Environment Canada   Environnement Canada

National Inventory Report

1990–2013

GREENHOUSE GAS SOURCES AND SINKS IN CANADA

The Canadian Government's Submission to the UN Framework Convention on Climate Change

Part 1

Canada

Acknowledgements

Readers' Comments

Comments regarding the content of this report should be addressed to Canada's National Greenhouse Gas Inventory Focal Point:

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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.

Recently revised UNFCCC reporting guidelines for national GHG inventories (24/CP.19) require Annex I Parties to develop their national inventories using the 2006 methodological guidance developed by the Intergovernmental Panel on Climate Change (IPCC). In addition, Annex I Parties are now required to use updated global warming potentials (GWPs) from the IPCC Fourth Assessment Report as well as to report several new GHGs. Inventory reports must also describe the formal arrangements for the preparation of inventories and indicate significant changes to inventory preparation and submission procedures.

Consistent with previous requirements, the reporting guidelines also commit Parties to improve the quality of national and regional emission and removal estimates on an ongoing basis. Improvement efforts include the quality of input data and of the methodologies used to develop emission and removal estimates.

This National Inventory Report complies with the most recent UNFCCC reporting guidelines for national GHG inventories. In addition to the description and explanation of inventory data, the report analyzes recent trends in emissions and removals and provides information on Canada's National Inventory Arrangements. This edition of the inventory incorporates several improvements; these improvements and subsequent recalculations of inventory estimates are also described in the report.

This report represents the efforts of many years of work and builds on the results of previous reports, published in 1992, 1994, and yearly from 1996 to 2014. Ongoing work, both in Canada and elsewhere, will continue to improve the estimates and reduce uncertainties associated with them.

April 2015

Director, Pollutant Inventories and Reporting Division
Science and Risk Assessment Directorate
Science and Technology Branch
Environment Canada

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_2O_3	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_0	maximum methane production potential
BC	average binder content in paste
BOF	basic oxygen furnace
BOD_5	five-day biochemical oxygen demand
BSM	emissions of benzene-soluble matter
C	carbon
CAC	Criteria Air Contaminant (for Land Use, Land-use Change and Forestry Sector)
CAC	Cement Association of Canada (for Industrial Proccesses and Product Use Sector)
CaC_2	calcium carbide
$CaCO_3$	calcium carbonate; limestone
$CaMg(CO_3)_2$	dolomite (also $CaCO_3 \cdot MgCO_3$)
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
CC	baked anode consumption per tonne of aluminium
CEA	Canadian Electricity Association
CEPA 1999	*Canadian Environmental Protection Act, 1999*
CESI	Canadian Environmental Sustainability Indicators
CF_4	carbon tetrafluoride
C_2F_6	carbon hexafluoride
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
CGA	Canadian Gas Association
CH_3OH	methanol
CH_4	methane
C_2H_6	ethane
C_3H_8	propane
C_4H_{10}	butane
C_2H_4	ethylene

C_6H_6	benzene
$CHCl_3$	chloroform
CIEEDAC	Canadian Industrial Energy End-Use Data Analysis Centre
CKD	cement kiln dust
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO	carbon monoxide
CO_2	carbon dioxide
CO_2 eq	carbon dioxide equivalent
COD	chemical oxygen demand
CORINAIR	Core Inventory of Air Emissions in Europe
CPPI	Canadian Petroleum Products Institute
CRF	Common Reporting Format
CRW	crown cover area growth rate
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
EAF	electric arc furnace
EC	Environment Canada
EDC	ethylene dichloride
EF	emission factor
EF_{BASE}	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
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
FLWL	forest land converted to wetland
FOCA	Federal Office of Civil Aviation
FOI	Swedish Defence Research Agency
F_{TILL}	tillage ratio factor
GCD	great-circle distance
GCV	gross calorific value
GDP	gross domestic product
GE	gross energy
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program

GIS	geographic information system
GO	gross output
Gt	gigatonne
GRI	Gas Research Institute
GTIS	Global Trade Information Services
GVWR	gross vehicle weight rating
GWP	global warming potential
H_2	hydrogen
H_2O	water
H_2S	hydrogen sulphide
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_3	nitric acid
HQ	Hydro-Québec
HRAI	Heating, Refrigeration and Air Conditioning Institute of Canada
HSS	horizontal stud Søderberg
HWP	harvested wood products
HWP-C	carbon stored in harvested wood products
IAI	International Aluminium Institute
ICAO	International Civil Aviation Organization
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
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
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
MMIC	Motorcycle & Moped Industry Council
MODTF	Modeling and Database Task Force
mol	mole
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
NCASI	National Council for Air and Stream Improvement
NCV	net calorific value
NE	not estimated
NEB	National Energy Board
NEU	non-energy use
NFI	National Forest Inventory
NFR	nomenclature for reporting
NGL	natural gas liquid
NH_3	ammonia
NH_4^+	ammonium
NH_4NO_3	ammonium nitrate
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
N_2O	nitrous oxide
NO	nitric oxide; also used for not occurring
NO_2	nitrogen dioxide
NO_3^-	nitrate
NO_x	nitrogen oxides
NOC	Nitrous Oxide of Canada
NPRI	National Pollutant Release Inventory
NRCan	Natural Resources Canada
NSCR	non-selective catalytic reduction
NT	no tillage
O_2	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
PFC	perfluorocarbon
PIRD	Pollutant Inventories and Reporting Division
PJ	petajoule
POP	persistent organic pollutant
P/PE	precipitation/potential evapotranspiration
PTRC	Petroleum Technology Research Centre
QA	quality assurance
QC	quality control
RA	reference approach
RESD	*Report on Energy Supply and Demand in Canada*
RPP	refined petroleum product
RT	reduced tillage
RTI	Research Triangle Institute
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_6	sulphur hexafluoride
SIC	Standard Industrial Classification
SiC	silicon carbide
SLC	Soil Landscapes of Canada
SMR	steam methane reforming
SO_2	sulphur dioxide
SO_x	sulphur oxides
SOC	soil organic carbon
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
UTC	urban tree crown
USDA	United States Department of Agriculture
VCM	vinyl chloride monomer
VKT	vehicle kilometres travelled
VSS	vertical stud Søderberg
VS	volatile solids
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 signed the Copenhagen Accord, under which Canada has committed to reducing its GHG emissions to 17% below the 2005 level by the year 2020.[1]

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.[2]

Canada's National Inventory is prepared and submitted annually to the UNFCCC by April 15 of each year, in accordance with recently 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 report represents Canada's first inventory submission to the UNFCCC following the recently revised UNFCCC Reporting Guidelines, adopted through Decision 24/CP.19 at COP 19 in Warsaw in 2013. It includes recalculations of previously reported estimates due to the use of the 2006 methodological guidance developed by the Intergovernmental Panel on Climate Change (IPCC) and updated global warming potentials (GWPs) from the IPCC Fourth Assessment Report as well as to the reporting of several new GHGs (Chapter 1–Table 1.1 provides

a complete list of GHGs to be reported and their GWPs). Of particular significance, the GWP of methane has increased from 21 to 25; this change contributed to the upward recalculation of Canada's total emissions over the 1990-2012 period. For example, the recalculated total emissions for 2012 have increased by 16.6 Mt (2.4%) (Chapter 8 provides more details on recalculations). Inventory reports must also describe the formal arrangements for the preparation of inventories and indicate significant changes to inventory preparation and submission procedures. This inventory report complies with the most recent UNFCCC reporting guidelines for national GHG inventories.

The inventory estimates include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) in the following five sectors defined by the 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 inventory guidelines prepared by the IPCC. 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 1990–2013 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 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 Copenhagen target[3] 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 three territorial governments.

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1   See http://www.climatechange.gc.ca/default.asp?lang=En&n=AA3F6868-1 .

2   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.

3   See http://www.climatechange.gc.ca/default.asp?lang=En&n=AA3F6868-1.

Section ES.5 details GHG emissions for Canada's 13 sub-national jurisdictions.

Canada's annual inventory submission to the UNFCCC embodies over a decade 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 2013, the most recent annual dataset in this report, Canada's total GHG emissions were estimated to be 726 megatonnes of carbon dioxide equivalent (Mt CO_2 eq[4]), excluding Land Use, Land-Use Change and Forestry estimates. The Energy Sector (consisting of the Stationary Combustion Sources, Transport,

and Fugitive Sources subsectors) accounted for the majority of Canada's total GHG emissions in 2013, at 81% or 588 Mt (Figure S–1). The remaining emissions were largely generated by Agriculture (8% of total emissions) and Industrial Processes and Product Use (7%), with minor contributions from Waste (3%). The LULUCF Sector was a net removal of 15 Mt in 2013; in accordance with UNFCCC reporting guidelines, these emissions are excluded from national inventory totals.

In 2013, CO_2 contributed 78% of Canada's total emissions (Figure S–2). The majority of these emissions result from the combustion of fossil fuels. CH_4 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_2O emissions, largely from agricultural soil management and transportation, accounted for 6% of emissions. Emissions of the synthetic gases (HFCs, PFCs, SF_6 and NF_3) constituted the remainder (slightly more than 1%).

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[4] Unless explicitly stated otherwise, all emission estimates given in Mt represent emissions of GHGs in Mt CO_2 equivalent.

