-4.8%</b>	<b>-1.4%</b>	<b>-1.4%</b>	<b>-1.2%</b>	<b>-1.2%</b>	<b>-1.2%</b>
	Wetlands remaining Wetlands	<b>kt</b>	<b>23</b>	<b>0.9</b>	<b>55</b>	<b>- 12</b>	<b>0.4</b>	<b>0.3</b>
		<b>%</b>	<b>0.5%</b>	<b>0.0%</b>	<b>2.7%</b>	<b>-0.8%</b>	<b>0.0%</b>	<b>0.0%</b>
	Land converted to Wetlands	<b>kt</b>	<b>87</b>	<b>- 48</b>	<b>- 190</b>	<b>- 530</b>	<b>- 530</b>	<b>- 520</b>
		<b>%</b>	<b>2.1%</b>	<b>-1.3%</b>	<b>-4.6%</b>	<b>-12%</b>	<b>-12%</b>	<b>-12%</b>
<b>e. Settlements</b>		<b>kt</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
		<b>%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>
	Settlements remaining Settlements	<b>kt</b>	<b>87</b>	<b>- 48</b>	<b>- 190</b>	<b>- 530</b>	<b>- 530</b>	<b>- 520</b>
		<b>%</b>	<b>1.3%</b>	<b>-0.8%</b>	<b>-2.9%</b>	<b>-7.7%</b>	<b>-7.6%</b>	<b>-7.4%</b>
	Land converted to Settlements	<b>kt</b>	<b>-2 000</b>	<b>-8 400</b>	<b>-6 300</b>	<b>-7 000</b>	<b>-8 900</b>	<b>-12 000</b>
		<b>%</b>	<b>-1.5%</b>	<b>-5.0%</b>	<b>-4.0%</b>	<b>-4.8%</b>	<b>-5.9%</b>	<b>-7.7%</b>
<b>g. Harvested Wood Products</b>		<b>kt</b>	<b>35</b>	<b>- 65</b>	<b>- 230</b>	<b>-1 100</b>	<b>-1 300</b>	<b>-1 200</b>
		<b>%</b>	<b>0.2%</b>	<b>-0.5%</b>	<b>-1.6%</b>	<b>-7.8%</b>	<b>-9.1%</b>	<b>-9.0%</b>
	Forest Conversion <sup>2</sup>	<b>kt</b>	<b>35</b>	<b>- 65</b>	<b>- 230</b>	<b>-1 100</b>	<b>-1 300</b>	<b>-1 200</b>
		<b>%</b>	<b>0.2%</b>	<b>-0.5%</b>	<b>-1.6%</b>	<b>-7.8%</b>	<b>-9.1%</b>	<b>-9.0%</b>
		<b>kt</b>	<b>35</b>	<b>- 65</b>	<b>- 230</b>	<b>-1 100</b>	<b>-1 300</b>	<b>-1 200</b>
		<b>%</b>	<b>0.2%</b>	<b>-0.5%</b>	<b>-1.6%</b>	<b>-7.8%</b>	<b>-9.1%</b>	<b>-9.0%</b>

Notes:

1. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

2. Not a reporting category.

of managed forests burned by wildfire. These fluctuations are carried over to the LULUCF Sector totals, which vary between net emissions and net removals, depending on the net flux from managed forests.

Emissions from the Harvested Wood Products category, which is closely linked to Forest Land, vary over the 1990–2014 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 128 Mt in 2009 (lowest harvest year) and 160 Mt in 1995 and 2000.

The combined net flux from Forest Land and Harvested Wood Products amounted to 72 Mt in 2014, which includes net removals of 64 Mt from Forest Land and net emissions of 136 Mt from HWP.

The Cropland category displays a steady trend towards decreasing emissions in the period 1990–2006, from emissions of 10.5 Mt in 1990 to net removals of 9.9 Mt in 2006. This trend is the result of changes in agricultural land management practices in western Canada, such as the extensive adoption of conservation tillage practices and reduction in summerfallow. Since 2006, net removals have decreased to 8.4 Mt in 2014, as the adoption rate of conservation tillage and reduction of summerfallow have decreased and the soil sink approaches equilibrium. In addition, higher emissions resulting from an increase in the proportion of annual crops within crop production systems in more recent years partially offset the removals. A decline in emissions from the conversion of Forest land to Cropland also contributes to this trend.

Over the period 1990–2014, net fluxes in the Wetlands category (peat extraction and flooded lands) fluctuate between 3.4 Mt (2014) and 6.2 Mt (1993). Emissions from flooded lands in 2014

account for 35% of all emissions in the Wetlands category, compared to 74% in 1990. Emissions from Land converted to Wetlands decreased over the reporting period from 4.7 Mt to 1.1 Mt.

Net emissions reported in the Settlements category fluctuate between 3.5 Mt (1998 and 2000) and 4.4 Mt (2007), mainly driven by trends in emissions from conversion from forested land, estimated to be 6.1 Mt in 2014. Steady removals around 2.5 Mt per year from the growth of urban trees offset these emissions by an average of 40% throughout 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 and Land converted to Settlements. Greenhouse gas emissions due to forest conversion decreased from 19.2 Mt in 1990 to 12 Mt in 2014. This decline in emissions includes a 5.0 Mt decrease in emissions due to conversion to Cropland, a 1.7 Mt decrease in emissions due to conversion to Wetlands, and a small decrease of 0.6 Mt in emissions due to conversion to Settlements.

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<sub>2</sub>, CH<sub>4</sub> and CO due to biomass burning, which are reported in Table 4(V). CO emissions are reported as CO<sub>2</sub> in Table 4(V) and as indirect CO<sub>2</sub> emissions in the crosscutting Table 6. Emissions and removals are automatically tallied in CRF Table 4.

This year's submission includes a number of recalculations (Table 6–2) mainly due to the implementation of an improved representation of residential firewood collection in the forest ecosystem, corrections to forest stand selection and sort-

ing criteria for harvesting, and a downward revision of areas deforested annually since 2005 based on new geospatial analysis (Table 6–3). The cumulative impact of these recalculations resulted in a small decrease in the calculated sink for 1990 of 0.3 Mt, a decrease in the calculated source in 2005 of 16 Mt and an increase in the calculated sink in 2013 of 15 Mt.

Estimates for all forest related categories are developed using the same modelling framework. Therefore, changes to the forest model and the distribution of disturbances on the landscape can change the forest stands available for modelling subsequent events, such as forest conversion, resulting in indirect recalculations and can have impacts on 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 work on the HWP model structure, in particular including the fate of HWP in solid waste disposal sites and further improvements to the integration of residential firewood harvest from forest lands and other land-use categories, completion of uncertainty estimates in all LULUCF categories, and the gradual integration of missing land use and land-use change categories.

**Table 6–3 Summary of Changes in the LULUCF Sector**

List of Changes	Change Category	Years Affected
<b>Forest Land</b>		
Improved representation of residential firewood collection	Continuous limprovement	Complete time series
Technical corrections to modelling of disturbances (wildfires, slash burning and harvesting)	Changes to model parameters and algorithms	Complete time series
Revisions to official harvest, slash burning and wildfire data	Activity data updates	1990–2013
Forest conversion activity data updates for 2005–2013	Activity data updates	2005–2013
<b>Cropland</b>		
Corrections to model code for tillage areas, crop extents and woody biomass	Changes to model parameters and algorithms	Complete time series
Forest conversion activity data updates for 2005–2013	Activity data updates	2005–2013
<b>Settlements</b>		
Forest conversion activity data updates for 2005–2013	Activity data updates	2005–2013
<b>Harvested Wood Products</b>		
Correction in moisture content assumption for industrial firewood	Changes to model parameters and algorithms	Complete time series
Correction in manufacturing efficiency parameters	Changes to model parameters and algorithms	Complete time series

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 short-grass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. All agricultural land that is not grassland is *de facto* classified as Cropland, including unimproved pastures where natural vegetation would be forest (eastern Canada and most of British Columbia).

Vegetated areas that do not meet the definition of Forest Land or Cropland are generally classified as Grassland. Extensive areas of tundra in the Canadian North are considered unmanaged grassland.

Wetlands are areas where permanent or recurrent saturated conditions allow the establishment of vegetation and soil

development typical of these conditions and that are not already included in the Forest Land, Cropland or agricultural Grassland categories. Currently, managed lands included in the Wetlands category are those where human interventions have directly altered the water table—which include peatlands drained for peat extraction and flooded lands (hydroelectric reservoirs) (IPCC 2006).

The Settlements category includes all built-up land: urban, rural residential, land devoted to industrial and recreational use; roads, rights-of-way and other transportation infrastructure; and resource exploration, extraction and distribution (mining, oil and gas). The diversity of this category has so far precluded a complete assessment of its extent in the Canadian landscape. However, the conversion of Forest Land and unmanaged grassland (tundra) to Settlements and the area of urban trees is 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 these by definition exclude areas where forests can grow naturally. Note that, in theory, the opposite can happen (i.e. grassland conversion to forest), although the direct human-induced conversion of agricultural grassland to forest has not been observed. Since grassland is defined as “native,” creation of grassland is mostly not occurring.

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). 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.

Table 6–4 illustrates the land-use areas (diagonal cells) and cumulative land-use change areas (non-diagonal cells) in 2014. Cumulative land-use change areas are the total land areas converted over the past 20 years (10 years for reservoirs). The diagonal cells related to Forest Land and Cropland refer to total land-use areas, that related to Grassland refers to agricultural grassland, and those related to Wetlands and Settlements refer only to areas where activities causing emissions have occurred. 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.

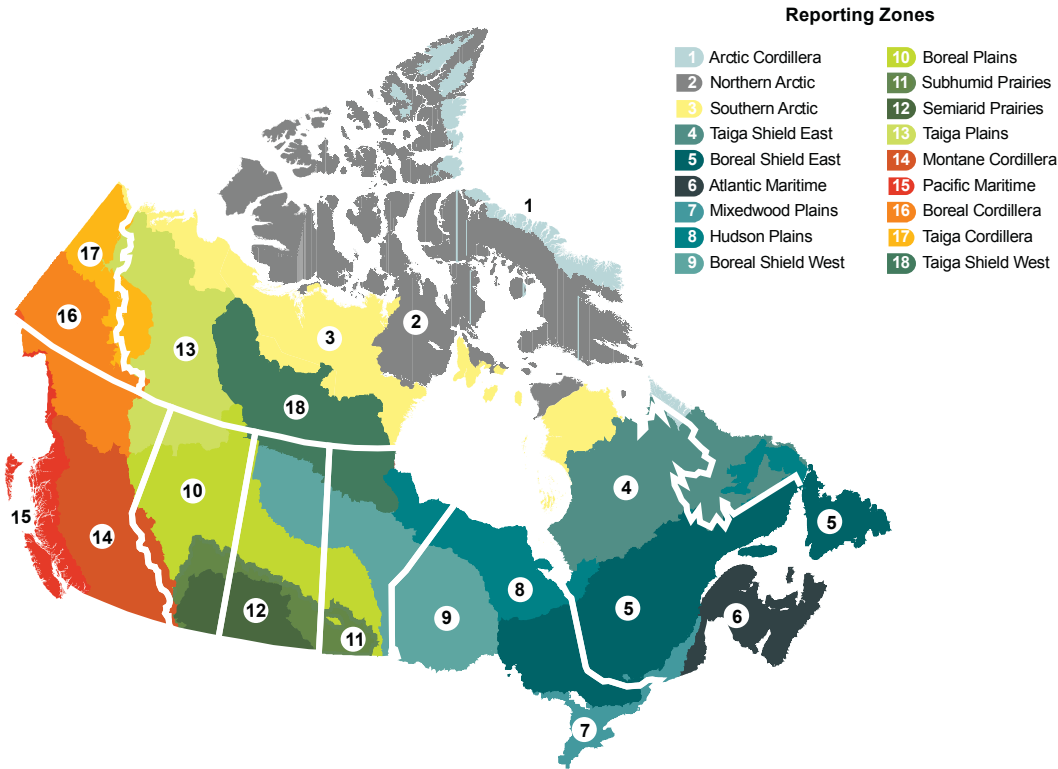


Table 6–4 Land Use and Land-use Change Matrix for the 2014 Inventory Year (Areas in kha)<sup>1</sup>

		Final Land Use					
		Forest Land	Cropland	Grassland	Wetlands	Settlements	Other
Initial Land Use	Forest Land	231 686	345	NO	49	493	NO
	Cropland	56	49 891	NO	NE	NE	NO
	Grassland	NO	27	7 138 <sup>2</sup>	NE	1	NO
	Wetlands	NO	NE	NO	420 <sup>3</sup>	NE	NO
	Settlements	NO	NE	NO	NO	442 <sup>3</sup>	NO
	Other	NO	NO	NO	53	NO	NE

Notes:  
1. Non-diagonal cells refer to cumulative areas, i.e., total land converted over the last 20 years (10 years for reservoirs).  
2. Only includes areas of agricultural grassland.  
3. Only includes areas for which emissions are reported in the CRF.  
NE = Not estimated.  
NO = Not occurring.

Figure 6–1 Reporting Zones for LULUCF Estimates



The LULUCF land monitoring system includes the conversion of unmanaged forests and grassland 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) repre-

sent a fraction of total reservoir areas (those flooded for 10 years or less), not the total area of reservoirs in Canada.

Similarly, the areas of land conversion reported in the CRF tables refer to the cumulative total land area converted over the last 20 years (10 years for reservoirs) and 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) 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 348 Mha (NRCan 2015). Managed forests, those under direct human influence, account for 232 Mha, or 67% of all forests. Four reporting zones (Boreal Shield East, Montane Cordillera, Boreal Plains and Boreal Shield West) account for 68% of managed forests.

In 2014, the net GHG balance of managed Forest Land amounted to removals of 64 Mt (Table 6–1 and CRF Table 4). This estimate includes net emissions and removals of CO<sub>2</sub>, as well as N<sub>2</sub>O, CO and CH<sub>4</sub> emissions from slash burning and wildfires. For the purpose of UNFCCC reporting, managed Forest Land is divided into the subcategories Forest Land remaining Forest Land (232 Mha, net removals of 63 Mt) and Land converted to Forest Land (0.06 Mha, net removals of 0.55 Mt) in 2014.

#### 6.3.1. Forest Land Remaining Forest Land (CRF Category 4.A.1)

##### 6.3.1.1. Methodological Issues

Vegetation absorbs CO<sub>2</sub> from the atmosphere through photosynthesis, and some of this carbon is sequestered in standing vegetation (biomass), dead organic matter (DOM) and soils. Carbon dioxide is returned to the atmosphere by vegetation respiration and the decay, through heterotrophic respiration, of organic matter. The natural CO<sub>2</sub> exchanges between the atmosphere and biota are large fluxes, globally recycling on the order of one seventh of the total atmospheric CO<sub>2</sub> content annually. These large gross fluxes result from the accumulation of minute processes dispersed over vast land areas. Only a small fraction of the carbon (C) taken up by photosynthesis accumulates in ecosystem C pools after all respiratory and disturbance C losses.

Human interactions with the land can directly alter the size and rate of these natural exchanges of GHGs, in both the immedi-

ate and long term. Land-use change and land-use practices in the past still affect current GHG fluxes to and from the terrestrial biosphere. This long-term effect is a unique characteristic of the LULUCF Sector, which makes it very distinct from other sectors, such as the Energy Sector.

While the intended focus is on anthropogenic impacts on the GHG balance, it is recognized that separating human from natural effects in the LULUCF Sector poses a unique challenge. Humans manipulate biological processes in a myriad of ways and intensities. What we observe is typically the outcome of these various manipulations and their combined interactions with an equally varied biophysical environment, including natural disturbances. Untangling the various cause-and-effect relationships in the long term and short term is still the object of scientific inquiry.

Canada emphasizes that while all efforts are made to provide IPCC-compliant GHG estimates, such estimates may not truly account for direct human effects or accurately reflect where and when emissions occur (Stinson et al. 2011).

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 (NFC-MARS) (Kurz and Apps 2006) 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 (fires, insect infestations) to estimate forest carbon stocks, stock changes and CO<sub>2</sub> 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. The conceptual approach remains that recommended by the IPCC (2006), in which net removals or emissions are calculated as the difference between CO<sub>2</sub> uptake by growing trees and emissions from forest management activities (harvesting), heterotrophic respiration and natural disturbances. Additional information on the estimation methodology is provided in Annex 3.5.

The main drivers influencing the net GHG flux in the managed forest simulated by the CBM-CFS3 include natural processes that impact ecosystem carbon uptake and loss as well as human and natural disturbances that produce both immediate GHG emissions and C transfers among pools (Figure 6–2). Immediate emissions resulting from direct anthropogenic activities (slash burning) and insect epidemics and wildfire can be identified in the year the disturbance occurs. In the years following the disturbance, the residual emissions and regrowth are simulated within annual (ecosystem) processes.

Immediate emissions from slash burning ranged from 6 to 11 Mt, corresponding largely to differences in the total areas subject

to this forestry management practice (from 65 kha in 1998 to 92 kha in 1995). Harvesting activities cause a transfer of carbon among pools and to the Harvested Wood Products category, but cause no immediate emissions. Note that the transfer of carbon from managed forests to wood products and the associated CO<sub>2</sub> emissions from the manufacturing, use and disposal of wood products are reported in the Harvested Wood Products category (Section 6.4).

Much of the interannual variability of the GHG budget of managed forests hinges on the occurrence, location and severity of fires. During the 1990–2014 period, immediate emissions from wildfire fluctuated between 11 and 277 Mt. The consumption of DOM by fires accounts for 76% of immediate emissions; much biomass is killed by forest fires and is thus transferred to the DOM pool, but is not immediately burned. A large amount of the actual fuel load consists of deadwood and litter on the forest floor. On average, 8% of immediate fire emissions in CO<sub>2</sub> equivalents are in the form of CO, 8% in the form of CH<sub>4</sub>, and 4% in the form of N<sub>2</sub>O.

Since 2000, insect epidemics have affected a total of over 55 Mha<sup>2</sup> of managed forests, with 77% being located in the Montane Cordillera reporting zone and corresponding to mountain pine beetle epidemics. Immediate emissions are minimal from

insect epidemics because, though the biomass is killed, the carbon is transferred to the DOM pool, where it is lost through decay in subsequent years with impacts being observed in annual processes (Figure 6–2) (Kurz et al. 2008).

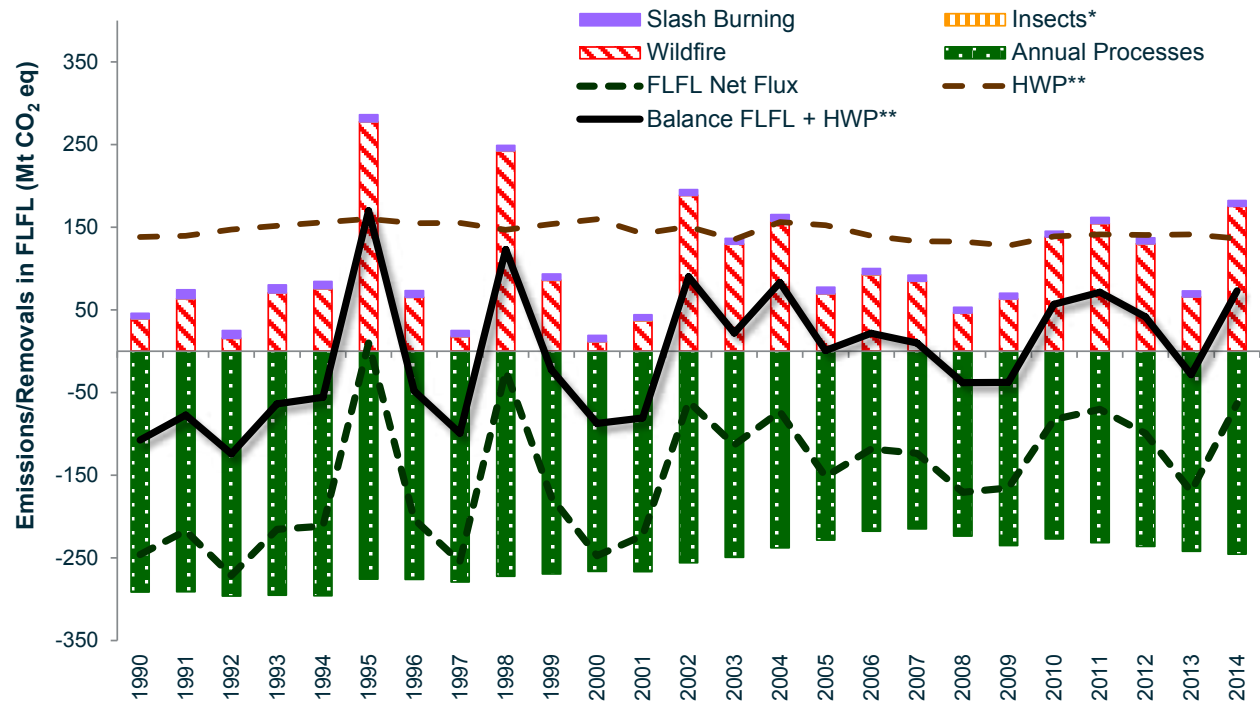
Annual processes represent the balance of two large carbon fluxes: the net carbon uptake by growing trees (net primary production) and carbon release due to the decay of organic matter through heterotrophic respiration (–3000 and 2700 Mt, respectively, in 2014). The long-term effect of past disturbances, such as insect epidemics, can be seen by the reduction in net removals from the annual processes. Areas impacted by insect epidemics increased significantly in the second part of the time series, resulting in both an upward trend in DOM decay and a decline in C uptake over the years 2000–2007.

The managed forest GHG balance is not spatially homogeneous. In 2014, managed forests were net sources in the Taiga Shield East, Semiarid Prairies, Taiga Plains, Montane Cordillera and Taiga Shield West reporting zones, and net sinks in the remaining reporting zones (Table 6–5). Note that the spatial distribution of emissions and removals is influenced by the occurrence and location of disturbances (namely wildfires) and would therefore not necessarily be constant in successive years.

Carbon stock changes in managed forests are reported in CRF Table 4.A, by reporting zone. For any given pool, carbon stock

2 May include areas repeatedly infested, e.g., a hectare infested in three successive years is counted as three hectares towards the 55 Mha.

Figure 6–2 Emissions and Removals Related to Forest Land



\* Insect epidemics cause minimal immediate emissions; however, their influence on the net flux of managed forests, due to tree mortality and DOM decay, can be seen in the Annual Processes component.  
\*\* Emissions from HWP are presented only for reference to show the net balance from managed forest after considering the impact of these emissions.

Table 6–5 GHG Balance of Forest Land Remaining Forest Land by Reporting Zone, 2014

Reporting Zone Number	Reporting Zone Name	Forest Area (kha)	Net GHG Balance (kt CO <sub>2</sub> eq)	C Transfers to HWP (kt C) <sup>2</sup>
1	Arctic Cordillera	–	NA	NA
2	Northern Arctic	–	NA	NA
3	Southern Arctic	–	NA	NA
4	Taiga Shield East	1 100	2 200	1
5	Boreal Shield East	56 000	-59 000	9 600
6	Atlantic Maritime	15 000	-22 000	6 100
7	Mixedwood Plains	2 700	-8 200	180
8	Hudson Plains	300	- 570	NA
9	Boreal Shield West	29 000	-21 000	2 600
10	Boreal Plains	38 000	-28 000	6 400
11	Subhumid Prairies	1 800	-1 300	250
12	Semiarid Prairies	40	45	NA
13	Taiga Plains	21 000	21 000	600
14	Montane Cordillera	36 000	68 000	11 000
15	Pacific Maritime	13 000	-14 000	6 100
16	Boreal Cordillera	17 000	-22 000	1 100
17	Taiga Cordillera	410	- 360	NA
18	Taiga Shield West	1 800	22 000	69
<b>Canada Total</b>		<b>230 000</b>	<b>-63 000</b>	<b>44 000</b>

## Notes

1. Negative sign indicates removal of CO<sub>2</sub> from the atmosphere.

2. The current design of the CRF tables for the LULUCF Sector does not enable representation of the transfer of forest biomass carbon to the Harvested Wood Products in-use pool. This transfer between LULUCF categories is presented here for information purposes.

NA = Not applicable.

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, 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 a transfer of carbon from the Forest Land category to the Harvested Wood Products category (Table 6–5). However, due to limitations in the current design of the CRF tables, the loss of carbon from the forest biomass and DOM pools cannot be reported in CRF Table 4.A since it would result in a double counting of emissions from harvest. Instead, this carbon loss is reported as carbon input into the HWP in-use pool in 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 CRF Table 4.A since the losses of carbon from these pools are not completely represented. More information on Canada's approach to HWP modelling is available in Annex 3.5.

### 6.3.1.2. Uncertainties and Time-Series Consistency

#### Uncertainty Estimates

Numerical techniques are used to quantify uncertainties about the outputs of the CBM-CF53 (Metsaranta et al. 2016). 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 2015 submission (covering the entire 1990–2013 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. For practical reasons, this computationally-intensive numerical analysis is not repeated annually. Thus, uncertainty bounds for annual estimates derived for the 2015 submission were extrapolated to estimate uncertainties associated with annual estimates for this submission.

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<sub>2</sub> estimates is 117 Mt in 1990, 106 Mt in 2005 and 100 Mt in 2013 (Table 6–1). On average, uncertainty was ±55 Mt of the median result from the Monte Carlo runs over the entire time series. Non-CO<sub>2</sub> emissions contribute little to total uncertainty. While the relative uncertainty is presented, these values can be misleading, as the relative uncertainty may be increased when the net CO<sub>2</sub> 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

**Table 6–6 Estimates of Net Annual CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O Fluxes for Forest Land Remaining Forest land, with 2.5<sup>th</sup> and 97.5<sup>th</sup> 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 <sub>2</sub>	1990	- 251	- 345	37	- 228	-9
	2005	- 161	- 235	46	- 129	-20
	2014	- 85	- 146	71	- 46	-46
CH <sub>4</sub>	1990	3.7	3.3	11	4.8	31
	2005	6.2	5.1	18	9.0	44
	2014	14.7	11.9	19	21.1	44
N <sub>2</sub> O	1990	1.8	1.6	14	2.5	36
	2005	3.1	2.5	19	4.6	47
	2014	7.4	5.9	19	10.8	46

estimate. During the production of the 2015 NIR, analyses suggested that a portion of the skew in the probability distribution may be due in part to a technical issue in the modelling process, not to uncertainty in the model inputs or parameters. However, it is currently impossible to evaluate to what degree it modifies the distribution. Though uncertainty ranges may be considered representative of the uncertainty in the model parameters and activity data, caution should be taken when considering the distribution of the uncertainty around the net flux estimate. This technical issue will be addressed for next year's submission.

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),<sup>3</sup> which comprises information from provincial resource management agencies, compiled and updated by the Canadian Forest Service. Estimates of area burned for the period 2004–2014 were obtained from the National Burned Area Composite (NBAC).<sup>4</sup> 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.

### 6.3.1.3. QA/QC and Verification

Tier 2 quality control (QC) checks (White and Dymond 2008; Dymond 2008) specifically address estimate development in the Forest Land category. 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.

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 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

3 <http://www.nrcan.gc.ca/node/13159>.

4 <http://www.nrcan.gc.ca/node/13159>.



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.

### 6.3.1.4. Recalculations

Recalculations in this category increased net removals by 2.2 Mt in 1990 and decreased net removals by 9.3 Mt and 8.6 Mt in 2005 and 2013, respectively. Throughout the time series, recalculations in emissions/removals ranged from a maximum increase of 16 Mt in 1998 (a 40% decrease in removals) to a decrease of 24 Mt in 2009 (a 17% increase in removals).

Recalculations are due to the combined effects of a methodological change for residential firewood collection, various changes to model parameters and algorithms, and activity data updates.

### Methodological Change – Improved Representation of Residential Firewood Collection

In previous submissions, statistics from the National Forestry Database were used as activity data for the quantity of residential firewood harvested in the managed forest. However, the amount of firewood harvested was substantially lower than estimates of wood used for residential firewood heating as developed by the Energy Sector used in HWP estimates in the 2015 submission. To improve consistency among the Energy Sector and both the Forest Land and the Harvested Wood Products categories in the LULUCF Sector, the harvest of residential firewood volumes, consistent with data used by the Energy Sector, from the managed forest carbon pools was simulated by the forest ecosystem model. Details on the implementation of firewood harvest in the forest ecosystem model can be found in Section 6.4.1 and in Annex 3.5, Section A3.5.7.

These changes generally led to increased emissions, as there was an increase in the amount of firewood harvested from the managed forest, which increased transfer of biomass to DOM and thus increased emissions from DOM decay.

### Changes to Model Parameters and Algorithms– Wildfires, Slash Burning and Harvesting

Changes were made to the way disturbances are modelled in this submission. The spatial referencing for wildfires was modified to correct past data processing errors that led to wildfires being applied to the wrong forest inventory stands. A new disturbance matrix was also developed for slash burning to remove an erroneous C transfer from aboveground biomass to HWP.

The most notable change in model parameters and algorithms related to the modelling of forest harvest was an undocumented change in the sorting criterion for harvest selection. This change prioritized stands with the highest amount of standing deadwood. The correction was made to improve the representation of salvage logging—i.e. the removal of merchantable timber after natural disturbances—and had a significant impact on total estimates in the second half of the time series. Repeated insect infestations in Western Canada since 2000 created large volumes of deadwood that was targeted for salvage logging. The revised sorting criterion led to large increases in net removals as less biomass and more deadwood was harvested, with less deadwood left to subsequently decay or burn.

The downward trend in recalculations in the second half of the time series is primarily driven by recalculations in the Montane Cordillera and Boreal Plains reporting zones, which can be attributed mainly to corrections to stand selection and sorting criteria for harvesting.

### Activity Data Updates

Updated activity data for wildfires, harvesting, slash burning and forest conversion were used in this submission. Revised data on wildfires for 2004–2013 from the National Burned Area Composite (NBAC) were used, resulting in large increases in area burned for 2011–2013. Revisions to forest management activity statistics were made in the National Forestry Database. These revisions notably included slash burning in provinces for which none there was previously none reported.

Forest conversion estimates for 2005–2013 were revised downwards by using forest conversion rates from updated geomatics analysis of a more current mapping period rather than extrapolating conversion rates from an earlier analysis. More detailed explanations on Forest Conversion recalculations are presented in Section 6.9.4.

There was also a notable increase in the amount of carbon transferred to the Harvested Wood Products category (on average 5 Mt C or 11%) resulting largely from changes in activity data for residential firewood collection. These changes in transfers to HWP are reflected in the Harvested Wood Products category as explained in Section 6.4.3.

### 6.3.1.5. Planned Improvements

Long-term planned improvements include enhancing the quality of forest inventory data and greater focus on drivers of anthropogenic emissions and removals.

Approaches are being explored to effectively remove the impact of natural disturbances on emission variability and trends, for example by temporarily excluding emissions/removals from managed forest lands subject to uncontrollable natural disturbances.



## 6.3.2. Land Converted to Forest Land (CRF Category 4.A.2)

### 6.3.2.1. Category Description

This category includes all lands converted to Forest Land through direct human activity. Post-harvest tree planting is not included, nor is abandoned farmland where natural vegetation is allowed to establish; hence, the category more precisely refers to forest establishment where the previous land use was not forest (typically, abandoned farmland).

The total cumulative area reported under the Land converted to Forest Land category declined from 174 kha in 1990 to 56 kha in 2014. 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 12% in the Prairie provinces (Boreal Shield West, Boreal Plains and Subhumid Prairies reporting zones) and the remaining 6% in western Canada (Pacific Maritime and Montane Cordillera).

Net removals declined throughout the period, from 1.0 Mt in 1990 to 0.6 Mt in 2014. Net carbon accumulation largely occurs in biomass (129 Gg C in 2014 – 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 2009–2014 inventory years.

GHG emissions and removals on lands newly converted to Forest Land were estimated using CBM-CFS3, as described in Annex 3.5. Changes in soil 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 procedures for estimates developed internally (refer to Section 1.3, Chapter 1), has implemented specific procedures for estimates obtained from data partners, as well as for all estimates and activity data contained in the LULUCF data warehouse and entered into the CRF reporter.

### 6.3.2.5. Recalculations

There were no recalculations 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)

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 128 Mt in 2009 (lowest harvest year) and peaks of 160 Mt in 1995 and 2000. In 2014, HWP amounted to total emissions of 136 Mt, slightly lower than the 138 Mt emitted in 1990 (Figure 6–2, Table 6–7).

Harvested Wood Products emissions are inextricably linked to emissions/removals from Forest Land, such that the sum of net emissions/removals from Forest Land and emissions from HWP provides an estimate of total net emissions/removals from the managed forest (Figure 6–2).

### 6.4.1. Methodological Issues

A country-specific model, the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP), was developed 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 ecosys-

tem 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 in any year) transferred from the CBM-CFS3 model (see Section 6.3.1.1). 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 Statistics Canada's Canada Facts surveys, while data on industrial consumption of firewood come from its annual Report on Energy Supply and Demand in Canada (RESO). 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.

The 2006 IPCC Guidelines (IPCC 2006) for firewood were partially implemented in the last submission since only the quantity of residential firewood, based on statistics compiled by the National Forestry Database Program (NFDP), was harvested in the for-

**Table 6–7 : Carbon Stocks in HWP Pool and Emissions Resulting from Their Use and Disposal**

Source Subcategories / Commodities	1990	2000	2005	2010	2011	2012	2013	2014
<b>Carbon Stocks (Mt C)<sup>1</sup></b>								
Inputs	49	58	57	42	44	44	45	45
Conventional Harvest <sup>2</sup>	40	51	51	35	37	38	38	38
Forest Conversion <sup>2</sup>	1.8	1.2	1.2	1.1	1.0	1.1	1.1	1.0
Residential Firewood <sup>3</sup>	6.9	6.3	5.2	5.4	5.4	5.5	5.5	5.5
Exports	19	28	31	18	19	19	21	22
Net Stocks <sup>4</sup>	300	420	500	530	540	540	550	560
<b>Emissions (Mt CO<sub>2</sub>)<sup>1</sup></b>								
Domestic Harvest	97	97	82	74	77	77	78	74
Solid Wood - Sawnwood	4.8	4.7	5.2	5.7	5.8	5.9	6.0	6.1
Solid Wood - Wood Panels	2.5	2.9	3.2	3.6	3.7	3.8	3.9	3.9
Other Solid Wood Products	0.8	1.4	1.8	2.0	2.0	2.1	2.1	2.1
Paper and Market Pulp	8.3	2.0	0.7	0.9	1.2	1.7	2.3	2.4
Firewood - Residential and Industrial	50	58	58	50	50	50	50	50
Mill Residue	31	29	13	11	14	13	13	9.0
Worldwide from Canadian Harvest	41	62	71	65	64	64	63	63
Solid Wood - Sawnwood	8.8	13	15	16	16	17	17	17
Solid Wood - Wood Panels	0.7	2.4	4.0	4.8	4.9	4.9	5.0	5.1
Other Solid Wood Products	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Paper and Market Pulp	31	46	50	43	41	40	40	39
Mill Residue	0.5	1.0	1.9	1.2	1.7	1.8	2.0	1.3

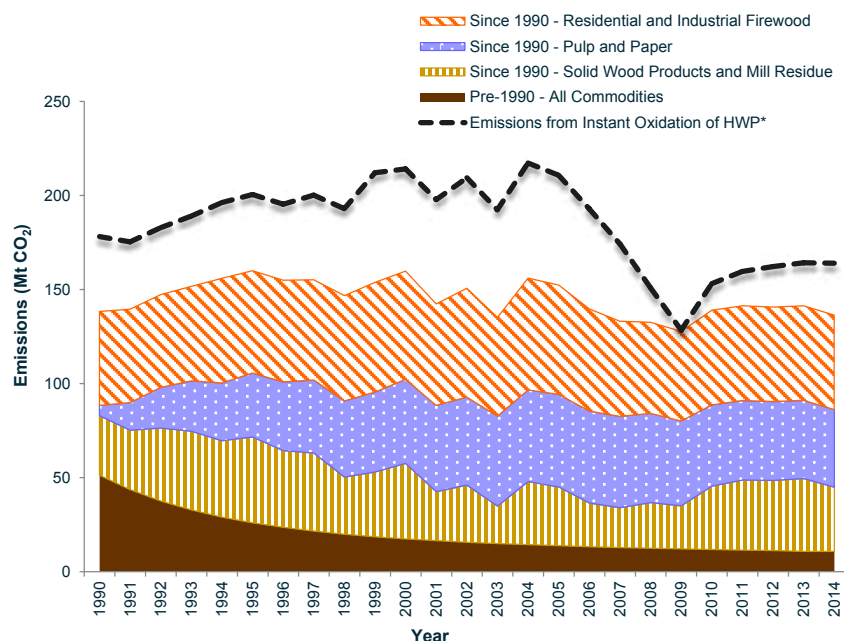
Notes:

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.