Figure S–1 Canada's Emissions Breakdown by IPCC Sector (2013)*

ENERGY–Stationary Combustion Sources 325 Mt CO_2 eq (45%)

ENERGY–Transport 204 Mt CO_2 eq (28%)

WASTE 25 Mt CO_2 eq (3%)

AGRICULTURE 60 Mt CO_2 eq (8%)

INDUSTRIAL PROCESSES AND PRODUCT USE 52 Mt CO_2 eq (7%)

ENERGY–Fugitive Sources 59 Mt CO_2 eq (8%)

Total: 726 Mt CO_2 eq
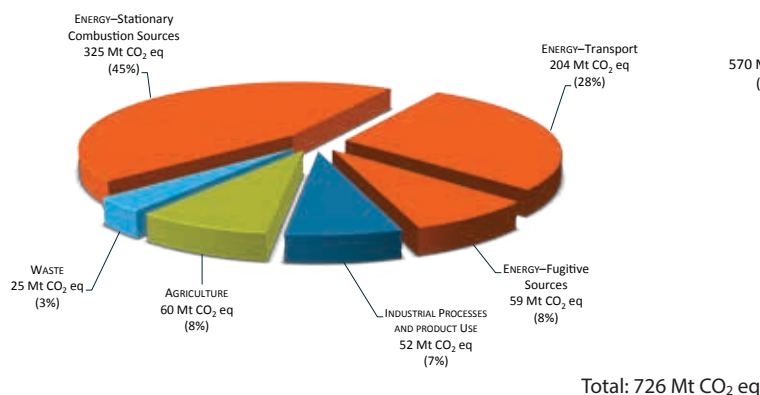
Figure S–2 Canada's Emissions Breakdown by Greenhouse Gas (2013)

CO_2 570 Mt CO_2 eq (78%)

CH_4 107 Mt CO_2 eq (15%)

HFCs, PFCs ,SF_6 & NF_3 8 Mt CO_2 eq (1%)

N_2O 41 Mt CO_2 eq (6%)

*Note: Totals may not add up due to rounding.
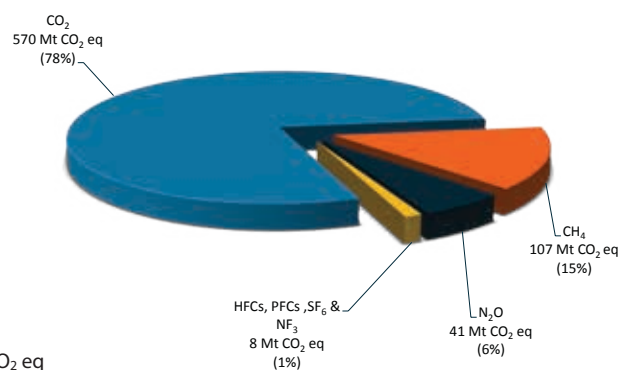
Figure S–3 Canadian GHG Emissions Trend (1990–2013) and Copenhagen Target

GHG Emissions (Mt CO_2 eq)

613

749 740 761 741 699 707 709 715 726

Copenhagen Target: 17% below 2005 emissions level
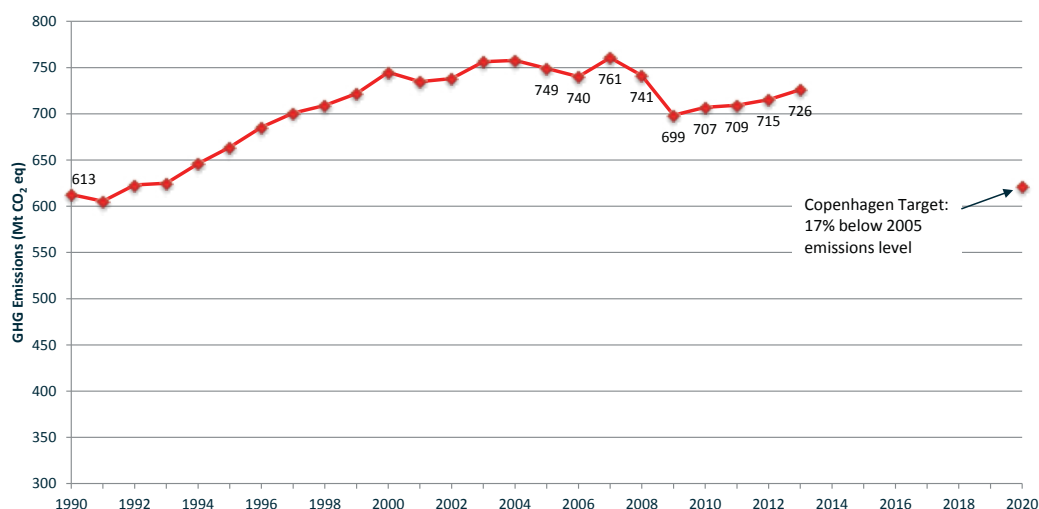
Canada's emissions in 2013 were 113 Mt (18%) above the 1990 total of 613 Mt (Figure S–3). Steady increases in annual emissions characterized the first 15 years of this period, followed by fluctuating emission levels between 2005 and 2008, a steep drop in 2009, and a slight increase thereafter. Between 2005 and 2013, emissions decreased by 23 Mt (3%), primarily due to decreases in emissions from Public Electricity and Heat Production (Table S–2).

Though GHG emissions have risen by 18% since 1990, Canada's economy grew much more rapidly, with the gross domestic product (GDP) rising by 71%. As a result, the emission intensity for the entire economy (GHG per GDP) has improved considerably, dropping by 31% (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). In 1995, GHG emissions started to decouple from economic growth, a shift that can be attributed to increases in efficiency, the modernization of industrial processes, and structural changes in the economy.

These long-term trends have led to continued improvement in emissions intensity since the late 1990s. However, emissions intensity seems to have stabilized in the last few years. Section ES.3 provides more information on trends in GHG emissions.

In general, Canada represents less than 2% of total global GHG emissions (CAIT 2015), although it is one of the highest per capita emitters, largely as a result of its size, climate (i.e., climate-driven energy demands) and resource-based economy. In 1990, Canadians released 22.1 tonnes (t) of GHGs per capita. In 2005, this indicator had risen to 23.2 t; however, by 2009, it had dropped to 20.8 t and has remained at historic lows ever since (Figure S–5).

Figure S–4   Indexed Trend in GHG Emissions and GHG Emissions Intensity (1990–2013)
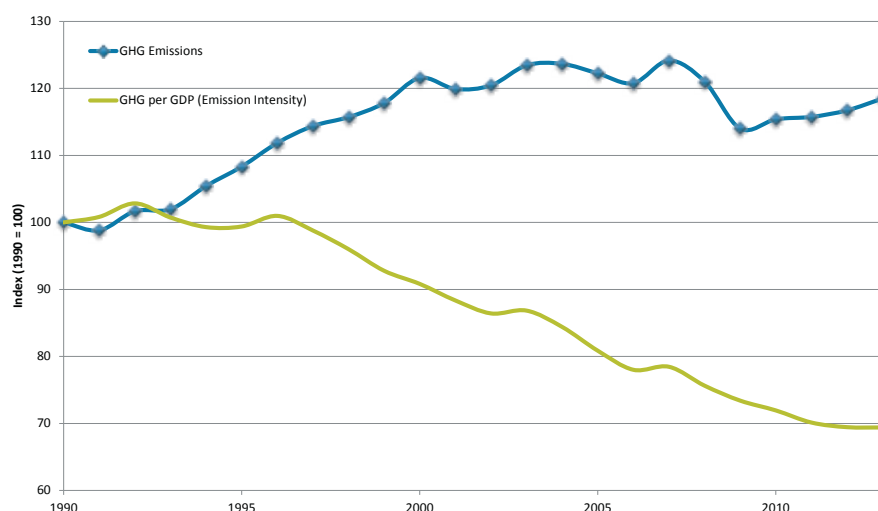
Table S–1   Trends in Emissions and Economic Indicators, Selected Years

Year	1990	2000	2005	2009	2010	2011	2012	2013
Total GHG (Mt)	613	745	749	699	707	709	715	726
Change Since 2005 (%)	NA	NA	NA	-6.7%	-5.6%	-5.3%	-4.5%	-3.1%
Change Since 1990 (%)	NA	21.6%	22.2%	14.0%	15.4%	15.7%	16.7%	18.5%
GDP (Billions 2007$)	989	1 324	1 496	1 537	1 587	1 633	1 663	1 689
Change Since 2005 (%)	NA	NA	NA	2.7%	6.1%	9.2%	11.2%	12.9%
Change Since 1990 (%)	NA	33.8%	51.2%	55.3%	60.4%	65.0%	68.1%	70.7%
GHG Intensity (Mt/$B GDP)	0.62	0.56	0.50	0.45	0.45	0.43	0.43	0.43
Change Since 2005 (%)	NA	NA	NA	-9.2%	-11.0%	-13.3%	-14.1%	-14.2%
Change Since 1990 (%)	NA	-9.2%	-19.2%	-26.6%	-28.1%	-29.9%	-30.6%	-30.6%

GDP data source: Statistics Canada (2014a)

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Figure S–5   Canadian per Capita Greenhouse Gas Emissions (1990–2013)