**Figure 6–3 Emissions from HWP Pool Using the Production Approach vs. Instant Oxidation**

\* This line represents an alternative estimate of emissions from HWP using an instant oxidation approach and is presented here only for information purposes.

est ecosystem model. Amounts of C associated with volumes of residential firewood provided by the Energy Sector were added incrementally to the HWP residential firewood pool without considering the corresponding C losses from the forest ecosystem. In this submission, 87% of the total firewood volume used in the Energy Sector estimates was used as input to simulate the harvest of firewood from the managed forest. The remaining 13% of the Energy Sector wood volumes came from post-consumer products (details are provided in Annex 3.5).

The temporal pattern of 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 submissions prior to 2015 (dotted line in Figure 6–3), with differences fluctuating between 37 Mt in 1993 and 61 Mt in 2004 (highest harvest year). 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.

### 6.4.2. Uncertainties and Time-Series Consistency

An assessment of the uncertainty of HWP estimates has been developed and is presented for the first time in this submission.

For this initial implementation, model parameters were varied for Monte Carlo simulations while holding the carbon inputs constant based on the output from the CBM-CFS3 forest ecosystem model. The results of this analysis (Table 6–8) therefore represent 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 6.3.1.2).

Several parameters of the model, including those related to product allocation values and product-in-use half-lives, were considered in the uncertainty analysis (Metsaranta et al. 2016). For each of these parameters, an expected range and distribution were assigned, based on published values and/or expert judgement. Distributions of parameter values were either triangular or uniform, using the latter in cases where knowledge about a parameter was low. For each Monte Carlo model run, the baseline model parameters were replaced with values randomly drawn

**Table 6–8 : Estimates of CO<sub>2</sub> Emissions from Harvested Wood Products for 2014, with 2.5<sup>th</sup> and 97.5<sup>th</sup> Percentiles**

Source of C inputs	Emissions (Mt CO <sub>2</sub> )	2.5th Percentile (Mt)	% Uncertainty (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
Conventional Harvest - since 1990	102.8	91.9	-11	110.9	8
Forest Conversion - since 1990	3.1	2.9	-8	3.3	4
Residential Firewood Collection	19.6	19.6	-0.1	19.7	0.1
Historical harvest - before 1990	10.9	10.3	-5	11.4	5

from relevant distributions, thereby creating 100 distinct sets of model parameters. Parameters were drawn independently of each other, thus assuming that there were no correlations among their values, except where parameters represent proportions that must add to one, in which case it was ensured that the sum of the proportions was exactly one. Each set of parameter values was applied to both contemporary and historical model runs, such that 200 simulation runs were required.

### 6.4.3. Recalculations

Recalculations in the HWP category are due to the combined effects of: i) correction in the moisture content assumption for industrial firewood used in the model, which impacted the mass estimate of industrial firewood and mill residue; ii) correction in the mass balance analysis of FAO statistics that determines allocation proportions to commodities, resulting in a decrease in the allocation of commercial harvest to commodities and an increase in material sent to mill residue; iii) 13% decrease in the residential biomass CO<sub>2</sub> emission factors used in the Energy Sector (see Section 3.2.7), which are also used for residential firewood in LULUCF; iv) alignment of residential firewood collection activity data with wood supply from the ecosystem model, impacting residential firewood estimates; and v) activity data updates for forest harvest and forest conversion. As a result, total emissions from HWP were recalculated downward by 2 Mt in 1990, 6.3 Mt in 2005 and 3.9 Mt in 2013.

### 6.4.4. 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, and further improvements will be therefore 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, and the expansion of temporal coverage, which is currently limited by available data.

Improvements are also planned to improve uncertainty analysis of HWP estimates, by considering the uncertainty inherent to the C inputs.

## 6.5. Cropland (CRF Category 4.B)

Cropland covers approximately 50 Mha of the Canadian territory. In 2014, the net GHG balance in the Cropland category amounted to removals of 8.4 Mt (Table 6–1). For the purpose of reporting under the UNFCCC, Cropland is divided into Cropland remaining Cropland (net removals of 11 Mt in 2014) and Land (either forest or grassland) converted to Cropland (net emissions of 3.0 Mt and 0.019 Mt, respectively, in 2014). The estimates in Land converted to Cropland include net emissions and removals of CO<sub>2</sub>, as well as N<sub>2</sub>O and CH<sub>4</sub> emissions.

### 6.5.1. Cropland Remaining Cropland (CRF Category 4.B.1)

Cultivated agricultural land in Canada includes areas of field crops, summerfallow, hay fields and tame or seeded pasture. Cropland is found mainly in the nine southernmost reporting zones. About 83% of Canada's cropland is in the interior plains of western Canada, made up of the Semi-arid Prairies, the Subhumid Prairies and the Boreal Plains reporting zones. Another 12% of cropland is found in the Mixedwood Plains reporting zone.

Cropland remaining Cropland includes CO<sub>2</sub> emissions/removals in mineral soils, CO<sub>2</sub> emissions from cultivation of organic soils, and CO<sub>2</sub> emissions/removals resulting from changes in woody biomass from specialty crops. An enhanced Tier 2 approach is used for estimating CO<sub>2</sub> emissions from and removals by mineral soils triggered by changes in land management practices

#### 6.5.1.1. CO<sub>2</sub> 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 primary 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<sub>2</sub> emission to or removal from the atmosphere.

In 1990, changes in mineral soil management amounted to a net CO<sub>2</sub> emission of about 0.3 Mt (Table 6–9). This small source steadily increased to a removal of 14 Mt in 2006, and subsequently gradually decreased to 12 Mt in 2014. The increasing trend in removals in the first 17 years partly reflects continuous efforts to reduce summerfallow and increase conservation tillage (Campbell et al. 1996; Janzen et al. 1998; McConkey et al. 2003), while in more recent years, net removals have tended to stabilize as the adoption of conservation tillage and the decrease in summerfallow have begun to level off and the soil sink from past adoption has approached a steady state. Higher emissions due to an increasing proportion of annual crops in the crop mixture have contributed to the recent decline in the net soil sink by partially offsetting soil carbon gains. The area of summerfallow declined by 81% from 1990 to 2014, resulting in a net sink that increased from 2 Mt in 1990 to 7.3 Mt in 2014. The increase in net sink due to the adoption of conservation tillage practices (from 1.2 Mt in 1990 to 6.3 Mt in 2014) is substantiated by a net increase of 17 Mha in areas under no-till and reduced tillage over the 1990–2014 period. The net change in crop mixture resulted in a reduction of the source from 3.4 Mt in 1990 to 0.2 Mt in 2014.

The net increase since 1990 in the sink arising from changes in management practices was partially offset by an increase in net residual CO<sub>2</sub> emissions from the decay of dead organic matter and SOC on land converted to cropland more than 20 years prior to the inventory year. Emissions from land converted for less than 20 years are included under Land converted to Cropland. The increase since 1990 in these residual emissions is due to a methodological artefact. Since forest conversion monitoring goes

back only to 1970, post-20-year residual emissions in 1990 only accounted for the land converted in 1970. Residual emissions display an apparent increase because the temporal coverage increases with each inventory year. In the CRF tables, these emissions are split among the dead organic matter and soil pools.

## Methodological Issues

Following the 2006 IPCC Guidelines, the premise is that the 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. This compendium provided the basis for selecting the key management practices and management changes likely to cause changes in soil carbon stocks. The availability of activity data (time series of management practices) from the *Census of Agriculture* was also taken into account. 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<sub>2</sub> changes in mineral soils were derived from the following LMCs:

**Table 6–9 : Base and Recent Year Emissions and Removals Associated with Various Land Management Changes on Cropland Remaining Croplands**

Categories	Land Management Change (LMC)	Emissions/Removals (Gg CO <sub>2</sub> ) <sup>1</sup>							
		1990	2000	2005	2010	2011	2012	2013	2014
Total Cropland remaining Cropland		630	-7 300	-13 000	-13 000	-12 000	-12 000	-12 000	-11 000
Cultivation of histosols		300	300	300	300	300	300	300	300
Perennial woody crops		31	60	- 0.1	- 25	- 20	- 42	- 57	- 72
Total mineral soils		300	-7 700	-13 000	-13 000	-13 000	-12 000	-12 000	-12 000
Change in crop mixture	Increase in perennial	-3 600	-7 900	-12 000	-13 000	-13 000	-13 000	-13 000	-13 000
	Increase in annual	7 000	7 900	8 200	10 000	11 000	12 000	12 000	13 000
Change in tillage	Conventional to reduced	- 810	-1 100	-1 000	- 900	- 870	- 850	- 840	- 820
	Conventional to no-till	- 410	-2 600	-3 600	-4 100	-4 200	-4 300	-4 400	-4 400
	Other	- 0.4	- 270	- 770	- 970	-1 000	-1 000	-1 000	-1 100
Change in summerfallow (SF)	Increase in SF	2 300	2 100	1 900	1 700	1 700	1 600	1 600	1 600
	Decrease in SF	-4 400	-7 100	-7 700	-8 400	-8 500	-8 700	-8 800	-8 900
Land conversion—Residual emissions <sup>2</sup>		180	1 400	1 700	1 900	1 900	1 900	1 900	1 800

Notes:

1. Negative sign indicates removal of CO<sub>2</sub> from the atmosphere.

2. Net residual CO<sub>2</sub> emissions from the conversion of Forest Land and Grassland to Cropland that occurred more than 20 years prior to the inventory year, including emissions from the decay of woody biomass and DOM.



- 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 a high degree of spatial disaggregation, namely by 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 an LMC. The annual CO<sub>2</sub> emissions/removals by mineral soils undergoing a specific LMC are expressed as:

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. Limits are imposed by the availability of activity data within the modelling framework. At this point, the inventory relies mainly extensively on the *Census of Agriculture* for estimates of areas of LMC (i.e. changes in tillage, types of crop and fallow). The area of LMC was determined individually for 3404 393 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, given the limitations imposed by confidentiality requirements of census data. 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<sub>2</sub> 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.<sup>5</sup>

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<sub>2</sub> from mineral soils were developed by McConkey et al. (2007), who reported uncertainty values at  $\pm 19\%$  for the level and  $\pm 27\%$  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<sub>2</sub> estimates is ensured through the use of the same methodology for the entire time series of estimates (1990–2014).

## 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.

<sup>5</sup> T. Huffman, Agriculture and Agri-Food Canada, personal communication to Brian McConkey, 2007.



Carbon change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). The comparison showed that empirical data on changes in SOC in response to no tillage were highly variable, particularly for eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. For the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, and this compared favourably with the range of 0.46–0.56 Mg C/ha per year in the modelled factors in western Canadian soil zones. For eastern Canada, only two empirical change factors were available, but they fell within the range of the modelled values (0.60–1.07 Mg C/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled). For conversion of crop fallow to continuous cropping, the modelled rate of carbon storage obtained (0.33 Mg C/ha per year) was more than twice the average rate of  $0.15 \pm 0.06$  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 summerfallow in the inventory. More details can be found in Annex 3.5.

In February 2009, Canada convened an international team of scientists and experts from Denmark, France, Japan, Sweden, the Russian Federation and the United States to conduct a quality assurance assessment of the Canadian Agricultural Monitoring, Accounting and Reporting System (Can Ag-MARS). 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 the next generation of Can Ag-MARS.

## Recalculations

In this submission an error in the programming script used to process the EO data that was incorporated for the first time in the 2015 submission was discovered; a function call failed to update SLC values for conventional tillage (IT) with revised crop proportions, while at the same time values for reduced tillage (RT) and no-till (NT) were updated. The problem was corrected, and as a result, there were significant changes in the areas of IT, RT and NT: IT increased by 0.95 Mha in 1990 and decreased by 2.1 Mha in 2013; RT decreased by 0.81 Mha in 1990 and increased by 0.56 Mha in 2013; and NT decreased by 0.14 Mha in 1990 and increased by 1.5 Mha in 2013. There were also small changes in crop areas because of error corrections in the programming code responsible for estimating crop extents for SLC polygons in which census data were suppressed or for which there was no record in the census.

These changes in cropland attributes for the Cropland remaining Cropland subcategory resulted in recalculations, with an increase

in emissions of 153 kt in 1990 and an increase in removals of 119 kt in 2005 and 724 kt in 2013.

## 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<sub>2</sub> 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 1990–2014) 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  $\pm 50\%$  (Hutchinson et al. 2007). The 95% confidence limits of the default emission factor are  $\pm 90\%$  (IPCC 2006). The overall mean and uncertainties associated with this source of emissions were estimated to be  $0.3 \pm 0.09$  Mt CO<sub>2</sub> eq for the level uncertainty and  $0 \pm 0.13$  Mt CO<sub>2</sub> eq for the trend uncertainty (McConkey et al. 2007).

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2014).

## 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<sub>2</sub> 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  $\pm 75\%$  (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  $\pm 75\%$  (i.e. 95% confidence limits) (IPCC 2006).

The overall mean and uncertainties associated with emissions or removals of CO<sub>2</sub> from woody specialty crops were estimated to be  $-72 \pm 7.4$  kt for the level uncertainty and  $-103 \pm 150$  kt for the trend uncertainty (McConkey et al. 2007).

The same methodology was used for the entire time series of emission estimates (1990–2014).

## 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

In this submission, an error in the programming code related to the confidentiality suppression of data in the *Census of Agriculture* was discovered. As a result of this error correction, the area of Christmas tree farms, vineyards and fruit orchards changed slightly, ranging from an increase of 278 ha in 1990 to a decrease of 266 ha in 1992 during the entire reporting period. There was a small decrease in emissions of 0.1 kt in 1990 and of 1.8 kt in 2005, and an increase in removals of 0.6 kt in 2013.

## 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)

### 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 35% of forest area conversion in 2014). 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 345 kha over the 20 years prior to 2014. 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 2014, immediate emissions from this year's Forest conversion to Cropland accounted for 1.2 Mt, while residual emissions from events that occurred in the last 20 years accounted for 1.7 Mt. More than 90% of emissions originate from the biomass and dead organic matter pools during and after conversion, with the remainder being attributed to the soil pool.

#### Methodological Issues – Dead Organic Matter and Biomass Pools

As stated above, emissions from the dead organic matter (DOM) and biomass pools account for almost all emissions due to the conversion of Forest Land to Cropland. 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 6.3.1.1. 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<sub>2</sub> source from change in management practices in the 20 years following conversion, and the N<sub>2</sub>O emissions from the decay of soil organic matter. 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<sub>2</sub>O emissions from agricultural soils (see Agriculture Sector, Chapter 5), emissions of N<sub>2</sub>O 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<sub>BASE</sub>). EF<sub>BASE</sub> 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<sub>2</sub>O.

## 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<sub>2</sub> emissions in the DOM pool; and (iii) net C losses from SOC. Note that immediate CO<sub>2</sub> 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<sub>2</sub> emissions are produced only by burning and occur during the conversion process.

Immediate and residual CO<sub>2</sub> emissions from the biomass and DOM pools represent the largest components 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. An extrapolation of uncertainty values from the Monte Carlo analysis produced for the last submission was utilized to estimate uncertainty for the entire time series for this submission. A description of the general approach is provided in Section 6.3.1.2. More information can be found in Section 3.5.2.4 of Annex 3.5.

The uncertainty in the net CO<sub>2</sub> 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<sub>2</sub> Emission Components and Non-CO<sub>2</sub> Emissions from Forest Land Converted to Cropland for the 2014 Inventory Year

Emission Components	Emissions (kt CO <sub>2</sub> eq)	Uncertainty (kt CO <sub>2</sub> eq)
Immediate CO <sub>2</sub> emissions	1,054	±664
Residual CO <sub>2</sub> emissions from the DOM pool	1,523	±365
Residual CO <sub>2</sub> emissions from the soil pool	209	±130
CH <sub>4</sub> emissions	98	±33
N <sub>2</sub> O emissions	57	±18

## 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 inclusion of the 2008–2013 mapping period, which added a fourth anchor point in 2010, resulted in less use of extrapolated information compared to the previous submissions (see Section 6.9). Large recalculations occurred in the area of Forest Land converted to Cropland, resulting in a cumulative decrease of 45 kha from 2005 to 2013. These changes were the main driver for a decrease in emissions of 24 kt in 1990, 17 kt in 2005, and 818 kt in 2013.

## 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<sub>2</sub> and N<sub>2</sub>O 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<sup>-1</sup> in the Brown Chernozem, and 1700 kg ha<sup>-1</sup> 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 2014 from soils amounted to 19 kt, down from 249 kt in 1990, including C losses and N<sub>2</sub>O 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<sub>2</sub>O emissions in Forest Land converted to Cropland, emissions of N<sub>2</sub>O 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<sub>BASE</sub>). EF<sub>BASE</sub> 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  $19 \pm 23$  kt for the level uncertainty, and  $-230 \pm 160$  kt for the trend uncertainty.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2014).

## 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 reporting of agriculturally managed grassland in the *Census of Agriculture* is highly variable. For this reason, the area of Grassland was recalculated each year using an 11-year average. Activity data on the area of Grassland conversion to Cropland were then generated by reconciling net changes in the Grassland area with changes in Cropland. The magnitude of the change was small, ranging from 100 to 1000 ha per year prior to 1980. There was no change greater than 3 ha after 1980. The change to the Grassland area estimates coupled with revisions to the Cropland area estimates resulted in small recalculations in emissions of +7.3 kt in 1990, +0.1 kt in 2005, and +0.2 kt in 2013.

## 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<sub>4</sub>, CO, NO<sub>x</sub> and N<sub>2</sub>O (IPCC 2006).

#### 6.6.1.2. Methodological Issues

The emissions of CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> (2.7 g CH<sub>4</sub> kg<sup>-1</sup> dry matter burned and 0.07 g N<sub>2</sub>O kg<sup>-1</sup> dry matter burned) were taken from the 2006 IPCC Guidelines (IPCC 2006).

Activity data 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  $\pm 50\%$ . The 95% confidence limits of the default emission factors are  $\pm 40\%$  for  $\text{CH}_4$  and  $\pm 48\%$  for  $\text{N}_2\text{O}$  (IPCC 2006). The overall uncertainties associated with this source of emissions using error propagation were estimated to be  $\pm 64\%$  for  $\text{CH}_4$ , and  $\pm 69\%$  for  $\text{N}_2\text{O}$ , respectively.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2014).

### 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 Canada 2003). 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 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 123 Mha of peatlands in Canada,<sup>6</sup> approximately 27 kha are, or were at some point in the past, drained for peat extraction. Some 15 kha are currently being actively managed. The other 11 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 only horticultural peat.

Since the 1980s, virtually all peat extraction in Canada has relied on vacuum harvest technology, and approximately 100 t/ha/yr (wet basis) of horticultural peat is typically extracted with this method (Cleary 2003). A drawback of the technology, as opposed to the traditional cut-block method, is poor natural vegetation regrowth in the post-production phase. Since the 1990s, peatland restoration activities have been pursued with greater interest.

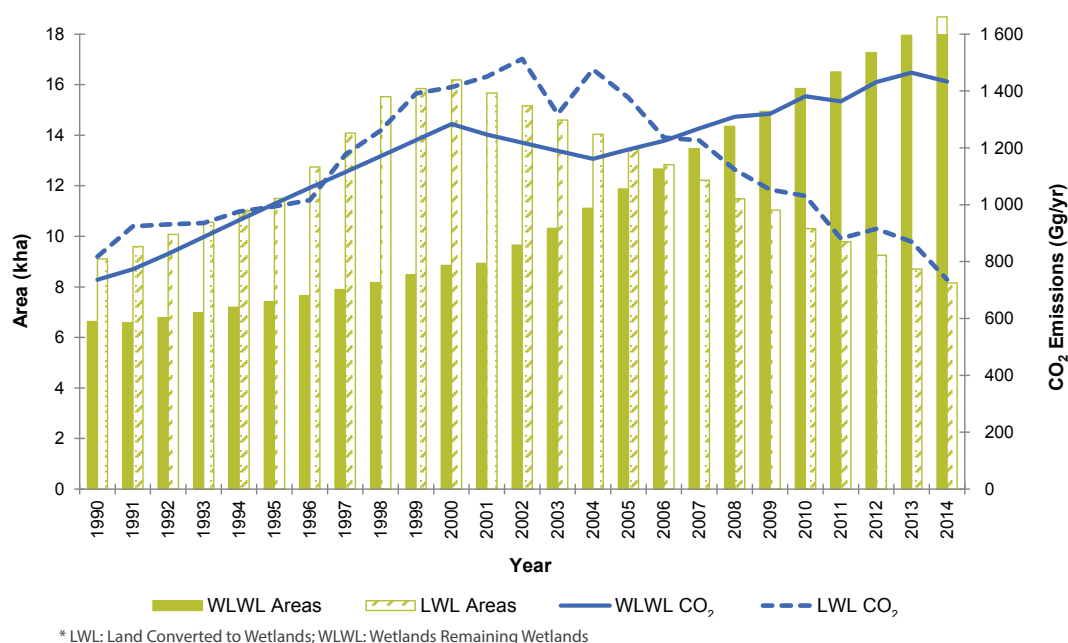
Peat extraction activities expanded during the 1990–2000 period, with a 47% increase in the land area under active peat extraction, from 9.5 kha in 1990 to 14 kha at the turn of the century. Owing to this expansion, emissions from peat extraction show a significant increase over the first half of the assessment period. Since then, emissions have declined (Table 6–4), from 2.7 Mt in 2000 to 2.2 Mt in 2014. Emissions from peat extraction are reported under Land converted to Wetlands for the first 20 years after conversion and under Wetlands remaining Wetlands thereafter.

### 6.7.1.2. Methodological Issues

The general phases of peat extraction are 1) drainage, 2) vegetation clearing, 3) extraction, 4) stockpiling, 5) abandonment and 6) peatland restoration and establishment of natural vegetation. Due to drainage,  $\text{CO}_2$  is the dominant GHG emitted from commercial peatlands and the only gas reported under this category.

<sup>6</sup> This area includes peatlands that would be classified as Forest, Cropland and Grassland in the IPCC land classification.



Figure 6–4 Areas Managed for Peat Extraction and CO<sub>2</sub> Emissions from These Lands, 1990–2014

The main sources of emissions are the rapid oxidation of exposed peat, resulting in a threefold increase in CO<sub>2</sub> emission rates compared to natural peatlands (Waddington and Warner 2001) and the decay of peat extracted and used off-site. Estimates were developed using a Tier 2 methodology, based on domestic emission factors derived mostly from flux measurements reported by multiple research studies. They include emissions and removals during all six phases as well as carbon losses from peat transported off-site. 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 carbon emissions and removals for peat extraction. The most important sources of uncertainty are discussed below.

All flux measurements used to derive emission factors were conducted in eastern Canada, adding uncertainties to estimates for western Canada.

Spatially referenced information on the areas of peatlands managed for peat extraction is currently not available; these areas are therefore modelled using information provided by the industry.<sup>7</sup> Reliance on this data source introduces uncertainty into the activity data. In addition, the fate of abandoned peatlands is not monitored in Canada; there is no information on older peat fields

that could have been converted to other uses. Therefore, the area estimate of abandoned peatlands is probably overestimated.

### 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. Areas were derived in collaboration with the Canadian Sphagnum Peat Moss Association.

### 6.7.1.5. Recalculations

There are no recalculations for this category.

### 6.7.1.6. Planned Improvements

Efforts are underway to assess additional methodological guidance applicable to peat extraction in the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2014).

## 6.7.2. Flooded Lands (CRF Categories 4.D.1.2 and 4.D.2.2)

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

<sup>7</sup> Gerry Hood, Canadian Sphagnum Peat Moss Association, personal communication to D. Blain, Environment Canada, 2006.

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 in reporting zones 4, 5, 7, 8, 10 and 14. The total land area flooded for 10 years or less declined from 900 kha in 1990 to 90 kha in 2014. In 2014, 52% of the 90 kha of reservoirs flooded for 10 years or less were previously forested (mostly unmanaged forests).

Total emissions from reservoirs declined from 4.3 Mt in 1990 to 1.2 Mt in 2014.

### 6.7.2.1. 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 clearing and 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-CF53 (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 (Touloustuc, 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions are calculated for hydroelectric reservoirs where flooding had been completed between 1981 and 2014.

For each reservoir, the proportion of pre-flooding area that was forest is used to apportion the resulting emissions to the sub-categories 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.

### 6.7.2.2. 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.

### 6.7.2.3. 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.

#### 6.7.2.4. Recalculations

Although activity data for flooded lands have not changed, there have been changes in the Forest Land category that altered the pool of forest stands available for subsequent simulation of disturbances, such as forest conversion to flooded lands, in the CBM-CFS3. These indirect modelling effects led to small recalculations across the time series, ranging from -75 kt (5%) in 2004 to +24 kt (1%) in 2005.

#### 6.7.2.5. Planned Improvements

Further refining estimates of CO<sub>2</sub> 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 (oil and gas, mining).

In Settlements remaining Settlements, urban trees contribute to the national GHG budget. Estimates for 2014 indicate removals of on average 2.5 Mt.

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 2014, 494 kha of Lands converted to Settlements accounted for emissions of 6 Mt. Forest Land converted to Settlements accounts for 98% of these emissions.

#### 6.8.1. Settlements Remaining Settlements (CRF Category 4.E.1)

##### 6.8.1.1. Source Category Description

This category includes estimates of carbon sequestration by urban trees in Canada. Estimates of CO<sub>2</sub> removals from tree growth on other Settlement subcategories outside of urban areas

are not included. Total removals from urban trees were relatively stable throughout the time series at 2.5 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 66% of total removals.

#### 6.8.1.2. Methodological Issues

The CO<sub>2</sub> 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 estimated 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<sub>2</sub> sequestration of urban trees is 30% for 1990 and 27% for 2012. Annex 3.5 provides more information.

The same methodology and coefficients are used for the entire time series of emission estimates (1990–2014).

#### 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 was no change in data or in the method for emission and removal estimates for this category since last year.

#### 6.8.1.6. Planned Improvements

Continued work will focus on improving 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)

#### 6.8.2.1. Source Category Description

In 2014, 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 2000. On average, during the 1990–2014 period, 24 kha of Forest Land were converted annually to Settlements, predominantly in the Boreal Plains, Boreal Shield East, Montane Cordillera and Atlantic Maritime reporting zones. Forest land conversion accounts for 98% 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 in the Canadian north, primarily the Arctic and Sub-Arctic regions and reporting zones 4, 8, 10 and 13. In 2014, the conversion of non forest land to Settlements in the Canadian north accounted for emissions of 152 kt. The major source of emissions in this category is associated with conversion of Grassland to Settlements in reporting zone 13, the Taiga Plains.

#### 6.8.2.2. Methodological Issues (Non-forest Land Converted to Settlements)

Resource development in Canada's vast northern ecumene is the dominant driver of land-use change. An accurate estimation of this direct human impact in northern Canada requires that activities be geographically located and the preconversion vegetation 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, 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 preconversion 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.

#### 6.8.2.3. Uncertainties and Time-Series Consistency

For Forest Land converted to Settlements, refer to the corresponding subheading in Section 6.9, Forest Conversion.

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 preconversion standing biomass varies between 33% and 53%. Annex 3.5 provides more information.

#### 6.8.2.4. 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 Settlements, refer to the corresponding subheading in Section 6.9, Forest Conversion.

#### 6.8.2.5. Planned Improvement

Future efforts to improve estimates for this category will focus on improving estimates of above-ground biomass for preconversion condition for land-use change events in the Arctic and Sub-Arctic regions, by updating estimates of activity data for land-use change in these regions for the post 2000 time period.

In addition, planned improvements described under Section 6.9, Forest Conversion, will also affect this category (see Section 6.9.5, Planned Improvements).

## 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.

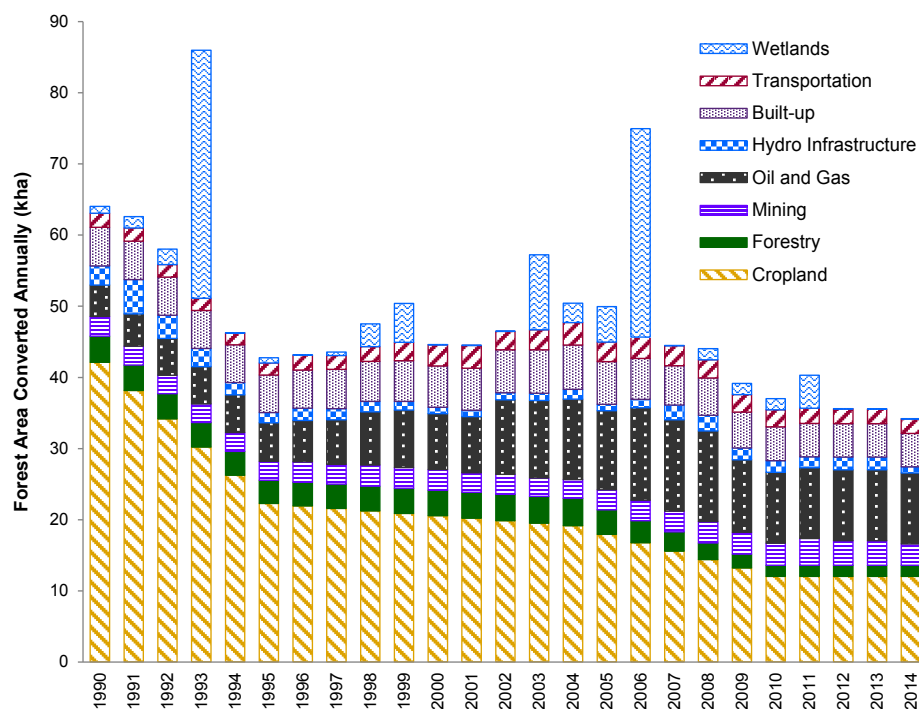
In 2014, Forest Land conversion to Cropland, Wetlands and Settlements amounted to total emissions of 12 Mt, down from 19 Mt in 1990. This decline includes a 5.0-Mt decrease in immediate and residual emissions from Forest Land conversion to Cropland and a 1.7-Mt decrease in emissions from Forest Land conversion to Wetlands (reservoirs). There was also a small decrease of 0.6 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) 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 34 kha in 2014) 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 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 2014, immediate emissions (2.5 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), 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 6–5).

Figure 6–5 Annual Forest Conversion Areas per End Land-Use





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 29 kha in 2006 and 2007, dropping to 22 kha in 2014 (Figure 6–5), based on preliminary results of the new mapping period. Since 2000, the Settlements category has become the main driver of forest conversion, accounting for more than 50% of the total area converted annually, except for the years 2003 and 2006 when forest was cleared for important hydro development projects (Figure 6–5). This trend is reflective of resource development, especially in the Boreal Plains region, which reached 12.6 kha in 2008. Forest conversion for resource development in this region has decreased since, but still contributes to 30% of the total forest area lost in 2014.

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 6–5). 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 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 activities causing forest losses are diverse; they result in heterogeneous spatial and temporal patterns of forest conversion, which have been systematically documented in recent decades. The challenge has been to develop an approach that integrates a large variety of information sources to capture the various forest conversion patterns across the Canadian landscape, while maintaining a consistent approach in order to minimize omissions and overlap.

The approach adopted for estimating forest areas converted to other uses is based on three main information sources: systematic or representative sampling of remote sensing imagery, records, and expert judgement. 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 for 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 6.3.1.1), 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  $\pm 30\%$  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 2014 between 24 kha and 44 kha. Care should be taken not to apply the 30% range to the cumulative area reported in the CRF tables for forest land converted to another land category over the last 20 years (10 years for reservoirs). Annex 3.5 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

Recalculations were mainly due to the use of updated activity data for 2005 to 2013. In the previous submission, forest conversion rates from 2004 onwards were based on average rates estimated from remote sensing mapping for the 2000–2008 period. In this submission, a new mapping period for 2008–2013 was incorporated into the procedure used to estimate forest conversion rates, which added a fourth anchor point in 2010. The new mapping period contains preliminary estimates of forest conversion based on remote sensing mapping. This addition resulted in less use of extrapolated information after 2005



compared to previous submissions. A constant forest conversion rate is assumed for the post-2010 period for agricultural expansion (Cropland) and oil and gas, and forestry roads (Settlements). For other drivers of forest conversion, expert judgement and full mapping of large events was applied for the post-2010 period (see Annex 3.5 for details).

The use of new remote sensing mapping improves forest conversion estimates in the later part of the time series, indicating that overall forest conversion rates have further decreased in recent years compared to previous estimates. From 2005 to 2013 there was a downward recalculation of forest conversion areas nationally by almost 68 kha.

The largest recalculations have occurred in the area of forest land annually converted to Cropland, with a total reduction of 45 kha over the period 2005–2013. Similarly, the annual rates of forest conversion to Settlements have decreased, with a cumulative reduction of 23 kha. Recalculations in land converted to Settlements were largely driven by lower rates of conversion than previously estimated for forestry roads, municipal and oil and gas sub-categories. Conversely, there was an upward recalculation in forest areas converted for hydroelectric infrastructure, mining and industry developments.

Recalculations were higher for the Boreal Plains and Boreal Shield East reporting zones, where forest conversion rates in 2013 decreased. Downward recalculations in the Boreal Plains reporting zone are mainly due to reduced estimates for forest conversion resulting from agricultural expansion, transportation, forestry roads and oil and gas. In the Boreal Shield East, downward recalculations are predominantly due to reduced estimates for forestry roads and agricultural expansion.

Preliminary results of the new mapping period led to annual downward recalculations over the revised period ranging from 0.2 Mt (1.6%) in 2005 to 1.3 Mt (9.8%) in 2013. For 2013, there was a 0.8-Mt reduction in emissions from Forest Land conversion to Cropland and a 0.5 Mt reduction from Forest Land conversion to Settlements. Recalculations in emissions for the years pre-2005 are below 3% and are inherent to the random selection of forest stands in the CBM-CFS3 model (see Annex 3.5 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. In addition, the preliminary results of the new mapping period 2008–2013 will be revised by applying increased mapping samples across Canada, which will result in minor variations in the current forest conversion estimates.

# Chapter 7

## Waste (CRF Sector 5)

### 7.1. Overview

This sector includes emissions from the treatment and disposal of wastes. Sources include solid waste disposal (landfills), biological treatment of solid waste, incineration and open burning of waste, and wastewater treatment and discharge. The scope includes CH<sub>4</sub> emissions from solid waste disposal, CH<sub>4</sub> and N<sub>2</sub>O emissions from biological treatment of solid waste and wastewater treatment, and CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions from incineration and open burning of waste.

Much of the waste treated or disposed of is derived from biomass. CO<sub>2</sub> emissions attributable to such wastes are not included in inventory totals, but are reported in the inventory as a memo item. CO<sub>2</sub> emissions of biogenic origin are not reported if they are reported elsewhere in the inventory or if the corresponding CO<sub>2</sub> uptake is not reported in the inventory (e.g. annual crops). Therefore, under these circumstances, the emissions are not included in the inventory emission totals, since the absorption of CO<sub>2</sub> by the harvested vegetation is not estimated by the Agriculture Sector and, thus, the inclusion of these emissions in the Waste Sector would result in an imbalance. Also, CO<sub>2</sub> emissions from wood and wood products are not included, because CO<sub>2</sub> removals in the Land Use, Land-use Change and Forestry (LULUCF) Sector are excluded from national totals. In contrast, CH<sub>4</sub> emissions from anaerobic decomposition of wastes are included in inventory totals as part of the Waste Sector.