Population data source: Statistics Canada (2014b).
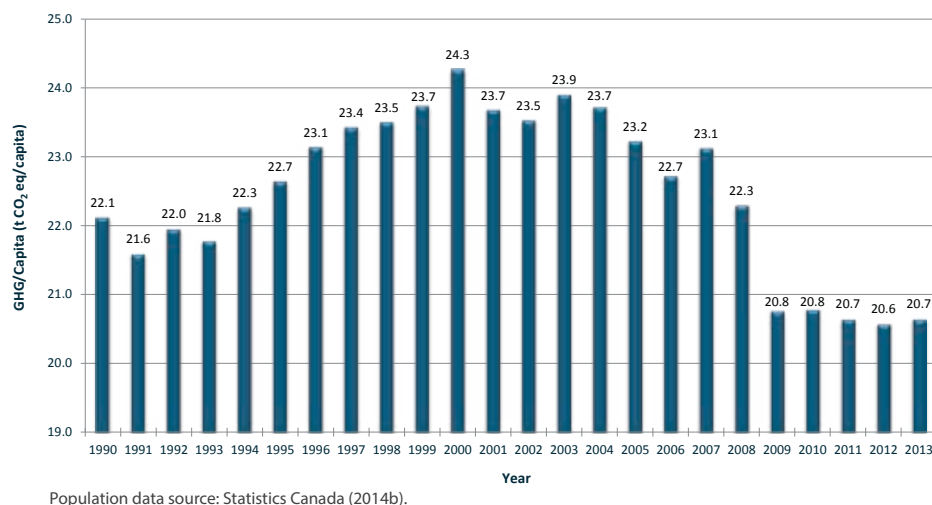
ES.3   Emissions and Trends by IPCC Sectors

Overall Trends in Emissions

Over the period 1990–2013, total emissions grew by 113 Mt or 18%. The Energy Sector dominated the long-term trend, with increases of 56 Mt (38%) in Transport and 37 Mt (13%) in Stationary Combustion. There was an increase of 11 Mt CO_2 eq (23%) in the Agriculture Sector as well. The Industrial Processes and Product Use Sector saw a decrease of 3 Mt CO_2 eq (5%) between 1990 and 2013, although emissions fluctuated over this period (Figure S–6 and Table S–2).

Table S–2 provides additional details about Canada's emissions and removals by IPCC sector for the years 1990, 2000, 2005 and 2009–2013. Further breakdowns by subsector and gas, and a complete time series, can be found in Annex 9.

In contrast to the increase of emissions over the longer term (1990–2013), total Canadian GHG emissions have decreased by 23 Mt (3%) since 2005. Stationary Combustion Sources within the Energy Sector have been the largest driver of the overall downward trend, dropping by 19 Mt (6%) since 2005 (Figure S–7), with the largest contributor to this decrease being from Public Electricity and Heat Production, where emissions fell 37 Mt (29%). Since 2005, emissions from Industrial Processes and Product Use, Waste, Fugitive Sources within the Energy Sector, and Agriculture

Figure S–6   Trends in Canadian GHG Emissions by IPCC Sector (1990–2013)
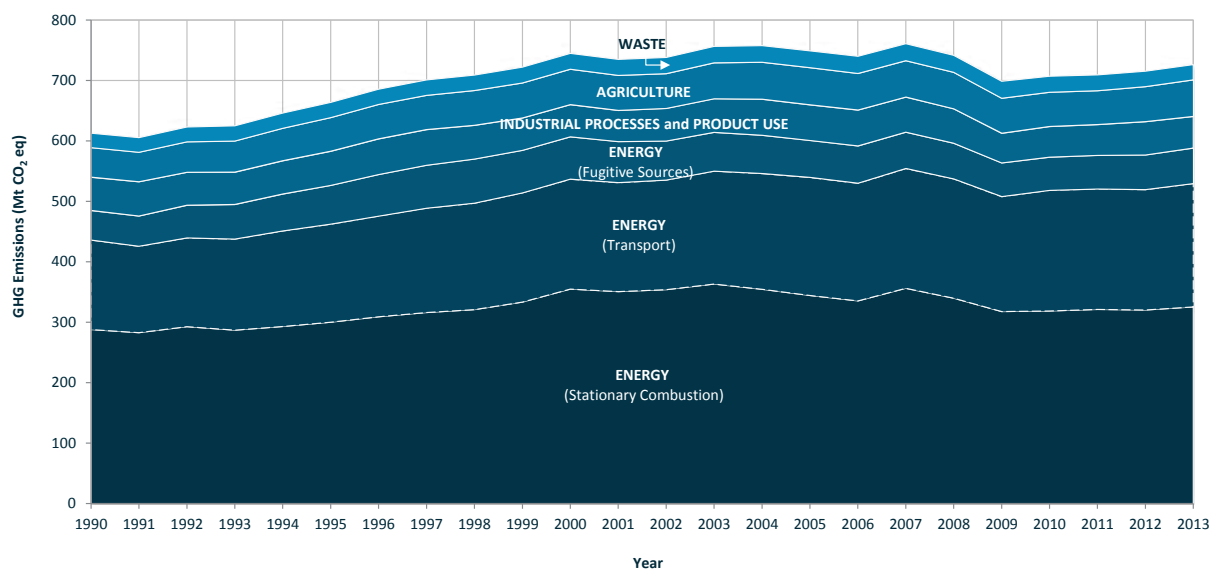
Table S–2   Canada's GHG Emissions by IPCC Sector (1990–2013)

Greenhouse Gas Categories		1990	2000	2005	2009	2010	2011	2012	2013
					Mt CO$_2$ equivalent				
TOTAL[1,2]		**613**	**745**	**749**	**699**	**707**	**709**	**715**	**726**
ENERGY		**485**	**606**	**601**	**563**	**573**	**576**	**577**	**588**
a.	Stationary Combustion Sources	288	355	344	318	318	321	320	325
	Public Electricity and Heat Production	95	131	124	100	102	95	89	88
	Petroleum Refining Industries	17	17	20	19	18	17	19	18
	Mining and Upstream Oil and Gas Production	41	63	68	78	80	82	91	94
	Manufacturing Industries	56	56	49	40	41	45	45	46
	Construction	2	1	1	1	2	1	1	1
	Commercial & Institutional	26	33	32	30	28	30	28	29
	Residential	49	50	48	47	45	48	44	46
	Agriculture & Forestry	2	3	2	3	3	3	4	4
b.	Transport	148	182	195	190	200	199	199	204
	Domestic Aviation	7	8	8	6	6	6	7	8
	Road Transportation	98	119	132	133	135	134	134	137
	Railways	7	7	7	5	7	8	8	7
	Domestic Navigation	5	5	7	7	7	6	6	5
	Other Transportation	31	43	43	38	44	46	45	47
c.	Fugitive Sources	49	70	61	56	55	56	57	59
	Coal Mining	3	2	2	1	2	2	2	2
	Oil and Natural Gas	46	68	59	54	53	54	56	57
d.	CO$_2$ Transport and Storage	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INDUSTRIAL PROCESSES AND PRODUCT USE		**55**	**53**	**59**	**49**	**51**	**51**	**55**	**52**
a.	Mineral Products	9	10	10	7	8	8	9	8
b.	Chemical Industry	14	5	7	4	4	4	4	5
c.	Metal Production	23	23	20	16	16	17	17	14
d.	Production and Consumption of Halocarbons, SF$_6$ and NF$_3$	1	4	5	6	6	6	6	7
e.	Non-Energy Products from Fuels and Solvent Use	7	11	16	16	17	15	19	18
f.	Other Product Manufacture and Use	0.2	0.4	0.4	0.3	0.2	0.3	0.3	0.3
AGRICULTURE		**49**	**59**	**62**	**58**	**57**	**56**	**58**	**60**
a.	Enteric Fermentation	23	28	31	27	26	25	25	25
b.	Manure Management	8	9	10	9	9	8	8	8
c.	Agriculture Soils[3]	17	19	19	20	21	21	22	24
d.	Liming, Urea Application and Other Carbon-containing Fertilizers	1	2	1	2	2	2	2	3
WASTE		**24**	**26**	**28**	**28**	**27**	**26**	**26**	**25**
a.	Solid Waste Disposal on Land	22	25	26	27	25	25	24	24
b.	Wastewater Handling	1	1	1	1	1	1	1	1
c.	Waste Incineration	1	1	1	1	1	1	1	1
LAND USE, LAND-USE CHANGE AND FORESTRY		**-87**	**-77**	**16**	**-8**	**81**	**82**	**60**	**-15**
a.	Forest Land and Harvested Wood Products	-109	-83	16	-8	81	81	58	-16
b.	Cropland	10	-2	-8	-9	-8	-8	-8	-7
c.	Grassland	1	1	1	0	0	1	2	1
d.	Wetlands	6	4	4	4	4	4	4	4
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

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Figure S–7   Short-term Emission Trends by IPCC Sector (2005–2013)
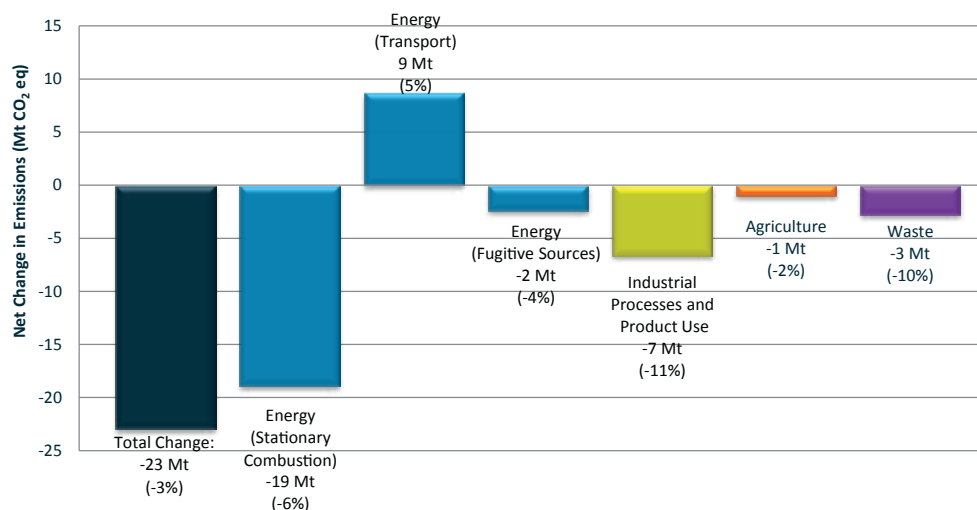
have also decreased (by 7 Mt, 3 Mt, 2 Mt and 1 Mt respectively), while emissions from Transport have increased by 9 Mt (5%) over the same period.