In 2014, the greenhouse gas (GHG) emissions from the Waste Sector contributed 29 Mt to total national emissions, compared to 26 Mt for 1990—an increase of 9.6%. The emissions from this

sector represented 4.2% and 3.9% of the overall Canadian GHG emissions in 1990 and 2014, 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 26 Mt or 91% of the emissions from this sector in 2014. The chief contributor to the Waste Sector emissions is the CH<sub>4</sub> released from MSW landfills, which for 2014 amounted to 22 Mt (0.87 Mt CH<sub>4</sub>). This net emission value is determined by subtracting the amount of CH<sub>4</sub> captured from the total estimated CH<sub>4</sub> generated within the landfill, then adding the quantity of the captured CH<sub>4</sub> that was not combusted by the flaring operation, where applicable. From our 2014 biennial survey of Canadian landfills, which collected 2012 and 2013 year data, approximately 34% of the CH<sub>4</sub> generated in Canadian MSW landfills was captured and combusted (either for energy recovery or flared). The next Environment Canada biennial landfill gas collection and utilization survey will be held in the spring/summer of 2016 for the data years 2014 and 2015. The survey results for 2013 were therefore assumed to be the same for 2014.

Overall, the increase in the CH<sub>4</sub> generation rate from MSW landfills is directly dependent on the quantity and composition of landfilled waste. These parameters are in turn influenced by population growth, average household disposable income, types and patterns of consumption, and urbanization rates. This upward influence is mitigated by landfill gas capture programs, provincial/municipal waste diversion projects and international exportation of MSW. It is expected that, as larger and more “state-of-the-art” landfills are constructed, where gas collection systems will be required, a greater portion of landfill gas will be captured in the future, resulting in a greater reduction of emissions from this sector. Nationally, in 2010, nearly 33 Mt of non hazardous waste (residential, institutional, commercial, industrial, construction and demolition) were generated. Waste diversion initiatives began in the early 1990s and, based on the national figures for 2012, approximately 25% of the waste generated is diverted from disposal (landfill or incineration) (Statistics Canada 2015b and 2015c) compared to 21% in 2000. Municipal and provincial government initiatives have resulted in the diversion of significant quantities of residential wastes from final disposal. From 2000 to

**Table 7-1 Waste Sector GHG Emission Summary, Selected Years**

GHG Source Category	GHG Emissions (Mt CO <sub>2</sub> eq)							
	1990	2000	2005	2010	2011	2012	2013	2014
Waste Sector	26	29	31	29	29	28	28	29
Solid Waste Disposal	24	26	28	26	26	26	26	26
Biological Treatment of Solid Waste	0.8	1	1	1	1	1	1	1
Wastewater Treatment and Discharge	0.87	0.95	0.98	1.03	1.04	1.04	1.05	1.06
Incineration and Open Burning of Waste	0.74	0.74	0.70	0.66	0.65	0.54	0.55	0.56

Note: Totals may not add up due to rounding.

**Table 7–2 Summary of Recalculation in the Waste Sector for Selected Years (kt CO<sub>2</sub> eq)**

	1990	2000	2005	2010	2011	2012	2013
<b>Waste Sector</b>							
Current (2016) submission	26.0	28.7	30.6	29.0	28.8	28.4	28.4
Previous (2015) submission	23.9	26.4	28.1	26.6	26.4	25.6	25.3
Net change in emissions	+2.1	+2.3	+2.4	+2.3	+2.5	+2.8	+3.1
<b>Solid Waste Disposal</b>							
Current (2016) submission	23.6	26.0	27.8	26.2	26.1	25.8	25.8
Previous (2015) submission	22.3	24.8	26.5	25.0	24.7	23.9	23.7
Net change in emissions	+1.3	+1.2	+1.4	+1.3	+1.4	+1.9	+2.0
<b>Biological Treatment of Solid Waste<sup>2</sup></b>							
Current (2016) submission	0.8	1.1	1.1	1.1	1.0	1.1	1.0
Previous (2015) submission	-	-	-	-	-	-	-
Net change in emissions	+0.8	+1.1	+1.1	+1.1	+1.0	+1.1	+1.0
<b>Incineration and Open Burning of Waste</b>							
Current (2016) submission	0.7	0.7	0.7	0.7	0.7	0.5	0.6
Previous (2015) submission	0.7	0.7	0.7	0.7	0.6	0.7	0.5
Net change in emissions	+0.0	+0.0	+0.0	+0.0	+0.0	-0.2	+0.0
<b>Wastewater Treatment and Discharge</b>							
Current (2016) submission	0.9	1.0	1.0	1.0	1.0	1.0	1.1
Previous (2015) submission	0.9	1.0	1.0	1.0	1.0	1.0	1.1
Net change in emissions	-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. New source category for Canada.

3. Waste Sector source categories with the largest recalculations are Solid Waste Disposal followed by Biological Treatment of Solid Waste.

2010, the percentage of diverted residential waste increased from 19% to 33%, while diversion of non-residential waste decreased from 22% to 19% over this period (Statistics Canada 2003, 2004, 2007a, 2008a, 2010b, 2013a).

Table 7–1 summarizes the Waste Sector and subsector GHG contributions for the following inventory years: 1990, 2000, 2005 and 2010 to 2014.

The introduction of revised and new activity data, the revised 2006 IPCC Guidelines and the new global warming potentials from the Fourth Assessment Report resulted in several changes to the estimations from the 2014 submission. Table 7–2 summarizes the proportional contributions of these recalculations. A more detailed description of the recalculations due to new methods and activity data are provided in the specific recalculation section for each source in this chapter.

## 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:

- 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. In an attempt to isolate the waste disposal amounts placed in unmanaged landfills, Environment Canada commissioned a study (CRA 2011). However after review, it was concluded that using the CRA methodology would only increase the uncertainty estimate for the sector. The notation key “IE” (included elsewhere) provided in the Common Reporting Format tables was therefore used for emissions from unmanaged landfills since the total quantities of waste landfilled in Canada since 1941 are accounted for under managed facilities. Residential; institutional, commercial and industrial (ICI); and construction & 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<sub>4</sub> collection systems, as the CH<sub>4</sub> generation rate is very low due to the minimal organic content in the waste stream. However, for completeness of this emission source and accuracy of emissions from MSW landfills, 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<sub>4</sub> emissions by comparison with MSW landfills.

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. It relates emissions to the cumulative biologically available waste that has been landfilled in previous years and is implemented with a Scholl Canyon model.

The Scholl Canyon model, used to estimate Canada's CH<sub>4</sub> emissions from landfills, has been validated independently through a study conducted by the University of Manitoba (Thompson et al. 2006). This model was modified for the present submission to include a normalization factor which was first presented in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC/OECD/IEA 1997) and corrected in IPCC 2006.

Landfill gas, which is composed mainly of CH<sub>4</sub> and CO<sub>2</sub>, is produced by the anaerobic decomposition of organic wastes. The first phase of this process typically begins after waste has been in a landfill for 10 to 50 days. Although the majority of the CH<sub>4</sub> and CO<sub>2</sub> gases are generated within 20 years of landfilling, emissions can continue for 100 years or more (Levelton 1991).

A 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. 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 CH<sub>4</sub> 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.

## 7.2.2. Methodological Issues

The use of a first-order decay model to estimate CH<sub>4</sub> produced from the decomposition of waste in landfills reflects the fact that waste degrades in landfills over many years. Data pertaining to landfill gas capture were obtained directly from the owners/operators of specific landfills with landfill gas collection systems.

CH<sub>4</sub> emissions are determined by calculating the amount of CH<sub>4</sub> generated from landfill waste decomposition (Equation 7-1) through the Scholl Canyon model, subtracting the CH<sub>4</sub> captured through landfill gas recovery systems, then adding the quantity of uncombusted CH<sub>4</sub> 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. Annex 3.6 provides detailed information on the methodologies used for various categories covered by this subsector.

### 7.2.2.1. CH<sub>4</sub> Generation

Equation 7-1:

$$Q_{T,x} = kAM_x L_o e^{-k(T-x)}$$

where:

Q <sub>T,x</sub>	=	amount of CH <sub>4</sub> generated in the current year (T) by the waste M <sub>x</sub> , kt CH <sub>4</sub> /year
x	=	the year of waste input
M <sub>x</sub>	=	the amount of waste disposed of in year x, Mt
k	=	CH <sub>4</sub> generation rate constant, year <sup>-1</sup>
A	=	normalization factor ((1/e <sup>k</sup> )-1)/k
L <sub>o</sub>	=	CH <sub>4</sub> generation potential, kg CH <sub>4</sub> /t waste
T	=	current year

Equation 7-2:

$$Q_T = \sum Q_{T,x}$$

where:

Q <sub>T</sub>	=	amount of CH <sub>4</sub> generated in the current year (T), kt CH <sub>4</sub> /year
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To calculate the net emissions for each year, the sum of Q<sub>T,x</sub> for every section of waste landfilled in past years was obtained

(Equation 7–2), from which the captured gas was subtracted for each province. A computerized model has been developed to estimate aggregate emissions on a regional basis (by province and territory) in Canada. The national CH<sub>4</sub> emission value is the summation of emissions from all regions. 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, it was decided to assume an oxidation factor of zero.

## Waste Disposed of Each Year or the Mass of Refuse (M<sub>x</sub>)

### MSW Landfills

For the purposes of the inventory, MSW includes residential wastes, institutional, commercial and industrial wastes, and construction and demolition wastes. Two primary sources were used in obtaining waste generation and landfill data for the GHG inventory. The amounts of MSW landfilled in the years 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) that is conducted by Statistics Canada on a biennial basis (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010b, 2013a). CANSIM Table 153-0041 (Statistics Canada 2015c), which presents data from feeder surveys that are used for the compilation of the WMIS, was used for 2012 disposal data, in the absence of the formal publication of the WMIS. For the intervening odd years (1999, 2001, 2003, 2005, 2007, 2009, 2011), the MSW disposal values, including both landfilled and incinerated MSW, were obtained by taking an average of the adjacent even years. The amounts of waste disposed for data years 2013 and 2014 were extrapolated by applying the Microsoft Excel Trend function to data from 2009 to 2012, which were obtained from the WMIS. Incinerated and exported waste quantities were subtracted from the Statistics Canada disposal values in order to obtain the amounts of MSW landfilled for 1998–2014. Exported waste quantities are provided in Annex 3.6. 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 1991–2014 are obtained by trending historical landfill data with the provincial populations for 1971–2014 (Statistics Canada 2006, 2015a). Waste quantities imported into Canada

are accounted for within the WMIS since the facilities report all wastes being disposed of at their facility, 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). The amount of wood waste landfilled in the years 1970 to 1992 was estimated at a national level based on the National Wood Residue Data Base (NRCan 1997). Data for the years 1998 and 2004 were provided by subsequent publications (NRCan 1999, 2005). A linear regression trend analysis was conducted to interpolate the amount of wood residue landfilled in the years 1991–1997, and an exponential extrapolation was used for 1999–2014.

### CH<sub>4</sub> Generation Rate Constant (k)

The CH<sub>4</sub> kinetic rate constant (k) represents the first-order rate at which CH<sub>4</sub> 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 attained and that, therefore, these factors are not limiting. In many parts of Canada, subzero conditions exist for up to seven months of the year, with temperatures dropping below –30°C (Thompson et al. 2006); however, evidence suggests that ambient temperature does not affect landfill decay rates (Maurice and Lagerkvist 2003; Thompson and Tanapat 2005). In addition, seasonal temperature variations in the waste are minimal when compared with atmospheric temperature variations (Maurice and Lagerkvist 2003). At depths exceeding 2 m, the landfill temperature is independent of the ambient temperature. It has been shown in Canadian field experiments that an insignificant amount of variation in landfill CH<sub>4</sub> 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.

### MSW Landfills

The k values used to estimate emissions from MSW landfills were obtained from a study conducted by Environment Canada that employed provincial precipitation data from 1941 to 2007 (Environment Canada 1941–2007). The provincial locations at which the average annual precipitations were calculated were major landfill sites over the 1941–1990 period (Levelton 1991). Since the k values are related to precipitation, and assuming that the moisture content of a landfill is a direct function of the annual precipitation, from these precipitation values, the associated k values were determined using a relationship prepared by the



**Table 7-3 MSW Landfill k Value Estimates for Each Province/Territory**

Time Series	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT & NU	YT
1941–1975	0.075	0.056	0.076	0.06	0.053	0.041	0.020	0.01	0.012	0.082	0.001	0.001
1976–1989	0.080	0.062	0.079	0.063	0.057	0.047	0.017	0.009	0.012	0.082	0.002	0.001
1990–2014	0.078	0.061	0.075	0.059	0.059	0.046	0.019	0.012	0.012	0.083	0.003	0.002

Note: It is assumed that the values estimated for the 1990 to 2014 period remain constant.

Research Triangle Institute (RTI) for the U.S. EPA (RTI 2004). The RTI assigns default decay values of less than 0.02/year, 0.038/year and 0.057/year to areas with an annual precipitation of less than 20 inches/year (< 500 mm), between 20 and 40 inches/year (500 to 1000 [average 750 mm]) and greater than 40 inches/year (> 1000 mm), respectively. The plot of these decay values and precipitation data showed a linear relationship. Using this relationship and Environment Canada's average provincial precipitation data for 1941–2007, average provincial landfill decay rates were calculated for three time periods that match those used to derive the methane generation potentials ( $L_0$ ), i.e., 1941–1975, 1976–1989 and 1990–2007 (Environment Canada 1941–2007). It is assumed that the provincial k values determined for 1990–2007 are also applicable from 2008 to 2014.

To support the applicability of the RTI relationship to the Canadian situation, information on landfilled waste composition in the United States and Canada was examined. The findings suggest that there is no significant difference between the composition of wastes placed in landfills in the United States and that in Canada, including organic wastes (paper and paperboard, food scraps, yard trimmings and wood).

Provincial and territorial k values from 1941 to 2014 are presented in Table 7-3.

## Wood Waste Landfills

Based on the default value for estimating wood products industry landfill  $\text{CH}_4$  emissions recommended by the National Council for Air and Stream Improvement, Inc., a k value of 0.03/year was assumed to represent the  $\text{CH}_4$  generation rate constant k for all of the wood waste landfills in Canada (NCASI 2003).

## $\text{CH}_4$ Generation Potential ( $L_0$ )

### MSW Landfills

$L_0$  is a function of degradable organic carbon (DOC), which in turn is determined from the composition of the waste. The values of theoretical and measured  $L_0$  range from 4.4 to 194 kg  $\text{CH}_4$ /t of waste (Pelt et al. 1998). Over the time series used by the MSW portion of the emission estimation model, i.e., 1941 to 2014, three different  $L_0$ s were used to represent discrete time periods where studies showed significant changes in waste composition

from one period to the next. For consistency with the quantities of MSW used in the Scholl Canyon model, the calculation of the  $L_0$  accounted for the characteristics of the three MSW sources: residential; institutional, commercial and industrial; and construction and demolition. Each of the percentage fractions (A, B, C and D; refer to Equation 7-4) is calculated from the combined quantities of the three aforementioned waste sources for the respective fraction, in the derivation of the aggregated DOC.

The provincial and territorial DOC values were calculated from waste disposal composition values for three distinct time periods: 1941–1975, 1976–1989 and 1990–2014. These time intervals coincide with those employed for the calculation of the  $\text{CH}_4$  generation rate constant k. DOC values were derived from waste composition data for the year 2002 (NRCAN 2006), and assumed to be constant over the period 1990–2014. Since waste diversion programs were not significant prior to 1990, a second set of DOC values was developed to represent the waste composition at disposal from 1976 to 1989 by adding the NRCAN landfill data to the 2004 Statistics Canada recycled waste composition data (Statistics Canada 2007a). A third set of DOC values was developed from a 1967 national study to cover the period from 1941 to 1975 (CRC Press 1973). A summary of the  $L_0$  values for the provinces and territories over the three time periods is given in Table 7-4. The percentages of organic waste diverted in 2002 for all Canadian provinces are also given as a reference for that year. As waste disposal practices in Canada change, and as new information is made available, the  $L_0$  values will be adjusted accordingly.

$L_0$  was determined employing the methodology provided by the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) (Equation 7-3) using the provincial waste composition data as input to the degradable organic carbon (DOC) calculation:



## Equation 7–3:

$$L_0 = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \times \frac{1000 \text{ kg CH}_4}{\text{t CH}_4}$$

where:

$L_0$	=	CH <sub>4</sub> generation potential (kg CH <sub>4</sub> /t waste)
MCF	=	CH <sub>4</sub> methane correction factor (fraction)
DOC	=	degradable organic carbon (t C/t waste)
DOC <sub>F</sub>	=	fraction DOC dissimilated
F	=	fraction of CH <sub>4</sub> in landfill gas
16/12	=	stoichiometric factor

The methane correction factor (MCF) for managed landfill sites has a value of 1.0 (IPCC/OECD/IEA 1997). The fraction (F) of CH<sub>4</sub> emitted from a landfill ranges from 0.4 to 0.6 and was assumed to be 0.5. A DOC<sub>F</sub> value of 0.6 was selected from a default range of 0.5 to 0.6 in IPCC (2000). This DOC<sub>F</sub> value best reflects the lower concentration of lignin in the MSW waste, since the majority of wood wastes from pulp and paper industries and saw mills are disposed of in dedicated wood waste landfills.

The DOC calculation is derived from the biodegradable portion of the MSW based on Equation 3-7 of Volume 5 of the IPCC Guidelines (IPCC 2006) where the default DOC content in percent of wet waste was obtained from Table 2.4 (IPCC 2006).

## Equation 7–4:

$$DOC = (0.4 \times A) + (0.2 \times B) + (0.15 \times C) + (0.43 \times D)$$

where:

A	=	fraction of MSW that is paper and textiles
B	=	fraction of MSW that is garden or park waste
C	=	fraction of MSW that is food waste
D	=	fraction of MSW that is wood or straw

## Wood Waste Landfills

Equation 7–3 generated an  $L_0$  value of 115 kg CH<sub>4</sub>/t of wood waste, which was used to estimate emissions from wood waste landfills by the Scholl Canyon model. IPCC defaults were used for MCF in unmanaged deep landfills (MCF = 0.8); the fraction of CH<sub>4</sub> in the landfill gas (F = 0.5); and the fraction of DOC dissimilated (DOC<sub>F</sub> = 0.5), where the lower end of the default range for wastes containing lignin was selected (IPCC/OECD/IEA 1997). A composition of 100% wood waste was assumed in calculating the fraction of DOC in Equation 7–4.

## 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 burning the gas for energy recovery. Gas capture does not occur at wood waste landfills. Combustion of the landfill gas converts CH<sub>4</sub> in the landfill gas to CO<sub>2</sub>, thus reducing the CH<sub>4</sub> emissions. To calculate the net CH<sub>4</sub> emissions from landfills, the amount of CH<sub>4</sub> captured, as provided by the landfill facilities, is subtracted from the quantity of CH<sub>4</sub> generated, as estimated by the Scholl Canyon model. Added to this value, to account for the combustion inefficiency of the flares, is the quantity of captured CH<sub>4</sub> that passes through

Table 7–4 CH<sub>4</sub> Generation Potential ( $L_0$ ) from 1941 to Present

Province/Territory	2002 Organic Waste Diversion (%)	1941 to 1975		1976 to 1989		1990 to Present	
		DOC	$L_0$ (kg CH <sub>4</sub> /t waste)	DOC	$L_0$ (kg CH <sub>4</sub> /t waste)	DOC	$L_0$ (kg CH <sub>4</sub> /t Waste)
Newfoundland and Labrador	NA	0.31	122.50	0.19	75.07	0.19	74.94
Prince Edward Island	NA	0.28	112.86	0.17	67.37	0.16	63.77
Nova Scotia	29.70	0.27	107.30	0.16	63.28	0.16	63.84
New Brunswick	19.80	0.25	99.35	0.17	67.29	0.16	64.11
Quebec	13.70	0.39	154.54	0.21	82.91	0.20	81.62
Ontario	16.40	0.37	149.72	0.21	83.48	0.21	83.51
Manitoba	4.90	0.35	139.26	0.19	77.74	0.19	77.65
Saskatchewan	4.30	0.38	151.65	0.22	86.32	0.22	86.55
Alberta	16.70	0.29	114.23	0.19	74.63	0.19	74.18
British Columbia	23.30	0.28	112.39	0.18	71.74	0.17	66.91
Territories (YT, NT and NU)	NA	0.23	93.26	0.15	60.11	0.17	66.14

Sources: All values are derived from data obtained from NRCan (2006), Statistics Canada (2007a) and CRC Press (1973), with the exception of the 2002 organic waste diversion figures, which were obtained from Thompson et al. (2006).

N/A = Unavailable categorical information.

the flare uncombusted. The captured gas is wholly or partially flared or combusted for electricity or heat generation. GHG emissions affiliated with the use of landfill gas for energy recovery are accounted for in the Energy Sector.

Flaring combustion efficiency for CH<sub>4</sub> in landfill gas of 99.7% was used to determine the quantity of CH<sub>4</sub> that circumvented the flare. This value was obtained from Table 2.4-3 of Chapter 2.4 of the U.S. EPA AP 42 (U.S. EPA 1995). The quantities of landfill gas collected from 1983 to 1990, 1995, and 1997 were obtained from a unit within Environment Canada.<sup>1</sup> This document, sent by Environment Canada's National Office of Pollution Prevention (NOPP), summarizes the provincial information on landfill gas collection, as obtained from the Levelton report (Levelton 1991) for the data years 1983 to 1990 and from their two internal surveys for the years 1995 and 1997. Data from 1991 to 1996 were interpolated from the 1990, 1995 and 1997 data sets (Environment Canada 2003d). Data for the 1997 to 2003 period were collected directly from individual landfill operators biennially by Environment Canada's NOPP (Environment Canada 1997, 1999b, 2001, 2003a). As of 2006, beginning with the 2005 data year, this survey is now being conducted by Environment Canada's Pollutant Inventories and Reporting Division (Environment Canada 2007, 2009, 2011a, 2013a, 2014a). Landfill gas capture data are collected every odd year; for the purposes of the national GHG inventory, the landfill gas capture data for the subsequent even years are averaged from adjacent odd years starting from 1997. However, since the 2008 survey, the Division has been collecting two years of data biennially, i.e., 2006–2007, 2008–2009, 2010–2011 and 2012–2013 data from the 2008, 2010, 2012 and 2014 facility surveys, respectively (Environment Canada 2009, 2011a, 2013, 2014a). As 2014 data were unavailable, they were assumed to be identical to those of 2013. The 2014 and 2015 data will be collected during the biennial survey conducted in 2016.

### 7.2.3. Uncertainties and Time-Series Consistency

The following discussion on uncertainty for the categories within this sector is based on the results as reported in an uncertainty quantification study of the NIR by ICF Consulting (2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (Environment Canada 2003b). However, modifications have been made to the methodology, emission factors and sources of information as a consequence of the findings of this uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. It is expected that the improvements made will result in a reduction of the uncertainty for this subsector.

<sup>1</sup> ME Perkin. 1998. Personal communication (email from M.E. Perkin to Frank Neitzert of the Greenhouse Gas Division dated July 15, 1998). National Office of Pollution Prevention, Environment Canada.

The CH<sub>4</sub> emissions from this key category include CH<sub>4</sub> emissions from MSW landfills and wood waste landfills. The level of uncertainty associated with the CH<sub>4</sub> emissions from the combined subsectors was estimated to be in the range of –35% to +40%, which closely resembles the uncertainty range of –40% to +35% estimated in this study for the CH<sub>4</sub> emissions from MSW landfills. The level uncertainty range provided by the ICF Consulting study (2004) is only slightly larger than the  $\pm 30\%$  span estimated with a 90% confidence level by a previous study, which used a Tier 1 approach based on 1990 data (McCann 1994). However, it should be noted that the uncertainty range of the ICF Consulting study (2004) is quoted for a 95% confidence interval, which would typically be larger than the range quoted for a 90% confidence interval.

The MSW landfills contributed to over 90% of the total CH<sub>4</sub> emissions from this key category in 2001 (Environment Canada 2003b). The uncertainty estimates for CH<sub>4</sub> emissions from MSW landfills seem to have been largely influenced by the uncertainty in the inventory values for L<sub>0</sub> for 1941–1989 and 1990–2001 and the CH<sub>4</sub> generation rate constant k, where the uncertainty for both k and L<sub>0</sub> were based on an estimate from one expert elicitation.

Although the uncertainty range estimated in this study 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. less than 10%) (Environment Canada 2003b). The uncertainty estimate for wood waste landfills seems to have been largely influenced by the CH<sub>4</sub> generation rate, carbon content of the waste landfilled, and biodegradable fraction of the waste, where the uncertainties were assumed by ICF Consulting (2004) based on the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) and/or the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), where available.

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. These included insertion of revised data obtained from the latest landfill gas capture survey and correction of a formula link for L<sub>0</sub> in the wood waste portion of the Waste Sector 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 1990–2013 time series to account for:

- revisions of the MSW landfill gas collection and utilization survey data (2010–2013);
- inclusion of the 2012 and revised 2010 MSW disposed data from Statistics Canada's Waste Management Industry Survey;
- corrections made to the year 1990 for MSW landfilled amounts in Ontario, Quebec, British Columbia and Nova Scotia due to a combination of incineration and exported amounts in error;
- Prince Edward Island MSW landfilled amounts adjusted to account for waste incinerated in that province (1990–2013);
- an adjustment of the MSW landfilled quantities due to a linkage correction in the model that now accounts for missing exported quantities from Quebec, Ontario and British Columbia over the 1990–1997 time series;
- an adjustment for MSW disposed for Prince Edward Island, Yukon, Northwest Territories and Nunavut affecting the years 1993–1998 due to a refinement in the interpolation method
- MSW incineration data from the Levelton report (1991) were subtracted from the disposed data to give the landfilled amounts for the years 1941 to 1990; previously, the Levelton disposed quantities were set equal to the landfilled amounts.
- an adjustment of the MSW disposed amounts interpolated from 1991 to 1997 due to a refinement of the curve fitting approach;
- a correction in the formula link for the wood waste L<sub>0</sub>, such that L<sub>0</sub> is derived using the IPCC 2006 default carbon content value for wood; and
- minor revisions of the provincial population values from 2012 to 2013 by Statistics Canada in its publication *Annual Demographic Estimates: Canada, Provinces and Territories*.

These combined changes resulted in emission increases in this subsector of 2.5% to 8.6% over the complete time series relative to the last submission.

### 7.2.6. Planned Improvements

A multi-year study is underway to provide a current review of recent MSW waste composition values for all provinces and territories for urban and rural areas. The purpose of the study is to update the percentage of specific waste types within MSW landfills provincially with a comparison between urban and rural areas to update bulk waste DOC values for recent years. The new composition data will be used for CH<sub>4</sub> estimations in NIR 2017. Also, and along with implementation of the IPCC 2006 equations for CH<sub>4</sub> estimation, in its next NIR, Canada will examine applicability of the IPCC default oxidation factor to its landfills (active, closed and abandoned).

The next in-house biennial landfill gas capture and utilization and waste export surveys are planned for the spring/summer of 2016.

## 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 61%, 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<sub>2</sub> emissions from biological treatment of solid waste are not included in inventory totals.

### 7.3.2. Methodological Issues

Greenhouse gas emissions from composting have been introduced into the NIR for the first time this year. Statistics Canada produces composting data through its *Waste Management Industry Survey: Business and Government Sectors* (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010b, 2013a, 2015b) 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 identified as involved in waste management and remediation services. Although there are data on the percentages of households participating in centralized and backyard composting, the quantity of organic waste used for backyard composting is currently unknown.

In addition to the lack of data on backyard composting quantities, in the development of the emission estimates for centralized composting, it was found that some large private-sector industrial level composting facilities may not have been identified as waste processing facilities and remediation services (may use composting feedstock other than MSW) and were thus excluded from the Statistics Canada data.

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.

### 7.3.2.1. CH<sub>4</sub> Generation

Emissions of CH<sub>4</sub> 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<sub>4</sub> wet waste basis emission factor of 4 g CH<sub>4</sub>/kg waste was used as per IPCC 2006 Volume 5, Chapter 4, Table 4.1. It was assumed that no CH<sub>4</sub> recovery was performed.

### 7.3.2.2. N<sub>2</sub>O Generation

Emissions of N<sub>2</sub>O 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<sub>4</sub> wet waste basis emission factor of 0.3 g N<sub>2</sub>O/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<sub>4</sub> and N<sub>2</sub>O 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

No recalculations have been performed on this category. Composting is, however, being introduced to Canada's inventory this year for the first time.

### 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, depending on factors such as 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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O.

As per the 2006 IPCC Guidelines, CO<sub>2</sub> emissions from biomass waste combustion are not included in the inventory totals. The only CO<sub>2</sub> emissions detailed in this section are from fossil fuel-based carbon waste, such as plastics and rubber.

According to the findings of a recent report commissioned by Environment Canada (CRA 2011), CH<sub>4</sub> emissions from Canadian MSW incinerators are negligible.

#### 7.4.1.2. Hazardous Waste Incineration

There are four hazardous waste incinerators in Canada located in Ontario and Alberta. CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> are the greenhouse gases emitted from this source. The emissions 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 2014b).

#### 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<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, as in the case of MSW incinerators. However, since the carbon present in the wastewater sewage sludge is of biological origin, the CO<sub>2</sub> 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 2014. 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<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> are the greenhouse gases emitted from this source.

As per the 2006 IPCC Guidelines, CO<sub>2</sub> emissions from biomass waste combustion are not included in the inventory totals. The only CO<sub>2</sub> emissions detailed in this section are from fossil fuel-based carbon waste, such as 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<sub>2</sub> Emissions

##### MSW Incineration

A Tier 1 method that uses Equation 5.2 (IPCC 2006) is employed to calculate CO<sub>2</sub> 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 2003c).
- *Developing emission factors:* Provincial CO<sub>2</sub> emission factors are founded on the assumption that the carbon contained in waste undergoes complete oxidation to CO<sub>2</sub>. 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<sub>2</sub> per tonne of waste by multiplying by the ratio of the molecular mass of CO<sub>2</sub> to that of carbon.

- *Calculating CO<sub>2</sub> emissions:* Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factor.

##### Hazardous Waste Incineration

CO<sub>2</sub> emissions were estimated from the quantities of hazardous wastes combusted over the 1990–2014 time series. The emission estimation method used the IPCC default values for carbon content of waste and fossil carbon as a percentage of total carbon of 50% and 90%, respectively, for hazardous waste (Table 5.6, IPCC 2000).

##### Sewage Sludge Incineration

CO<sub>2</sub> 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<sub>2</sub> emissions were estimated from the quantities of clinical waste combusted over the 1990–2014 time series. The emission estimation method uses the IPCC default carbon content and fossil carbon percent of total carbon of 60% and 40%, respectively, for clinical waste (IPCC 2006 Volume 5 Chapter 5 Table 5.2).

#### 7.4.2.2. N<sub>2</sub>O and CH<sub>4</sub> Emissions

##### MSW Incineration

Emissions of N<sub>2</sub>O 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. According to the findings of a recent report commissioned by Environment Canada (CRA 2011), CH<sub>4</sub> emissions from Canadian MSW incinerators are negligible.

##### Hazardous Waste Incineration

N<sub>2</sub>O and CH<sub>4</sub> 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<sub>2</sub>O and CH<sub>4</sub> emissions for 2009 (Environment Canada 2011b). The resulting emission factors were  $3.16 \times 10^{-3}$  kt N<sub>2</sub>O/kt waste and  $1.69 \times 10^{-4}$  kt CH<sub>4</sub>/kt of waste.

## Sewage Sludge Incineration

Emissions generated by the incineration of sewage sludge are dependent on the amount of dried solids incinerated. To calculate CH<sub>4</sub> emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor for each province. 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 1999a). Activity data for 1999, 2000 and 2001 were taken from another study conducted for Environment Canada (Environment Canada 2003c). To estimate the amount of sewage sludge incinerated in the years 2002–2014, a regression analysis was completed using the incineration values in the most recent study report.

CH<sub>4</sub> 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<sub>4</sub>/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<sub>2</sub>O from sewage sludge incineration were estimated using the IPCC default emission factor for fluidized beds, 0.8 kg N<sub>2</sub>O/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<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> 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<sub>2</sub>O emission factors from IPCC 2006, Volume 5, Chapter 5, Table 5.6, for stoker-type continuous and batch-type incineration of 50 g N<sub>2</sub>O/t waste and 60 g N<sub>2</sub>O/t waste were applied.

## 7.4.3. Uncertainties and Time-Series Consistency

The following discussion on uncertainty for the categories within this subsector is based on the results as reported in an uncertainty quantification study of the Canadian NIR (ICF Consulting 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (Environment Canada 2003b). However, modifications have been made to the methodology, emission factors and sources of information as a result of the findings of this uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. It is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the waste incineration source category was estimated to be in the range of –12% to +65%. For 2001 inventory estimates, the overall trend uncertainty associated with the total GHG emissions (comprising CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) 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 2014 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.

The ICF Consulting 2004 study did not include hazardous waste incineration, clinical waste incineration or N<sub>2</sub>O emissions from sewage sludge incineration. They have therefore been calculated separately using the propagation of error approach. The overall level uncertainty associated with clinical waste incineration is 30% for CO<sub>2</sub> emissions and 107% for CH<sub>4</sub> and N<sub>2</sub>O emissions. The overall level uncertainty associated with hazardous waste incineration is 94% for CO<sub>2</sub> emissions and 107% for CH<sub>4</sub> and N<sub>2</sub>O emissions. The overall level uncertainty associated with N<sub>2</sub>O 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 (data obtained from the latest waste incineration survey pertaining to hazardous



wastes), 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

Minor recalculations were conducted for MSW incineration to account for revised Statistics Canada population data for 2012 and 2013 (Statistics Canada 2015a). Other recalculations were due to:

- a correction in the model formula for Quebec hazardous waste incineration in 2011;
- refinement of the MSW incineration quantities polynomial curve fit for 1991 and from 1993 to 1997 for all provinces with the exception of Prince Edward Island and the three territories;
- a correction for Quebec incineration quantities for 1990 to be consistent with the Levelton report data; and
- Prince Edward Island and Nova Scotia 2002 to 2013 MSW incineration data are now trended using 1999 to 2001 data years rather than 1998 to 2001 data years in order to be consistent with the methodology used for other provinces.

The overall result of these changes ranged from a decrease of 24% to an increase of 1.6% in emissions from this subsector relative to the last submission.

### 7.4.6. Planned Improvements

Emissions from waste incinerators where energy is recovered will be allocated to the Energy Sector.

The next biennial incineration survey is planned for the spring/summer of 2016. Facility-level incineration surveys had been conducted in 2008, 2010, 2012 and 2014. Canada is planning to use the updated methodology and emission factors for estimating N<sub>2</sub>O emissions from this category (see Table 5.4 in Volume 5, Section 5.4.3).

## 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<sub>4</sub>, which is typically contained and combusted via anaerobic digestion systems. CH<sub>4</sub> emissions from aerobic

systems are assumed to be negligible. Both types of treatment system generate N<sub>2</sub>O through the nitrification and denitrification of sewage nitrogen.