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

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

Energy—2013 GHG Emissions (588 Mt)

Short-term Trends

In 2013, GHG emissions from the IPCC Energy Sector were 13 Mt (2%) below 2005 levels. Similar to the national trend, this decline was primarily driven by a decline in fossil fuel consumption for 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 a 37-Mt (about 29%) decrease in emissions associated with Electricity Production between 2005 and 2013. The permanent closure, at the end of 2013, of all but one coal generating station in the province of Ontario was a determinant factor. However, there were some fluctuations in emissions over the period, largely as a result of changes in the mix of electricity generation sources.[5]

GHG emissions from Manufacturing Industries decreased by 2.6 Mt (5%) between 2005 and 2013. While industries continue

to recover from the 2009 decrease in production, emissions still remain below 2005 levels.

In contrast, emissions from Mining and Upstream Oil and Gas Production increased by 26 Mt, consistent with continued growth in oil and gas extraction activities (see *Long-term Trends*).

Long-term Trends

The long-term emission trends in the Energy Sector (1990–2013) show a net growth of 103 Mt or 21%. The majority of the increase has taken place in Mining and Upstream Oil and Gas Production and Road Transportation, which both fall under the Energy Sector. The largest decreases in Energy Sector emissions were observed in the Manufacturing Industries (10 Mt), followed by Public Electricity and Heat Production (7 Mt).

In 2013, emissions from Mining and Upstream Oil and Gas Production were more than twice their 1990 values. This trend is consistent with a 79% increase in total production of crude oil and natural gas over the period, largely for export.

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 is a significant contributor to the long-term increase in emissions (representing 38.9 Mt or 69% of the net

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5   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.

increase in total transport GHG emissions). The primary source of this net trend of rising emissions is the increase in the vehicle population and the associated vehicle kilometres travelled. However, vehicles are becoming more efficient, and the 3.7% increase in emissions since 2005 remains lower than the 12.5% increase in vehicle kilometres travelled.

The most significant sources of emissions in transportation are light-duty (i.e. passenger) vehicles and heavy-duty diesel vehicles for freight transport. Within the light-duty vehicle[6] segment, the use of light trucks—a vehicle class that includes sport-utility vehicles, pickups and minivans—increased much more rapidly than cars. Light trucks 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 22.7 Mt (112%) between 1990 and 2013. Growth in emissions reflected a 137% increase in tonne-kilometres shipped by trucks between 1990 and 2003 (Statistics Canada 2013a). Between 2004 and 2011, tonne-kilometres shipped varied within a range of +4% to -7%, and ultimately resulted in zero growth across the seven-year period (Statistics Canada 2013b). 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— 2013 GHG Emissions (52.2 Mt)

The Industrial Processes and Product Use Sector covers non-energy GHG emissions from industrial sources, such as limestone calcination (CO_2) 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 2013, emissions were 5.2% (2.9 Mt) below their 1990 level, and 11.2% (7 Mt) below the 2005 level. Of note in this sector is the rapid increase in emissions from the use of HFCs as refrigerants in place of ODSs, an increase of 1.1 Mt (22%) since 2005.

In Metal Production, CO_2 emissions from production of iron and steel have been fairly stable since the early 1990s, despite moderate increases in steel production, indicating the effect of increased use of recycled steel in Canadian steelmaking operations. The year 2009 saw a significant decline in production, followed by a gradual recovery from 2010 to 2012, and then a drop of 2.3 Mt (23%) between 2012 and 2013 due to a decrease in production. The aluminium industry, while increasing its production by almost 100% since 1990, shows a 3.6 Mt (35%) decrease in its process emissions, largely due to emission control technology introduced to mitigate PFC emissions. The 68% overall decrease

in GHG emissions from Chemical Industries between 1990 and 2013 is primarily a result of the closure of an adipic acid plant in Ontario. Decreases were partly offset by increases in emissions from Ammonia Production.

Agriculture—2013 GHG Emissions (60 Mt)

Canadian agriculture can be differentiated into livestock (enteric fermentation and manure management) and crop production components (agricultural soils, lime and fertilizers). The livestock industry is dominated by beef, but also has significant swine, dairy and poultry components. Crop production is mainly dedicated to the production of cereals and oilseeds. A wide variety of specialty crops and animals are produced, but represent a very small portion of the overall agricultural economy.

Emissions directly related to animal and crop production accounted for 60 Mt or 8.3% of total 2013 GHG emissions for Canada, an increase of 11 Mt or 23% since 1990. Agriculture accounts for 27% and 70% of the national CH_4 and N_2O emissions, respectively.

The main drivers of the trend in emissions in the Agriculture Sector since 1990 are the intensification, expansion and then decline of the beef cattle and swine industries and continued increases in the application of inorganic nitrogen fertilizers, mainly on the Prairies. From 1990 to 2005, the proportion of agricultural emissions associated with livestock increased from 68% to 73% of total emissions, but has since declined to only 61% of total agricultural emissions.

From 2005 to 2011, livestock populations decreased. Until 2008, declines in emissions from livestock production were compensated for by increases in emissions from crop production. However, from 2008 to 2011, livestock populations continued to decrease sharply and combined with lower crop production, total agricultural emissions decreased by 6 Mt from their peak emissions of 62 Mt in 2005. In 2012 and 2013 livestock populations stabilized, fertilizer use has once again increased sharply and crop production in 2013 was higher than any year in the reporting period; as a result, emissions have increased by 4 Mt since 2011.

Waste—2013 GHG Emissions (25 Mt)

The primary source of emissions in the Waste Sector is CH_4 from Solid Waste Disposal, which accounts for about 94% of emissions for this sector. The CH_4 emissions from publicly and privately owned municipal solid waste landfills (MSW) make up the bulk of emissions from Solid Waste Disposal (approximately 82%). The remainder (approximately 18%) originates from on-site industrial landfills of wood residues; such landfills are declining in number as markets for wood residues grow.

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6   Light-Duty Vehicles (LDVs) include all light-duty vehicles and trucks regardless of fuel type.

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Since 1990, overall emissions from Waste grew by 6%, 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_4 emissions generated by all MSW landfills increased by 35% to 1302 kilotonnes (kt), the amount of CH_4 captured increased by 144% to 470 kt in 2013. Of the overall CH_4 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 2013.

Wastewater treatment and waste incineration facilities in Canada are minor sources of CH_4 and N_2O emissions and have generally remained stable.

Land Use, Land-use Change and Forestry—2013 (Net Removal of 15 Mt)

The Land Use, Land-use Change and Forestry (LULUCF) Sector reports GHG fluxes between the atmosphere and Canada's managed lands, as well as those associated with land-use change. 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. All emissions and removals in the LULUCF Sector are excluded from the national totals.

In this sector, the net GHG flux is the sum of CO_2 emissions to, and removals from, the atmosphere, plus emissions of non-CO_2 gases. In 2013, this net flux amounted to removals of 15 Mt, which would have decreased the total Canadian GHG emissions by about 2.1% but does include non-anthropogenic sources, specifically wildfires and insect infestations in the Forest Land subsector. Trends in the LULUCF Sector are primarily driven by those in Forest Land, Cropland and Forest Conversion. Emissions in the new category of Harvested Wood Products (HWP) originate from the burning or eventual disposal of domestically harvested wood and are therefore closely associated with current and past forest management activities.

The net flux in forest land is dominated by inter-annual variability due to the erratic pattern of forest wildfires, which masks the impact of forest harvest. However, important harvest trends have occurred; between 1990 and the peak harvest year of 2004, there was a 28% increase in the carbon removed in harvested wood. Since then, significant reductions in forest management activities have occurred, with harvest levels 27% below the peak harvest year, reaching a 24-year low in 2009 (30 Mt carbon) for the period covered by this report.

Emissions from HWP fluctuate between 134 Mt in 2009, the lowest harvest year, and 168 Mt in 2000, one of the peak harvest years. Emissions from HWP are influenced by the trend in forest

harvest rates during the reporting period and by the long-term impact of forest harvest and forest conversion levels that occurred before 1990. Nonetheless, the immediate and long-term effect of major natural disturbances in managed forests, notably the Mountain Pine Beetle infestation in western Canada and periodic wild fires, will undoubtedly continue to dominate the apparent trend of emissions and removals from forest lands. Emissions in Harvested Wood Products only partly reflect current forest management activities, since a significant proportion of emissions result from the decay of long-lived wood products reaching the end of their economic lives decades after the wood was harvested.

The net flux in cropland shows a steady decline in the period 1990–2006, from emissions of 10 Mt in 1990 to net removals of 9.6 Mt in 2006. This trend is a result of changes in agricultural land management practices in western Canada, the adoption of conservation tillage practices (over 13 million hectares of cropland since 1990) and a 79% reduction in summer fallow, as well as a decline in the conversion of forest land to cropland. However, since 2006, net removals have gradually declined to 7.4 Mt as a result of the soil sink approaching equilibrium and an observed increase in conversion of perennial to annual crop consistent with the increasing N_2O emissions from crop production in agriculture.

ES.4   Economic Sectors

As previously noted, there are several methods to categorize the sources of GHG emissions that arise across Canada. For the purposes of analyzing 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 2013 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 72 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 40 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 10 Mt and 19 Mt, respectively.