CO<sub>2</sub> is also a product of aerobic and anaerobic wastewater treatment. However, as detailed in Section 7.1, CO<sub>2</sub> 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<sub>4</sub> from anaerobic wastewater treatment and N<sub>2</sub>O 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<sub>4</sub> Emissions

##### Municipal Wastewater Treatment

A country-specific method developed for Environment Canada (AECOM Canada 2011) was used to calculate an emission factor that best suits the available activity data. Based on the amount of organic matter generated per person in Canada and the conversion of organic matter to CH<sub>4</sub>, it was estimated that 1.97 kg CH<sub>4</sub>/person per year could potentially be emitted from anaerobically treated wastewater. Additional information on the incorporated methodology is provided in Annex 3.6. The maximum methane producing capacity Bo value of 0.36 kg CH<sub>4</sub> per kg BOD<sub>5</sub>, as adopted by Canada, is less than IPCC 2006 Volume 5, Section 6.2.2.2. Table 6.2 default value of 0.6 kg CH<sub>4</sub>/kg BOD. The IPCC default Bo was not used by Canada since it was found to be in error. As discussed in the AECOM report, the IPCC guidelines default Bo value of 0.6 kg CH<sub>4</sub>/g BOD was derived erroneously from the ratio of 2.5 COD<sub>total</sub>/BOD<sub>5</sub>. Although the ratio is correct, the Bo is the mass of methane produced per mass of COD degraded. Therefore, Bo should be multiplied by the COD<sub>b</sub> (the COD that can be biologically degraded)/BOD<sub>5</sub> ratio and not the COD<sub>total</sub>/BOD<sub>5</sub> ratio. AECOM points out that the typical range for BOD<sub>5</sub> is between 70% to 80% of the BOD<sub>u</sub> (i.e. BOD ultimate), where the generally accepted standard in the industry is 68% of the BOD<sub>u</sub>. Using this value, AECOM gives the typical ratio of BOD<sub>u</sub>/BOD<sub>5</sub> (or COD<sub>b</sub>/BOD<sub>5</sub>) as 1.47:1. Thus, the Bo should be 0.25 g CH<sub>4</sub>/g COD<sub>b</sub> × 1.47 g COD<sub>b</sub>/g BOD<sub>5</sub> = 0.36 kg CH<sub>4</sub>/kg BOD<sub>5</sub> degraded. Therefore, the 2000 and 2006 IPCC guidelines made two errors in the derivation of Bo. First, they did not distinguish between degradable and total COD and second, they converted Bo from a per COD<sub>b</sub> to a per BOD<sub>5</sub> using the COD<sub>total</sub>/BOD<sub>5</sub> ratio.

CH<sub>4</sub> emissions were calculated by multiplying the emission factor by the population of the respective province (Statistics Canada

2006, 2015a) and by the fraction of wastewater that is treated anaerobically.

## Industrial Wastewater Treatment

Environment Canada conducts facility level surveys on a biennial bases to obtain methane emissions from industrial facilities that treat their effluent anaerobically on-site. The last survey covered the 1990–2013 time series. Data for the 2014 and 2015 years will be collected in 2016. In lieu of 2014 survey data, it was assumed that the 2013 data remained constant into the following year. 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<sub>2</sub>O Emissions

## Municipal Wastewater Treatment

An N<sub>2</sub>O emission factor is calculated as the product of the annual per capita protein consumption, the assumed protein nitrogen content (16%), the quantity of N<sub>2</sub>O-N produced per unit of sewage nitrogen (0.01 kg N<sub>2</sub>O-N/kg sewage nitrogen) and the N<sub>2</sub>O/N<sub>2</sub>O-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, 2010a). The protein consumption values used are those adjusted to account for retail, household, cooking and plate loss, as recommended by AECOM Canada (2012). Data are provided for the years 1991, 1996 and 2001 to 2009. Protein consumption data for missing years are estimated by applying a linear regression application to the Statistics Canada data. Protein consumption values for 2010–2014 were extrapolated using a growth function in the absence of current data due to the discontinuation by Statistics Canada of the Food Statistics publication. Emissions were calculated by multiplying the emission factor by the population of each province (Statistics Canada 2006, 2015a). A summary of the values for these two parameters over the time series is given in Table 7–5.

### 7.5.3. Uncertainties and Time-Series Consistency

## Municipal Wastewater Treatment

The following discussion on uncertainty for the categories within this sector is based on the results as reported in an uncertainty quantification study of the NIR (ICF Consulting 2004). This Tier 2 evaluation of uncertainty employed values from the 2001 inventory year (Environment Canada 2003b). However, modifications have been made to the methodology, emission factors and sources of information as a consequence of the findings of this

**Table 7–5 N<sub>2</sub>O Emission Factors**

Year	Annual Per Capita Protein Consumption (kg protein/person per year)	N <sub>2</sub> O Emission Factor (kg N <sub>2</sub> O/ 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
1995a	25.01	0.063
1996a	25.04	0.063
1997a	25.50	0.064
1998a	25.75	0.065
1999a	26.01	0.065
2000a	26.26	0.066
2001b	26.63	0.067
2002b	26.57	0.067
2003b	26.19	0.066
2004b	26.35	0.066
2005c	25.96	0.065
2006c	25.93	0.065
2007c	26.20	0.066
2008c	25.64	0.064
2009c	25.50	0.064
2010c	25.47	0.064
2011c	25.34	0.064
2012c	25.22	0.063
2013c	25.09	0.063
2014c	24.97	0.063

Sources: <sup>a</sup>Statistics Canada (2007b), <sup>b</sup>Statistics Canada (2008b) and <sup>c</sup>Statistics Canada (2010a). The data have been adjusted to account for retail, household, cooking and plate loss.

uncertainty study. Therefore, the results of this study may not be an accurate representation of the current uncertainty around the emissions from this subsector and the model inputs. It is expected that the improvements made would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the wastewater treatment and discharge subsector was estimated to be in the range of -40% to +55%. Based on 2001 data, the trend uncertainty associated with the total GHG emissions (comprising CH<sub>4</sub> and N<sub>2</sub>O) 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 2014 inventory should be made with caution, as trend uncertainty is more sensitive than level uncertainty to the changes in the inventory estimate values for the more recent years.

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

Minor recalculations were conducted for wastewater treatment and discharge to account for revised Statistics Canada population data for 2012 and 2013 (Statistics Canada 2015a). Municipal wastewater treatment data were revised for the national methane emissions from anaerobic treatment by using a weighted average of the provincial and territorial values based on population rather than a simple average. This affected the complete 1990–2013 time series. The overall result of these changes ranged from a decrease of  $2.1 \times 10^{-3}\%$  to an increase of  $2.5 \times 10^{-3}\%$  in emissions from this subsector from last submission.

#### Planned Improvements

The next biennial industrial wastewater treatment facility survey will be conducted during the summer of 2016.

# 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 to 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 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 activity data and energy statistics provided by Statistics Canada, reallocations of emissions, or minor incremental enhancements. The trend between 1990 and 2013 is now reported as a 19.3% increase in total GHG emissions since 1990 instead of the previously reported 18.5% increase. The trend between 1990 and 2014 shows a 19.5% increase in GHG emissions.

The most significant recalculations occurred in 2012 and 2013 and resulted in revised national totals that were 3.1 Mt (0.44%) and 5.4 Mt (0.74%) higher than what was reported in the 2015 NIR (718 Mt and 731 Mt vs. 715 Mt and 726 Mt) (Table 8–1 and Figure 8–2).

Although emissions and removals from the Land Use, Land-use Change and Forestry (LULUCF) Sector are not included in the calculation of the national total, it is important to note that recalculations also occurred. These recalculations were mainly due to the implementation of an improved representation of residential firewood harvest from the forest ecosystem, modification to parameters that define harvesting selection and sorting criteria for forest stands, and the use of updated activity data for forest conversion since 2005 based on geospatial analysis. The cumulative impact of these recalculations on LULUCF estimates resulted in a small decrease of 0.3 Mt in the calculated sink for 1990, a decrease of 16 Mt in the calculated source in 2005 and an increase of 15 Mt in the calculated sink in 2013.

#### 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 for the Energy subsectors (Stationary Combustion, Transport and Fugitive Sources) for all years in the time series (1990–2013).

Figure 8–1 Comparison of Emission Trends (2015 NIR vs 2016 NIR)

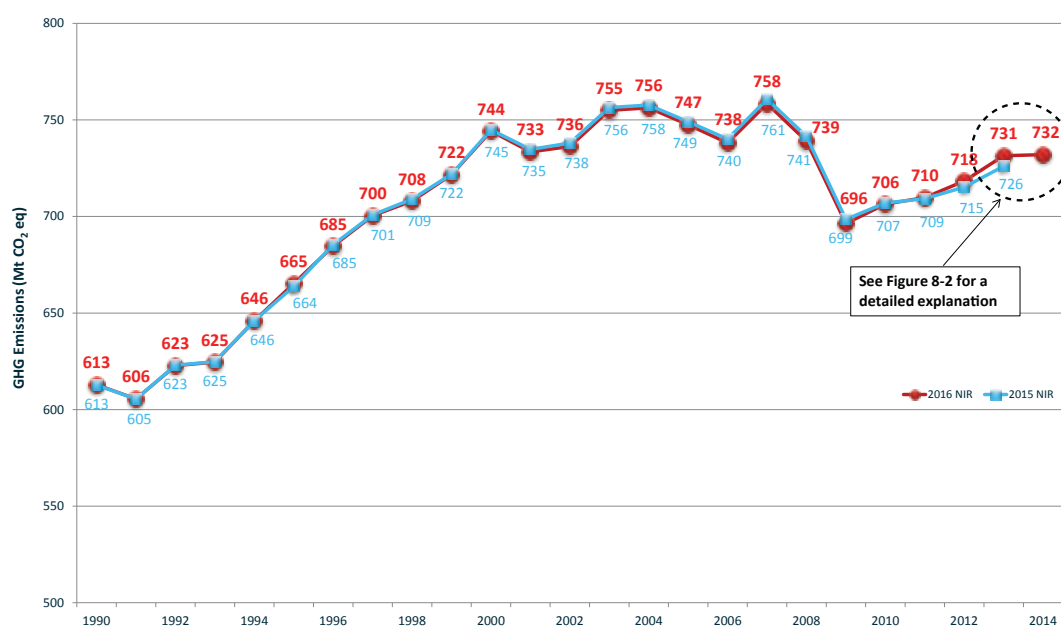


Table 8–1 Summary of Recalculations in the 2016 National Inventory (excluding LULUCF)

NATIONAL TOTAL	Annual Emissions (kt CO <sub>2</sub> eq)								Trend	
	1990	2000	2005	2009	2010	2011	2012	2013	(1990-2013)	(2005-2013)
Previous Submission (2015 NIR)	612	744	749	698	707	709	715	726	18.5%	-3.1%
Current Submission (2016 NIR)	745	876	024	540	031	222	213	051	19.3%	-2.1%
	612	744	747	696	706	709	718	731		
	866	241	458	312	403	764	347	424		
Change in Emissions:	121	- 635	- 1 566	- 2 228	- 628	543	3 134	5 373	-	-
Total Change: %	0.02%	-0.09%	-0.21%	-0.32%	-0.09%	0.08%	0.44%	0.74%	-	-

Figure 8–2 Explanation of Changes from 2013 in Previous Submission to 2014 in Current Submission

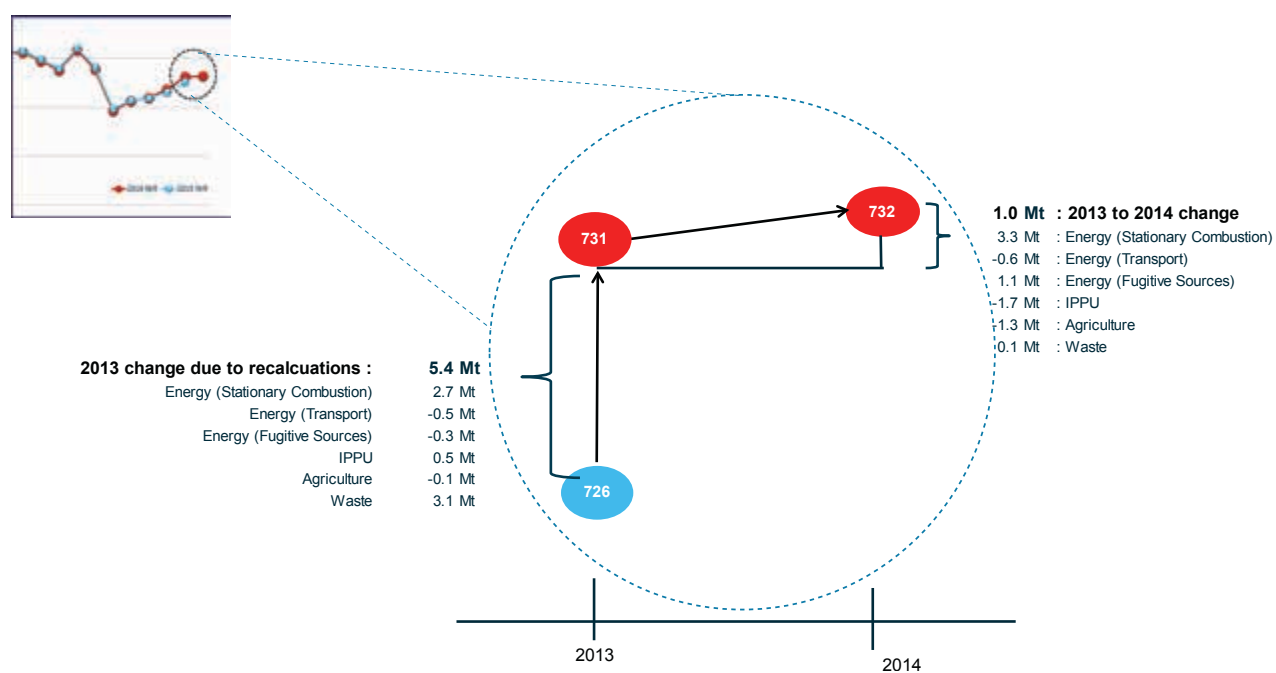


Table 8–2 Summary of Recalculations by Category

	Annual Emissions (kt CO <sub>2</sub> eq)								Trend	
	1990	2000	2005	2009	2010	2011	2012	2013	(1990-2013)	(2005-2013)
<b>ENERGY (Stationary Combustion)</b>										
Previous Submission (2015 NIR)	287 962	354 662	344 178	317 750	318 471	321 042	320 174	325 245	12.9%	19.5%
Current Submission (2016 NIR)	285 360	352 129	341 872	315 632	316 852	319 584	320 844	327 908	14.9%	19.8%
Change in Emissions: kt CO <sub>2</sub> eq	- 2 602	- 2 534	- 2 306	- 2 118	- 1 619	- 1 459	669	2 663	-	-
%	-0.9%	-0.7%	-0.7%	-0.7%	-0.5%	-0.5%	0.2%	0.8%	-	-
<b>ENERGY (Transportation)</b>										
Previous Submission (2015 NIR)	147 871	181 882	195 255	189 971	199 688	199 303	198 991	204 070	38.0%	32.0%
Current Submission (2016 NIR)	147 788	181 487	194 522	189 201	198 895	198 572	198 164	203 602	37.8%	31.6%
Change in Emissions: kt CO <sub>2</sub> eq	- 83	- 395	- 733	- 770	- 793	- 730	- 827	- 468	-	-
%	-0.1%	-0.2%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.2%	-	-
<b>ENERGY (Fugitive)</b>										
Previous Submission (2015 NIR)	48 803	69 851	61 103	55 672	54 610	55 590	57 377	58 700	20.3%	25.2%
Current Submission (2016 NIR)	48 803	69 851	60 848	55 455	54 399	55 385	57 264	58 436	19.7%	24.7%
Change in Emissions: kt CO <sub>2</sub> eq		-	- 255	- 218	- 211	- 205	- 113	- 264	-	-
%	0.0%	0.0%	-0.4%	-0.4%	-0.4%	-0.4%	-0.2%	-0.4%	-	-
<b>IPPU</b>										
Previous Submission (2015 NIR)	55 087	53 447	58 809	49 072	50 730	50 879	55 014	52 198	-5.2%	6.8%
Current Submission (2016 NIR)	55 880	53 524	58 262	48 312	50 482	51 431	55 753	52 676	-5.7%	4.3%
Change in Emissions: kt CO <sub>2</sub> eq	793	77	- 546	- 760	- 248	551	739	477	-	-
%	1.4%	0.1%	-0.9%	-1.5%	-0.5%	1.1%	1.3%	0.9%	-	-
<b>AGRICULTURE</b>										
Previous Submission (2015NIR)	49 086	58 594	61 547	57 880	56 889	56 033	58 048	60 497	23.2%	25.4%
Current Submission (2016 NIR)	49 008	58 503	61 396	57 779	56 805	55 950	57 934	60 371	23.2%	25.3%
Change in Emissions: kt CO <sub>2</sub> eq	- 79	- 91	- 151	- 101	- 83	- 83	- 114	- 126	-	-
%	-0.2%	-0.2%	-0.2%	-0.2%	-0.1%	-0.1%	-0.2%	-0.2%	-	-
<b>WASTE</b>										
Previous Submission (2015 NIR)	23 936	26 440	28 132	28 195	26 644	26 374	25 608	25 340	5.9%	17.5%
Current Submission (2016 NIR)	26 028	28 747	30 557	29 933	28 970	28 843	28 388	28 431	9.2%	17.4%
Change in Emissions: kt CO <sub>2</sub> eq	2 092	2 307	2 425	1 738	2 327	2 469	2 780	3 091	-	-
%	8.7%	8.7%	8.6%	6.2%	8.7%	9.4%	10.9%	12.2%	-	-
<b>LULUCF</b>										
Previous Submission (2014 NIR)	- 87 499	- 76 599	16 424	- 7 856	81 381	82 203	60 093	- 15 073	-	-
Current Submission (2015 NIR)	- 87 189	- 81 616	507	- 39 804	54 633	69 420	40 702	- 29 632	-	-
Change in Emissions: kt CO <sub>2</sub> eq	310	- 5 016	- 15 917	- 31 948	- 26 749	- 12 783	- 19 391	- 14 559	-	-
%	-0.4%	6.5%	-96.9%	406.6%	-32.9%	-15.6%	-32.3%	96.6%	-	-

Revisions for 2013 are higher in comparison to all other years due to revised energy statistics from Statistics Canada resulting in an increase of 5.2 Mt mostly within mining and upstream oil and gas production, which was partly offset by downward recalculations elsewhere. In addition, changes and improvements in the underlying data and quantification methodologies have resulted in increased emissions from the Waste Sector for all years in the time series (Table 8–2).