Further information on the IPCC and economic sector definitions and trends, as well as a detailed cross-walk between IPCC

Figure S–8   Canada's Emissions Breakdown by Economic Sector (2013)

Waste & Others
54 Mt CO_2 eq
(7%)

Agriculture
75 Mt CO_2 eq
(10%)

Buildings
86 Mt CO_2 eq
(12%)

Oil and Gas
179 Mt CO_2 eq
(25%)

Emissions-Intensive
and Trade-Exposed
Industries
76 Mt CO_2 eq
(11%)

Transportation
170 Mt CO_2 eq
(23%)

Electricity
85 Mt CO_2 eq
(12%)

Total: 726 Mt CO_2 eq
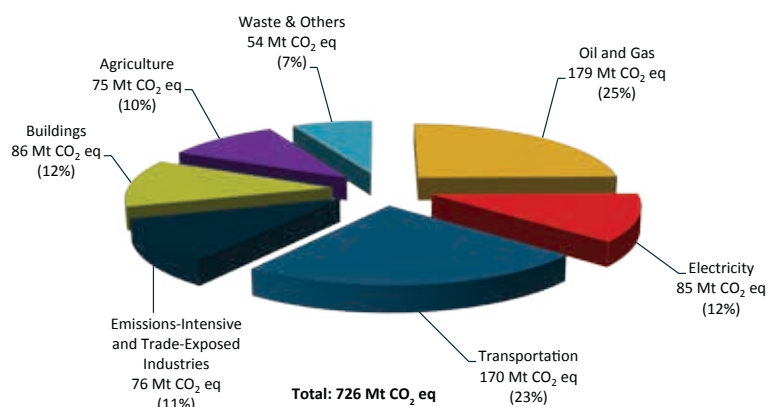
Note: Totals may not add up due to rounding.

Table S–3   Canada's GHG Emissions by Economic Sector (1990–2013)

Greenhouse Gases	1990	2000	2005	2009	2010	2011	2012	2013
				Mt CO_2 equivalent				
NATIONAL GHG TOTAL	613	745	749	699	707	709	715	726
Oil and Gas	107	158	157	158	160	161	174	179
Electricity	95	130	121	98	99	91	86	85
Transportation	130	157	169	164	169	167	168	170
Emission Intensive & Trade Exposed Industries[1]	95	92	89	73	75	79	77	76
Buildings	76	88	87	85	82	87	85	86
Agriculture	57	69	71	68	70	70	72	75
Waste & Others[2]	54	52	54	52	53	53	53	54

Note: Totals may not add up due to rounding.

Estimates presented here are under continual improvement. Historical emissions may be changed in future publications as new data 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 & Trade Exposed Industries represent emissions arising from non 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.   .

and economic sector categories, can be found in Chapter 2, Table 2-15.

ES.5   Provincial and Territorial GHG Emissions

Emissions vary significantly by province, due to factors such as population and socio-economic circumstances and economic structure. Provinces where the economy is oriented more toward resource extraction will tend to have higher emission levels, while service-based economies tend to have lower emission levels. Electricity generation sources also vary, with provinces that rely on fossil fuels for their electricity generation having higher emissions than provinces relying more on hydroelectricity.

Although Ontario, with its large manufacturing base, started off as the largest-emitting province in 1990, as of 2005 it had been surpassed by Alberta (see Figure S–9), where emissions have

increased 53% since 1990—mostly driven by the enhanced production of petroleum resources.

Since 2005, Ontario's electricity sector saw its emissions decrease by 23.6 Mt (68%)—largely due to the closures of coal-fired electricity generation plants. By the close of 2013, all but one of these had been taken out of service.

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 an 8.4% (7.5 Mt) decrease from its 2005 emissions level, while British Columbia had a decline of 2.6% (1.7 Mt). In contrast to these decreases, emissions in Saskatchewan increased by 7.6% (5.3 Mt) between 2005 and 2013, as a result of activities in the oil and gas industry as well as potash and uranium mining.

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Figure S–9   Emissions by Province in 1990, 2005 and 2013
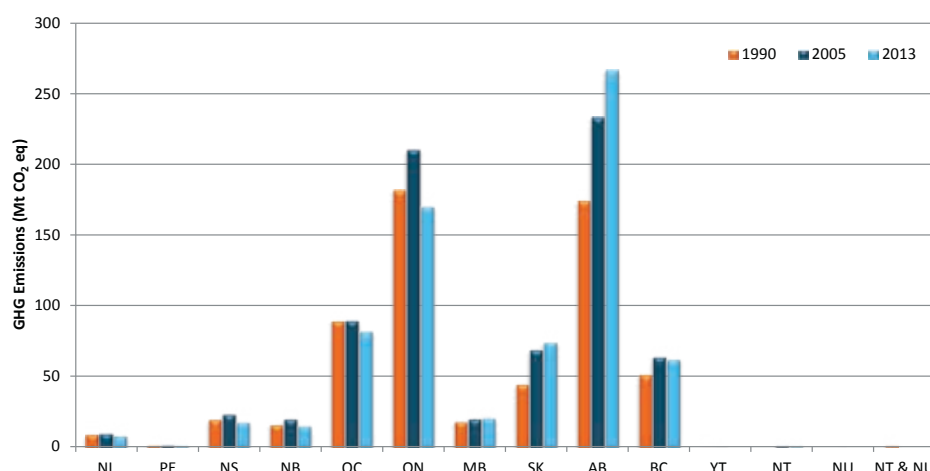
ES.6   National Inventory Arrangements

Environment Canada is the single national entity with responsibility for the preparation and submission of 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 Canada 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 both the annual compilation and submission of the National Inventory Report and Common Reporting Format 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 a summary of ozone and aerosol precursors.

Part 3 comprises Annexes 8 to 11, which present rounding procedures, summary tables of GHG emissions at the national level 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 considered 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, the recent warming has been largely attributed to human activity, primarily the ongoing release of carbon dioxide (CO_2), methane (CH_4) and other greenhouse gases to the atmosphere. As a result of these human-driven releases, the atmospheric concentrations of greenhouse gases have risen substantially, intensifying the natural greenhouse effect.

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

It is now well known that atmospheric concentrations of GHGs have grown significantly since pre-industrial times. Since 1750, the concentration of atmospheric CO_2 has increased by 142%, CH_4 by 253% and nitrous oxide (N_2O) by 121% (WMO 2014). In 2011 the concentrations of CO_2, CH_4 and N_2O exceeded pre-industrial levels by about 40%, 150% and 20%, respectively. 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).

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 2013 was 0.8°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 66 years (Environment Canada 2014).

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 Conven-

Figure 1–1   Annual Canadian Temperature Departures and Long-term Trend, 1948–2013
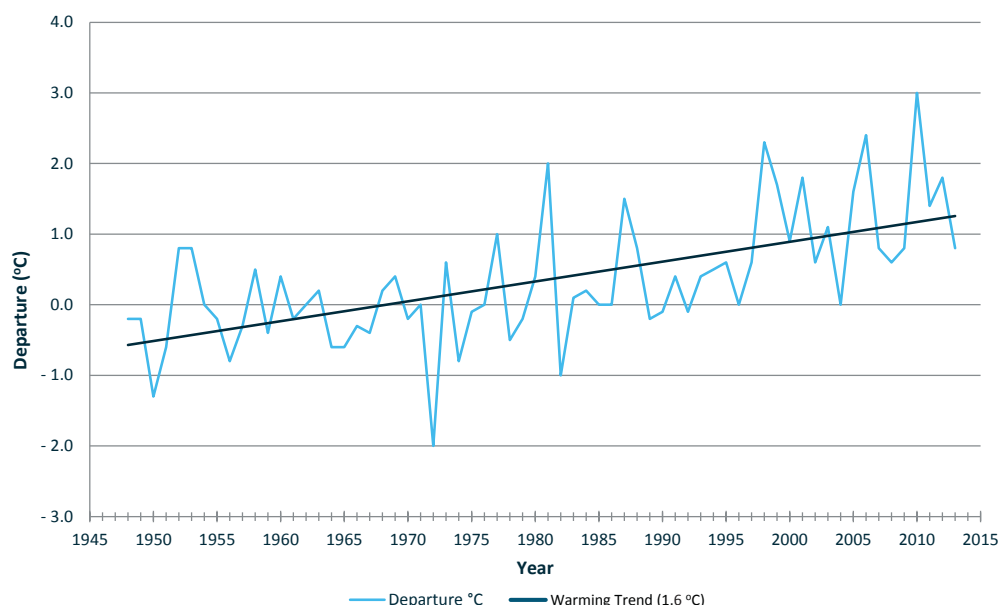
Data source: Environment Canada (2014)

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tion came into force in March 1994. The ultimate objective of the UNFCCC is to stabilize atmospheric GHG concentrations at a level that would prevent dangerous interference with the climate system. In its actions to achieve its objective and to implement its provisions, the UNFCCC lays out a number of guiding principles and commitments. It requires governments to gather and share information on GHG emissions, national policies and best practices; to launch national strategies for addressing GHG emissions and adapting to expected impacts; and to cooperate in preparing for adaptation to the impacts of climate change. Specifically, Articles 4 and 12 and Decision 24/CP.19 of the Convention commit all Parties to develop, periodically update,[1] publish and make available to the Conference of the Parties (COP) national inventories of anthropogenic[2] emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol[3] that use comparable methodologies.

This National Inventory Report (NIR) provides Canada's annual GHG emissions estimates for the period 1990–2013. The NIR, along with the Common Reporting Format (CRF) tables, comprise Canada's 2015 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 COP at its nineteenth session in 2013. Notable changes are:

- Implementation of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) which required several methodological changes and reporting of new source categories;

- Use of updated global warming potentials (GWPs) from the IPCC 4th Assessment Report (see Section 1.1.3); and

- The reporting of new greenhouse gases (GHGs) including NF_3 along with a few new species of hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

1.1.2.   Greenhouse Gases

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

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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.

Carbon Dioxide (CO₂)

CO_2 is a naturally occurring, colourless, odourless, incombustible gas formed during respiration, combustion, decomposition of organic substances, and the reaction of acids with carbonates. It is present in the Earth's atmosphere at low concentrations and acts as a GHG. The global carbon cycle is made up of large carbon flows and reservoirs. Through these, CO_2 is constantly being removed from the air by its direct absorption into water and by plants through photosynthesis and, in turn, is naturally released into the air by plant and animal respiration, decay of plant and soil organic matter, and outgassing from water surfaces. Small amounts of carbon dioxide are also injected directly into the atmosphere by volcanic emissions and through slow geological processes such as the weathering of rock (Hengeveld et al. 2005). Although human-caused releases of CO_2 are relatively small (1/20) compared to the amounts that enter and leave the atmosphere due to the natural active flow of carbon (Hengeveld et al. 2005), human influences now appear to be significantly affecting this natural balance. This is evident in the measurement of the steady increase of atmospheric CO_2 concentrations since preindustrial times across the globe (Hengeveld et al. 2005). Anthropogenic sources of CO_2 emissions include the combustion of fossil fuels and biomass to produce energy, building heating and cooling, transportation, land-use changes including deforestation, the manufacture of cement, and other industrial processes.

Methane (CH₄)

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

Nitrous Oxide (N₂O)

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

Perfluorocarbons (PFCs)

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

Hydrofluorocarbons (HFCs)

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

Sulphur Hexafluoride (SF_6)

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

Nitrogen Trifluoride (NF_3)

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

1.1.3. Global Warming Potentials

GHGs are not all equal: each GHG has a unique atmospheric lifetime and heattrapping potential. The radiative forcing[4] effect of a gas within the atmosphere is a quantification of its ability to cause atmospheric warming. Direct effects occur when the gas itself is a GHG, whereas indirect radiative forcing occurs when chemical transformation of the original gas produces a gas or gases that are GHGs or when a gas influences the atmospheric lifetimes of other gases.

By definition, a GWP is the time-integrated change in radiative forcing due to the instantaneous release of 1 kg of the substance expressed relative to the radiative forcing from the release of 1 kg of CO_2. The global warming potential (GWP) of a GHG takes into account both the instantaneous radiative forcing due to an incremental concentration increase and the lifetime of the gas; it is a relative measure of the warming effect that the emission of a radiative gas (i.e. a GHG) might have on the surface atmosphere.

The concept of a GWP has been developed to allow some comparison of the ability of each GHG to trap heat in the atmosphere relative to CO_2. It also allows characterization of GHG emissions in terms of how much CO_2 would be required to produce a similar warming effect over a given time period. This is called the carbon dioxide equivalent (CO_2 eq) value and is calculated by multiplying the amount of the gas by its associated GWP. This normalization to CO_2 eq enables the quantification of "total national emissions" expressed as CO_2 eq.

The IPCC develops and updates the GWPs for all GHGs. As GWP values are based on background conditions of GHG concentrations and climate, 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_4) used in this inventory is 25 (compared to a GWP of 21 for methane used in previous years). As such, an emission of one hundred kilotonnes (100 kt) of methane is equivalent to 25 x 100 kt = 2500 kt CO_2 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 Canada. The National Inventory Focal Point is:

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

Table 1–1   IPCC Global Warming Potentials (GWPs)

GHG	Formula	Updated 100-year GWP[1]	Previously used 100-year GWP[2]
Carbon Dioxide	CO_2	1	1
Methane[3]	CH_4	25	21
Nitrous Oxide	N_2O	298	310
Sulphur Hexafluoride	SF_6	22 800	23 900
Nitrogen Trifluoride	NF_3	17 200	-
Hydrofluorocarbons (HFCs)			
HFC-23	CHF_3	14 800	11 700
HFC-32	CH_2F_2	675	650
HFC-41	CH_3F	92	150
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1 640	1 300
HFC-125	CHF_2CF_3	3 500	2 800
HFC-134	CHF_2CHF_2	1 100	1 000
HFC-134a	CH_2FCF_3	1 430	1 300
HFC-143	CH_2FCHF_2	353	300
HFC-143a	CH_3CF_3	4 470	3 800
HFC-152	CH_2FCH_2F	53	-
HFC-152a	CH_3CHF_2	124	140
HFC-161	CH_3CH_2F	12	-
HFC-227ea	CF_3CHFCF_3	3 220	2 900
HFC-236cb	$CH_2FCF_2CF_3$	1 340	-
HFC-236ea	CHF_2CHFCF_3	1 370	-
HFC-236fa	$CF_3CH_2CF_3$	9 810	6 300
HFC-245ca	$CH_2FCF_2CHF_2$	693	560
HFC-245fa	$CHF_2CH_2CF_3$	1 030	-
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794	-
Perfluorocarbons (PFCs)			
Perfluoromethane	CF_4	7 390	6 500
Perfluoroethane	C_2F_6	12 200	9 200
Perfluoropropane	C_3F_8	8 830	7 000
Perfluorobutane	C_4F_{10}	8 860	7 000
Perfluorocyclobutane	$c\text{-}C_4F_8$	10 300	8 700
Perfluoropentane	C_5F_{12}	9 160	7 500
Perfluorohexane	C_6F_{14}	9 300	7 400
Perfluorodecalin	$C_{10}F_{18}$	7 500	-
Perfluorocyclopropane	$c\text{-}C_3F_6$	17 340	-

Note:
1. Data source: IPCC's *Fourth Assessment Report - Errata* (IPCC 2012).
2. Data source: IPCC's Summary for Policymakers and Technical Summary of the Working Group I Report (IPCC 1995).
3. The GWP for methane includes indirect effects from enhancements of ozone and stratospheric water vapour.

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

1.2.1.   Institutional Arrangements

As the federal agency responsible for preparing and submitting the national inventory to the UNFCCC, Environment 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 Canada has defined roles and responsibilities for the preparation of the inventory, both internally and externally. As such, Environment 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,

Figure 1–2   Partners and Contributors to National Inventory Arrangements
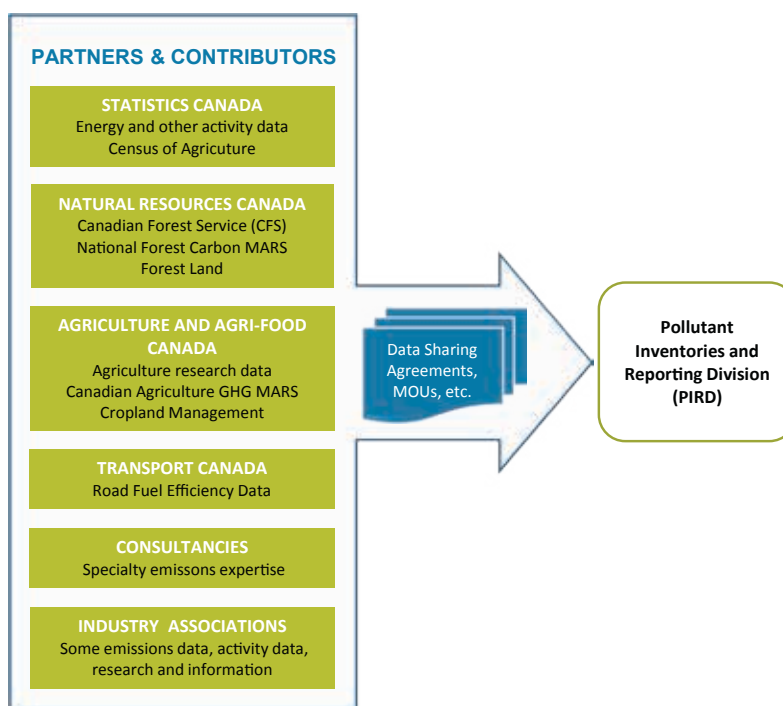
namely Statistics Canada, Natural Resources Canada (NRCan), Agriculture and Agri-Food Canada (AAFC), and Transport Canada; arrangements with industry associations, consultants and universities; and collaborative agreements with provincial and territorial governments on a bilateral basis.

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

1.2.1.1.   Statistics Canada

Canada's national statistical agency, Statistics Canada, provides Environment Canada with a large portion of the underlying activity data to estimate GHG emissions for the Energy and the Industrial Processes and Product Use Sectors. Statistics Canada is responsible for the collection, compilation and dissemination of Canada's energy balance in its annual *Report on Energy Supply and Demand in Canada* (RESD). The energy balance is transmitted annually to Environment 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 RESD and ICE data and provide advice, direction and recommendations on improvements to the energy balance. Refer to Annexes 3 and 4 of this report for additional information on the use of the energy balance in the development of energy estimates.

Statistics Canada also collects other energy data, such as mining and electricity information, and other non-energy-related industrial information, including urea and ammonia production information. 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 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

1

established formal and explicit governance mechanisms to that effect through memoranda of understanding (MOUs).

NRCan/CFS annually develops and delivers estimates for forest land and harvested wood products, land conversion to forest land (afforestation) and forest land converted to other land (deforestation). The Deforestation Monitoring Group provides estimates of forest conversion activity.

AAFC delivers cropland estimates 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.

In addition, the Earth Science Sector of NRCan has supported the development of Earth observation products to improve land information within LULUCF.

Environment Canada manages and coordinates the annual inventory development process, develops all other LULUCF estimates, undertakes cross-cutting quality control and quality assurance, and generally 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 fuel efficiency data are provided by both Transport Canada and NRCan.