In the LULUCF Sector, recalculations also occurred in the Harvested Wood Products category due to corrections of errors in modelling parameters (moisture content in industrial wood and the proportion of recoverable fibre) and a modification of combustion emission factors for consistency with the Energy Sector. As a result, total emissions from HWP were recalculated downward by 2 Mt in 1990, 6.3 Mt in 2005 and 3.9 Mt in 2013. These recalculations do not correct the erratic emission pattern due to natural disturbances in managed forests.

The details of the sector-specific recalculations can be found in Chapters 3 to 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 involve a methodological change or refinement are reviewed and agreed to by the Prioritization and



Planning Committee (P&PC) within the Pollutant Inventories and Reporting Division (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 IPCC Guidelines for National Greenhouse Gas Inventories (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 following agreed-upon UNFCCC review guidelines<sup>1</sup> as adopted in Decision 13/CP.20 at COP 20 in Lima in 2014. Reviews are coordinated by the UNFCCC Secretariat, and the ERT is composed of inventory experts from developed and developing countries. The purpose of the review is to provide a thorough and comprehensive technical assessment of the implementation of the Convention and adherence to the UNFCCC Reporting Guidelines. At the end of the review, the ERT provides technical feedback on any methodological and procedural issues encountered. The ERT will focus on instances where the guiding principles of transparency, consistency, comparability, completeness and accuracy of the inventory could be improved. The outcome of the review is reflected in an annual review report (ARR) that is provided to the country under review and made public by the UNFCCC.

Inventory reviews can be conducted either as a desk review, centralized review or in-country review. The review of Canada's 2014 inventory took place as an in-country review, which meant that the review team visited Canada and performed a thorough review of the inventory information as well as the national inventory arrangements. In the 2014 ARR<sup>2</sup>, the ERT recommended a variety of ways Canada could enhance and improve its GHG inventory, and inventory experts took these recommendations into consideration when identifying potential improvements for this year.

The 2015 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 recommendations, the bulk of the recommendations arising from last year's review will be considered for the 2017 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 previous 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<sub>4</sub> emissions from underground abandoned mines), improved default emission factors and parameters (e.g. updated oxidation factors), and changes to reported source/sink categories.

Last year (2015) was the first year 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 for 2015. 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 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 improved representation of residential firewood harvest from the forest ecosystem and incorporation of new vehicle population data, which improved characterization of vehicle fleet and driving patterns.

Table 8–3 provides additional information and justification regarding the improvements implemented this year.

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>.

2 Canada's 2014 ARR report entitled Canada. Report of the individual review of the inventory submission of Canada submitted in 2014 is available on the UNFCCC website at [http://unfccc.int/documentation/documents/advanced\\_search/items/6911.php?prirref=600008444#beg](http://unfccc.int/documentation/documents/advanced_search/items/6911.php?prirref=600008444#beg).

Table 8–3 Improvements to Canada's 2016 NIR

Sector	Category	Improvement	Description of Improvement	Basis of Improvement (Continuous Improvement, 2006 IPCC GLs or ERT Recommendation)	Section in NIR for more details
Energy	Residential Biomass (CRF 1.A.4.b)	Updated emission factors for residential firewood	CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O emission factors for the combustion of residential firewood have been updated.	Continuous improvement	Annex 6.6
	Fugitive Emissions from Fuels, – Natural Gas (CRF 1.B.2.b.vi.1)	Update the source of activity data.	The data source for number of capable oil and gas wells producing in a calendar year for British Columbia, Alberta and Saskatchewan has been updated.	Continuous improvement	Annex 3.2.2 (Table A3-6)
	Road Transportation - Liquid Fuels and Biomass (CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O) (CRF 1.A.3.b)	Activity data updates for on-road transportation.	New vehicle population data for the years 2005-2014 (except motorcycles) and updated kilometre accumulation rates leading to improved characterization of the vehicle fleet and driving patterns.	Continuous improvement	Annex 3.1.4.2.1
IPPU	Petrochemical and Carbon Black Production (CRF 2.B.8)	Quantified CO <sub>2</sub> emissions arising from production of petrochemicals and carbon black.	Emissions of CO <sub>2</sub> have been modelled and estimated in 2016 NIR. This category was included in NIR 2015 as part of 2.D (Non-Energy Products from Fuels and Solvent Use).	2006 IPCC Guidelines	Section 4.9
	Non-Energy Products from Fuels and Solvent Use (CRF 2.D)	Revised method to exclude CO <sub>2</sub> emissions associated with the new Category 2.B.8 (Petrochemical and Carbon Black Production).	Method and model for Non-Energy Products from Fuels and Solvent Use had to be revised to take into account the removal of CO <sub>2</sub> emissions associated with petrochemicals production from the category, for allocation to the new Category 2.B.8.	2006 IPCC Guidelines	Section 4.13
	Product Uses as Substitutes for ODS (CRF 2.F)	1995 imported and exported manufactured items have been reviewed and updated. Errors detected in the calculation model have been corrected.	The 1995 imports and exports of manufactured items was estimated and incorporated. The NIR 2015 HFC emissions contained errors due to the newly implemented Access model for estimation. These errors have now been rectified and the estimates have been recalculated.	Continuous improvement	Section 4.16
	Various categories in Mineral Industry (CRF 2.A) and Metal Industry (CRF 2.C)	Re-allocation of emissions in the subject subsectors, implicating emissions from: 2.A.3 Glass Production (new source); 2.A.4.b Other Uses of Soda Ash; 2.A.4.d Other (Limestone and Dolomite Use), and 2.C.1. Iron and Steel Production.	Continued implementation of the reporting requirements of the 2006 IPCC Guidelines.	2006 IPCC Guidelines	Sections 4.4 and 4.10
Agriculture	General	Revision to QA/QC procedures for new upload procedures in the online CRF tool.	Corrections and new QC processes were developed to remove transcription errors and inconsistencies between the NIR and CRF.	Continuous improvement	Annex 3.4/ CRF tables
	Enteric Fermentation/ Manure Management (CRF 3.A/3.B)	Revised mink and fox numbers to be consistent with IPCC emission factors.	Mink, fox and rabbit populations used in the 2015 inventory were inconsistent with the application of the emission factors, as the emission factors were based on breeding stock and not total numbers.	Continuous improvement	Annex 3.4
	Enteric Fermentation/ Manure Management (CRF 3.A/3.B)	Incorporated estimates of mules and ass populations	Incorporated estimates of mules and ass populations and reported with IPCC Tier 1 methods.	ERT recommendation	Annex 3.4
	Agricultural Soils (CRF 3.D)	Update of livestock distribution, crop areas and tillage practices 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. There were significant changes in the areas of intensive tillage (IT), reduced tillage (RT) and no-tillage (NT) in this year's submission. A review of the implementation of EO-based crop areas in the 2015 NIR resulted in the identification of errors in the distribution of tillage areas on the agricultural land base.	Continuous improvement	Section 5.4.1.5.5
	CO <sub>2</sub> Emissions from Liming, Urea Application and Other Carbon-Containing Fertilizers (CRF 3.G, 3.H, 3.I)	Including a portion of dolomite contained in the lime consumption data.	Lime data collected by Natural Resources Canada contain dolomite. The proportion of dolomite is estimated to be 24% based on the data collected from 1998 to 2002 by the Canadian Fertilizer Institute.	ERT recommendation	Section 5.6.5

Table A8-3 Improvements to Canada's 2016 NIR (cont'd)

Sector	Category	Improvement	Description of Improvement	Basis of Improvement (Continuous Improvement, 2006 IPCC GLs or ERT Recommendation)	Section in NIR for more details
LULUCF	Cross-cutting	Included information on land-use change transition times.	Improved reporting transparency by including information in the NIR clarifying that the land-use change transition period of 20 years (10 years for reservoirs) for reporting emissions and removals is more procedural than related to estimation methods.	ERT recommendation	Section 6.2
	Cross-cutting	Address completeness of LULUCF sub-categories with estimates reported as "NE".	Canada now reports land conversions not observed to occur in Canada sub-categories as NO, specifically CSC from all pools in Grassland and Wetlands converted to other land and CSC from all pools in other land converted to Settlements. CSC from living biomass in Grassland remaining Grassland is reported as Not Applicable (NA). Emissions are not estimated in Grassland remaining Grassland because there is no evidence that carbon stock changes are occurring in grassland soils as a result of management change. Emissions or removals are estimated to be indistinguishable from zero.	ERT recommendation	Section 6.5/6.6
	Forest Land (CRF 4.A)	Improved representation of harvesting for residential firewood.	New disturbance types and disturbance matrices were developed to better represent residential firewood collection of both biomass and DOM in managed forests.	Continuous improvement / Implementation of 2006 IPCC Guidelines	Section 6.3.1
	Forest Land (CRF 4.A)	Included information on pool-specific uncertainties.	Include information on pool-specific uncertainties of CBM-CFS <sub>3</sub> in NIR from recent publication.	ERT recommendation	Section 6.3.1.3
	Forest Land (CRF 4.A)	Changes to model parameters and algorithms.	Technical corrections were made to improve the modelling of disturbances for wildfires, slash burning and harvesting.	Continuous improvement	Section 6.3.1.4
	Forest Land Conversion LCL, LWL, LSL (CRF 4.B.2, 4.D.2, 4.E.2)	Updated forest conversion data.	Addition of a new mapping time period (2008–2013) reduces uncertainties associated with extrapolation of activity data from the previous mapping time period.	Continuous improvement	Section 6.8
Waste	Biological Treatment of Solid Waste - Composting (CRF 5.B.1)	Added a new category on composting.	Composting model, based on IPCC 2006 GL T <sub>1</sub> method, was produced and used in estimating of CH <sub>4</sub> and N <sub>2</sub> O emissions from the source category. Uncertainty estimates were calculated for CH <sub>4</sub> and N <sub>2</sub> O emissions and added to Canada's inventory.	2006 IPCC Guidelines	Section 7.3
	Waste Incineration – Biogenic and Non-biogenic - Other (Clinical) (CRF 5.C.1.1.b and 5.C.1.2.b)	Added a new category on clinical waste incineration.	Clinical waste incineration model, based on IPCC 2006 GL T <sub>1</sub> method, was produced and used in estimating CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O emissions from the source category. Uncertainty estimates calculated for CH <sub>4</sub> and N <sub>2</sub> O emissions and added to Canada's inventory.	2006 IPCC Guidelines	Section 7.4

## 8.3. Planned Inventory Improvements

As set out in Table 8-4, Canada has identified planned improvements 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.	UNFCCC 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.	UNFCCC ERT recommendation	Data analysis underway
	Other Transportation (Off-road) (CRF 1.A.3.e.ii)	Improved, bottom-up methodology for off-road GHGs.	The planned improvement will lead to more accurate GHG estimation by using a Canadianized version NONROAD, a model developed to calculate emissions from off-road equipment. This would be an improvement of the current method of using residual RESD fuel allocations. A secondary benefit is improved allocation of emissions to economic sectors and more detailed reporting in the CRF.	Continuous improvement	Alternative methods being considered
	Road Transportation (CRF 1.A.3.b)	Migration from MGEM to MOVES.	In conjunction with the off-road methodology, it is planned to migrate from MGEM to MOVES, creating a single model for GHG and air emissions for on-road transportation, keeping a consistent set of fleet activity data. While the overall approach will be the same (AD x EF), the impacts of changing models needs to be investigated. Changing the provincial distribution of emissions estimates from a fuel basis to an equipment/fleet basis will also be explored.	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
	Railways (CRF 1.A.3.c)	Determine whether steam trains are an emissions sources in Canada.	Review of operating steam trains in Canada and quantification of GHG emissions.	ERT recommendation	Verification and finalization of improvement
	Transport (CRF 1.A.3)	Update gross calorific values (GCVs), to improve transparency in reporting in the CRF (note: does not impact emissions).	Review of GCVs for motor gasoline and diesel and update if necessary (with Statistics Canada).	ERT recommendation	Alternative methods being considered
	Road Transportation (CRF 1.A.3.b)	Create Canada-specific factors for vehicles using compliance test data.	Using Environment and Climate Change Canada vehicle testing data and review the potential to use this data for development of country-specific parameters.	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
IPPU	Other Process Uses of Carbonates - Ceramics (CRF 2.A.4.a)	CO <sub>2</sub> emissions from organic carbon contained in raw materials used in production of ceramics to 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 to develop a quantification methodology and activity data stream to quantify such emissions.	2006 IPCC Guidelines	No significant progress made
	Lead Production and Zinc Production (CRF 2.C.5 and 2.C.6)	Implement a 2006 IPCC Guidelines estimation method for zinc and lead, based on production quantities of the metals.	CO <sub>2</sub> emissions from lead and zinc production in Canada are currently estimated based on estimates of reductant quantities used in such productions and reported under Non-Energy Products from Fuels and Solvent Use. Study contract planned for spring/summer 2016.	2006 IPCC Guidelines	Initiated data collection / study
	Iron and Steel Production (CRF 2.C.1)	Allocate natural gas and coal emissions associated with manufacturing of iron and steel to IPPU Sector's Iron and Steel Production category instead of the Energy Sector's Manufacturing Industries and Construction category, and to IPPU Sector's Non-energy Products from Fuels and Solvent Use, respectively.	A part of the process CO <sub>2</sub> emissions associated with Iron and Steel Production originates from the use of reductants other than metallurgical coke, more importantly natural gas and coal. Natural gas is used as a reductant in the direct reduced iron (DRI) method of iron manufacturing and is currently reported as part of the Energy Sector's CO <sub>2</sub> emissions associated with iron and steel production. A fraction of coal, shown in the RESD's non-energy line, is used in iron and steel making and is currently reported under the Non-energy Products from Fuels and Solvent Use subcategory. It is planned to allocate the aforementioned emissions to the Iron and Steel Production category of IPPU.	Continuous improvement	Data analysis underway
	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 identified options accepted in principle by expert livestock committee. Review and adoption require 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 that 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/3.B)	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 the 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. Approval and alignment with AAFC methodologies is required, followed by database implementation.	Continuous improvement	New parameters are under development
	Agricultural Soils (CRF 3.D)	Revision of methodologies for estimating nitrous oxide emission factors.	A compilation of soil N <sub>2</sub> O 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—that explain N <sub>2</sub> O emissions from agricultural soils in Canada, and to re-evaluate the empirical relationship between N <sub>2</sub> O emission factors and the growing season precipitation and evapotranspiration.	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)	Agricultural Soils (CRF 3.D)	Improve estimates of ammonia emissions from inorganic N fertilizers and thus nitrous oxide emissions.	An empirical model will be developed to derive ammonia emission factors based on type of N fertilizers, degree of incorporation into soil, crop type, soil cation exchange capacity and pH.	Continuous improvement	Data analysis underway
	Field Burning of Agricultural Residues (3.F)	Improve estimates of crop residue burning.	Data on crop residue burning are available from Farm Environmental Management Survey (2011), but these data have not been updated for estimating emissions of GHGs. Survey data on field burning of agricultural residues will be extracted, and incorporated into the database.	Continuous improvement	Data analysis underway
LULUCF	Cross-cutting	Address completeness of LULUCF subcategories with estimates reported as "NE".	Improve the completeness of reporting of pools in mandatory categories currently reported as NE.	UNFCCC ERT recommendation	Alternative methods being considered
	Forest Land (CRF 4.A)	Determine if drainage on Forest Land occurs in Canada.	A contract is underway to gather information to document the major forestry management practices applied in forested peatlands in Canada, including drainage.	UNFCCC ERT recommendation	Initiated data collection / study
	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.	UNFCCC ERT recommendation	Alternative methods being considered
	Wetlands, Peat Extraction (CRF 4.D.1.1, 4.D.2.1)	Assess additional guidance applicable to peat extraction in the IPCC Wetlands Supplement.	New guidance in the IPCC Wetlands Supplement on drainage and re-wetting of organic soils which is applicable for peat extraction will be assessed to determine how it can be used operationally considering domestic science and data developments.	Continuous improvement	Alternative methods being considered
	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, by updating estimates of activity data for land-use change in these regions for the post 2000 time period.	Continuous improvement	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.	Continuous improvement	Data analysis underway
	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	Initiated data collection / study
Waste	Solid Waste Disposal (CRF 5.A)	Update waste composition data and associated degradable organic carbon values.	A multi-year study on waste composition and associated degradable organic carbon values has been initiated, and future improvements are likely in the 2017 NIR.	UNFCCC ERT recommendation	Initiated data collection / study
	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	No significant progress made
	Solid Waste Disposal (CRF 5.A)	Evaluate a Canada-specific $DOC_F$ value for harvested wood products.	Evaluate Canada-specific $DOC_F$ values for harvested wood products (wood and paper) for use in the 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)	Modifying present SWD landfill model to the 2006 version of the first order decay (FOD) method.	Changing the old equation to the 2006 IPCC Guidelines version of the first order decay method, for all provinces and territories.	2006 IPCC Guidelines	No significant progress made



Table A8-4 Summary of Canada's Inventory Improvement Plan (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Waste (cont'd)	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 MSW incineration where energy recovery is involved will be separated out and transferred to the Energy Sector.	UNFCCC ERT recommendation	Data analysis underway
	Incineration and Open Burning of Waste (CRF 5.C)	Update of CH <sub>4</sub> and N <sub>2</sub> O emission factors.	Canada is planning to use the updated methodology and emission factors for estimating CH <sub>4</sub> and N <sub>2</sub> O emissions from this category.	2006 IPCC Guidelines	New parameters are under development
	Wastewater Treatment and Discharge – CH <sub>4</sub> and N <sub>2</sub> O (CRF 5.D)	Additional transparency in NIR text.	Include a detailed overview of wastewater streams and wastewater treatment discharge pathways in the NIR to improve transparency and to underpin the use of the selected EFs.	UNFCCC ERT recommendation	No significant progress made
	Wastewater Treatment and Discharge (CRF 5.D)	Update industrial wastewater treatment activity data.	The next in-house biennial industrial wastewater treatment facility surveys will be conducted during the summer of 2016. Implementation of 2014–2015 industrial wastewater treatment activity data is planned for the 2017 NIR and will replace the assumption of 2014 data remaining constant from 2013 values.	Continuous improvement	No significant progress made

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