Environment Canada annually collects GHG emissions data from facilities that directly emit large amounts of GHGs under its GHG Emissions Reporting Program (GHGRP). The facility-level GHG data are used as an important component of the overall inventory development process in comparing and verifying certain inventory estimates in the NIR. For more information on the facility data reported under the GHGRP, refer to Section 1.3.4.1.

A bilateral agreement with the Aluminum Association of Canada (AAC) has been signed, under which process-related emission estimates for CO_2, PFCs and SF_6 are to be provided annually to Environment Canada. A similar agreement has been negotiated with the Canadian Electricity Association (CEA) for provision of SF_6 emissions and supplementary data relating to power transmission systems. Environment 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.

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. During February the NIR text and CRF tables are 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.

Over the months of February 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

Figure 1–3   Inventory Preparation Process
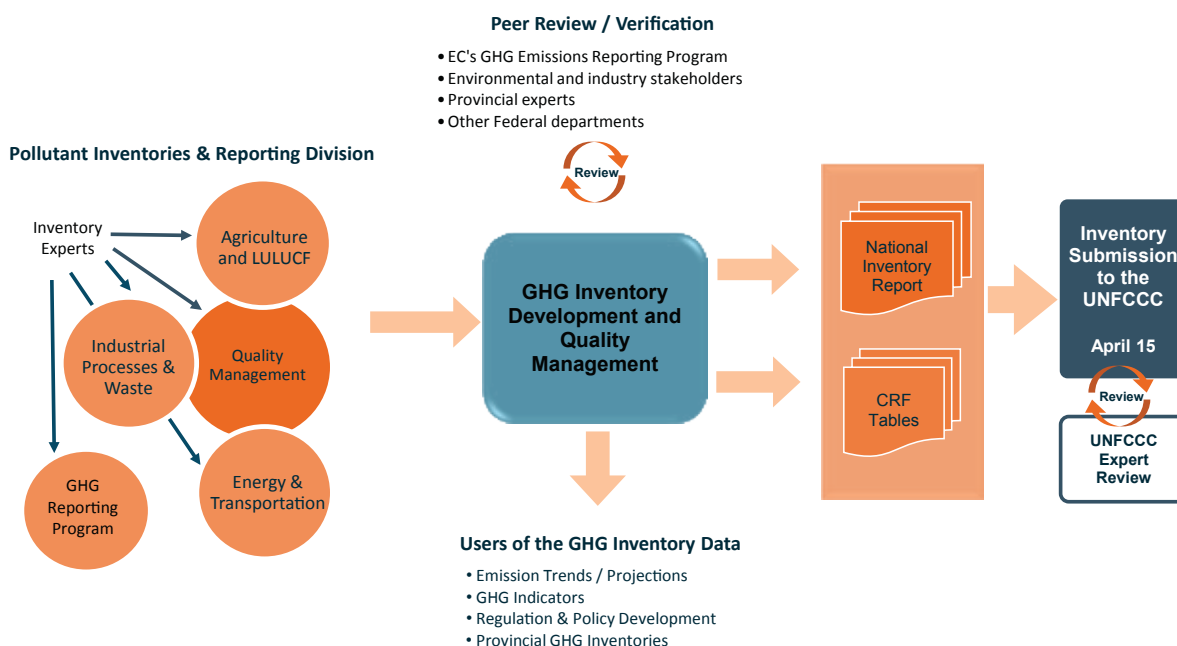
checks of the April submission are performed by the UNFCCC in May and June. Once finalized, the NIR is then translated and made available in French.

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, proce-

dures 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 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 schedule for completing the various NIR related tasks and activities.

1.3.2. Canada's Quality Assurance/ Quality Control Plan

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

Documentation of QA/QC procedures is at the core of the Plan. Standard checklists are used for the consistent, systematic

documentation of all QA/QC activities in the annual inventory preparation and submission. QC checks are completed during each stage of the annual inventory preparation and archived along with other procedural and methodological documentation, by inventory category and by submission year.

1.3.2.1. Quality Control Procedures

Quality control procedures consist of routine technical checks to measure and control the quality of the inventory, ensure data consistency, integrity, correctness and completeness, and identify and address errors and omissions. The QC procedures (Tier 1 and Tier 2) 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 2010.

External partners and contributors are relied upon to provide activity data and/or develop GHG estimates (e.g. Statistics Canada, LULUCF partners, industry associations) and in such cases are responsible for delivering error-free, consistent information. In addition, inventory experts perform additional QC procedures on the data in addition to QC procedures already implemented by the external agencies. As well, inventory experts must assess and document the QA/QC procedures in their respective data collection systems to determine whether they meet the minimum requirements of the QA/QC plan.

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—after the submission of the latest NIR, and before the start of the next inventory cycle—to ensure there is enough time to consider improvements scheduled for implementation. 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 1999), it collects GHG emissions information annually. As per the legal notice published annually in the *Canada Gazette*, facilities that have emissions of 50 kt CO_2 eq or more during any given year are required to submit a GHG emission report by June 1 of the following year. Voluntary submissions from facilities with GHG emissions below the reporting threshold are accepted.

The types of large industrial facilities reporting GHG emissions to Canada's GHGRP include:

- 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 own particular industry or application. However, reporting facilities must use methods for estimating emissions that are consistent with the guidelines adopted by the UNFCCC and developed by the IPCC 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 Canada's GHGRP website[5] provides public access to the reported GHG emission information (GHG totals by gas by facility). The total facility-reported GHG emissions for 2013 represent just over one third (36%) of Canada's total GHG emissions in 2013 (726 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 50-kt reporting threshold (Figure 1–4).

Facility-level GHG emission data are used, where appropriate, to confirm 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 on GHG emissions. 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 Canada's GHGRP, including short- and long-term changes observed in facility emissions, refer to *Facility Greenhouse Gas Emissions Reporting Program – Overview of Reported 2013 Emissions* (Environment Canada 2015).

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

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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.

Figure 1–4   2013 Facility-Reported Emissions as a Percentage of Industrial GHG Emissions by Province/Territory
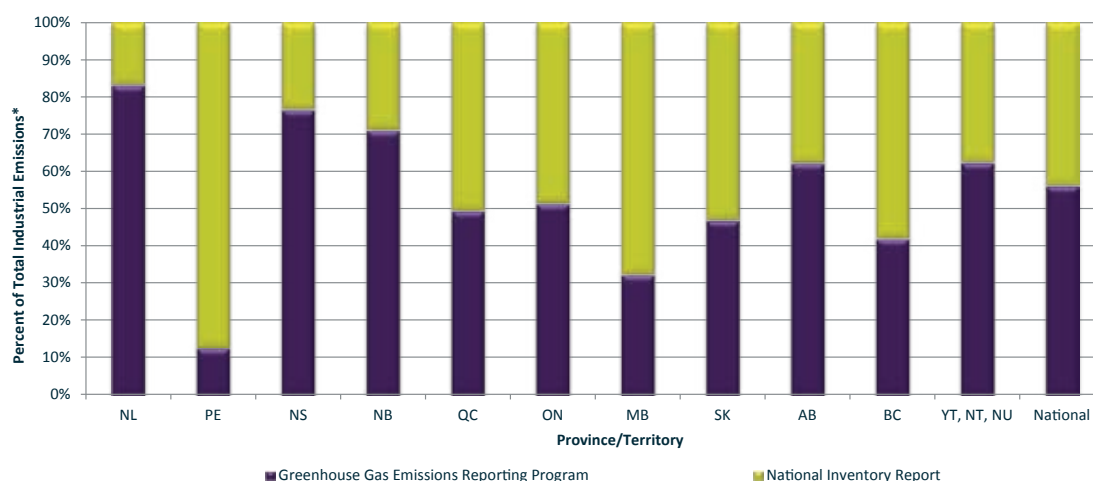
* Canada's industrial GHG emissions include the following GHG categories from the *National Inventory Report 1990–2013: Greenhouse Gas Sources and Sinks in Canada:* Stationary Combustion Sources (except Residential), Other Transportation, Fugitive Sources, Industrial Processes and Product Use, and Waste.

review taking place in 2014.[6] Review reports are posted on-line by the UNFCCC Secretariat once finalized.[7] At the time of preparing this NIR, the results of Canada's in-country review were still forthcoming.

1.5.   Methodologies and Data Sources

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

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

While not mandatory, the UNFCCC reporting guidelines encourage Parties to provide information on the following indirect GHGs: SO_x, NO_x, CO and NMVOCs (see Annex 7: Ozone and Aerosol Precursors). For all sectors except LULUCF, these gases are inventoried and reported separately to the United Nations Economic Commission for Europe.[8]

In general, an inventory of emissions and removals can be defined as a comprehensive account of anthropogenic emissions by sources and removals by sinks where and when they occur, consistent with the specified time frame and 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.

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.

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

7   Annual Inventory Review Reports are available online at http://unfccc.int/national_reports/annex_i_ghg_inventories/inventory_review_reports/items/8452.php.

8   Available online at http://www.ceip.at/.

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For the 1990–2013 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[9] in the inventory estimates may be caused by systematic and/or random uncertainties present within the input parameters or estimation models. Quantifying and reducing uncertainty may require in-depth reviews of the estimation models, improvements to the activity data regimes and evaluation of emission factors and other model parameters. In a limited number of cases, uncertainty may be reduced based on a validation exercise with an independent data set, such as the total emissions reported by individual facilities in a given industry sector. IPCC guidelines specify that the primary purpose of quantitative uncertainty information is to assist in setting priorities to improve future inventories and to guide decisions about which methods to use. Typically, the uncertainties associated with the trends and the national totals are much lower than those associated with individual gases and sectors.

Annex 2 presents the uncertainty assessment for Canadian GHG emissions. While more complex (Approach 2) methods are in some cases applied to develop uncertainty estimates at the sectoral or category level, for the inventory as a whole these uncertainties were combined with the simple (Approach 1) error propagation method, using Table 3.3 in IPCC (2006). Separate analyses were conducted for the inventory as a whole with and without LULUCF. 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 ±3%, consistent with the previously reported range of -3% to +6%. The Energy Sector had the lowest uncertainty, at ±3%, while the Waste Sector had the highest uncertainty, at ±38%. The Industrial Processes and Product Use and Agriculture Sectors had uncertainties of ±8 and ±15%, respectively.

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

- Energy – Fuel Combustion – Other (Off-road) Transportation, N_2O;
- Energy – Fuel Combustion – Public Electricity and Heat Production, CO_2;
- Waste – Solid Waste Disposal on Land, CH_4;
- Energy – Fuel Combustion – Manufacturing Industries and Construction, CO_2; and
- Agriculture – Agricultural Soils – Indirect Emissions, N_2O.

When the LULUCF emissions and removals are included, the uncertainty in the national total was found to be 13%.

The trend uncertainty, not including LULUCF, was found to be 0.56%. Therefore, the total increase in emissions since 1990 has a 95% probability of being in the range of 17.9 to 19.1%. 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.

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).

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

Chapter 2

Greenhouse Gas Emission Trends

2.1. Summary of Emission Trends

In 2013, Canada's greenhouse gas (GHG) emissions, excluding the Land Use, Land-use Change and Forestry (LULUCF) Sector, were 726 megatonnes of carbon dioxide equivalent (Mt CO_2 eq),[1] a net increase of 113 Mt in total emissions or 18% over 1990 emissions. Steady increases in annual emissions characterized the first 15 years of this period, followed by fluctuating emission levels between 2005 and 2008, a steep drop in 2009, and a slight increase thereafter.

The two largest contributors to this long-term increase in emissions are Transport at 56 Mt and Fossil Fuel Industries[2] at 54 Mt. Significant increases in oil and gas production and in the use of motor vehicles are the main drivers of this rise in emissions.

In 2013, GHG emissions were approximately 23 Mt (3.1%) lower than in 2005, primarily due to decreases in Public Electricity and Heat Production. During this period, GHG emissions from electric power generation decreased by about 37 Mt, primarily the result of reduced generation by coal (especially in the province of Ontario), switching to renewable energy generation (hydro, solar and wind), nuclear, or less GHG-intensive sources (natural gas), and improved efficiencies in combustion generation. Emissions in the Industrial Processes and Product Use (IPPU) Sector decreased overall by about 7 Mt (11.2%) between 2005 and 2013. These decreases in emissions were offset by emission increases from the Fossil Fuel Industries (24 Mt) and from Transport (8.8 Mt).

Between 2012 and 2013, emissions increased by 1.5% (11 Mt). This change was primarily due to a 2.8 Mt increase in emissions from the Fossil Fuel Industries and a 1.5 Mt increase in Residential emissions (mostly from heating).

Section 2.3 provides more detail on the drivers of these long- and short-term trends.

Since 1990, Canada's gross domestic product (GDP) grew much more (about 71%) than GHG emissions; the overall economic GHG intensity of the Canadian economy (or GHGs per $GDP) decreased by about 31% (Table 2–1). These long-term changes can be attributed to increases in efficiency, the modernization of industrial processes, and structural changes in the composition of the economy (e.g. a shift from industrial-oriented to more service-based industries). Over the long term, the link between growth in GDP and emissions has weakened, resulting in the decoupling of economic growth and emissions.

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

2   Fossil Fuel Industries are the sum of the categories *Petroleum Refining and Mining & Upstream Oil and Gas Production* shown in the National and Provincial Summary Tables of Annexes 9 and 10 in this document. Fossil Fuel Industries comprise the sum of CRF categories Petroleum Refining (1.A.1.b), Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c) and Mining (1.A.2.g.iii).

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

Year	1990	2000	2005	2009	2010	2011	2012	2013
Total GHG (Mt)	613	745	749	699	707	709	715	726
Change Since 2005 (%)	NA	NA	NA	-6.7%	-5.6%	-5.3%	-4.5%	-3.1%
Change Since 1990 (%)	NA	21.6%	22.2%	14.0%	15.4%	15.7%	16.7%	18.5%
GDP - (Billions 2007$)	989	1324	1496	1537	1587	1633	1663	1689
Change Since 2005 (%)	NA	NA	NA	2.7%	6.1%	9.2%	11.2%	12.9%
Change Since 1990 (%)	NA	33.8%	51.2%	55.3%	60.4%	65.0%	68.1%	70.7%
GHG Intensity (Mt/$B GDP)	0.62	0.56	0.50	0.45	0.45	0.43	0.43	0.43
Change Since 2005 (%)	NA	NA	NA	-9.2%	-11.0%	-13.3%	-14.1%	-14.2%
Change Since 1990 (%)	NA	-9.2%	-19.2%	-26.6%	-28.1%	-29.9%	-30.6%	-30.6%

GDP Data Source: Statistics Canada. 2014a. Table 380-0106 - Gross domestic product at 2007 prices, expenditure-based, annual (dollars), CANSIM (database).

How the Use of Updated Global Warming Potentials Impacts Canada's Emission Trends

This inventory report represents Canada's first inventory submission to the UNFCCC following the revision of the UNFCCC reporting guidelines on annual inventories for Annex I Parties (UNFCCC Reporting Guidelines), as adopted through Decision 24/CP.19 at COP 19 in Warsaw in 2013. As such, this inventory applies updated global warming potentials (GWPs) to normalize emissions of all GHGs to a reference gas (CO_2) in accordance with the revised reporting guidelines (Table 2–2). These updated GWP values reflect the refined scientific understanding of the impact of each greenhouse gas on the atmosphere's radiative balance, compared to CO_2.

Table 2–2   Examples of Global Warming Potentials (GWPs) Over a 100-Year Time Horizon

Greenhouse Gas	GWP used in past reports	Updated GWP	% Change
Carbon Dioxide (CO_2)	1	1	-
Methane (CH_4)	21	25	19.0%
Nitrous Oxide (N_2O)	310	298	-3.9%
HFC 134a	1 300	1 430	10.0%
PFC: CF_4	6 500	7 390	13.7%
Sulphur hexafluoride (SF_6)	23 900	22 800	-4.6%

Note: Chapter 1 provides a complete list of greenhouse gases and GWPs used in this report.

 The impact of the updated GWPs ranges from an increase of 16–19 Mt CO_2 eq (2.3% to 2.7%) in total emissions for any given year throughout the time-series (Figure 2–1). The updated GWP values also alter the relative contributions of each of the GHGs to Canada's national total (expressed in CO_2 eq). Importantly, the change in GWP alone does not affect emissions trends, regardless of how these emissions are expressed (Mt CH_4 or Mt CO_2 eq); (Table 2–3). Chapter 1, Section 1.1.2, of this report provides more information about greenhouse gases and their associated GWPs.

In addition to using updated GWPs, this inventory has also implemented several methodological changes. Chapter 8 of this report summarizes these changes and the resulting recalculations. These methodological changes and the updated GWPs can interact with one another in non-intuitive ways. For example, methodological improvements to the calculations of methane emissions have resulted in an overall decrease in methane emissions in recent years, compared to emissions reported from the same sources in 2014. However, due to the change in GWP, methane emissions expressed in CO_2 eq are nevertheless higher over the same period (Figure 2–3).

Figure 2–1   Impact of Updated Global Warming Potentials on Annual GHG Emissions in Canada
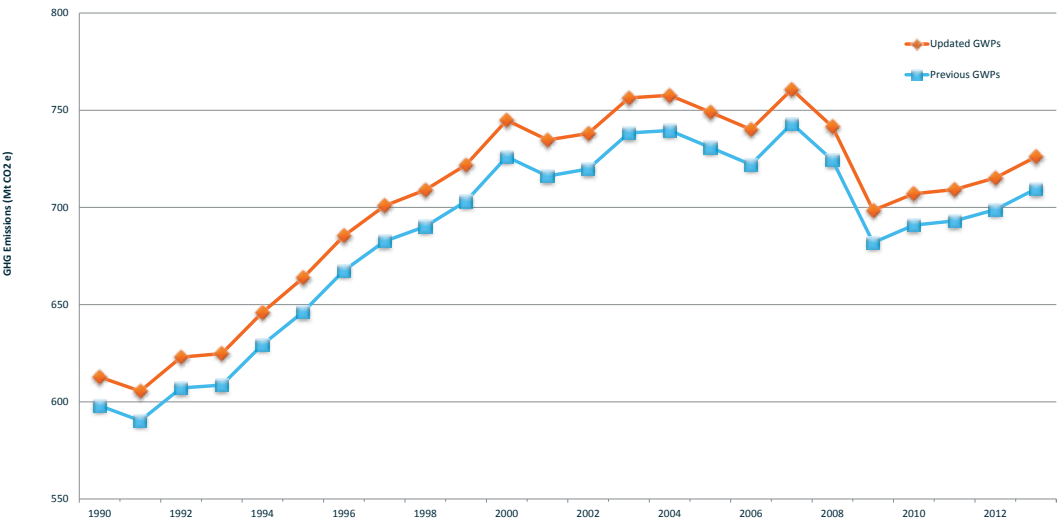
Figure 2–2   Recalculation of Methane Emissions and Use of Updated GWPs
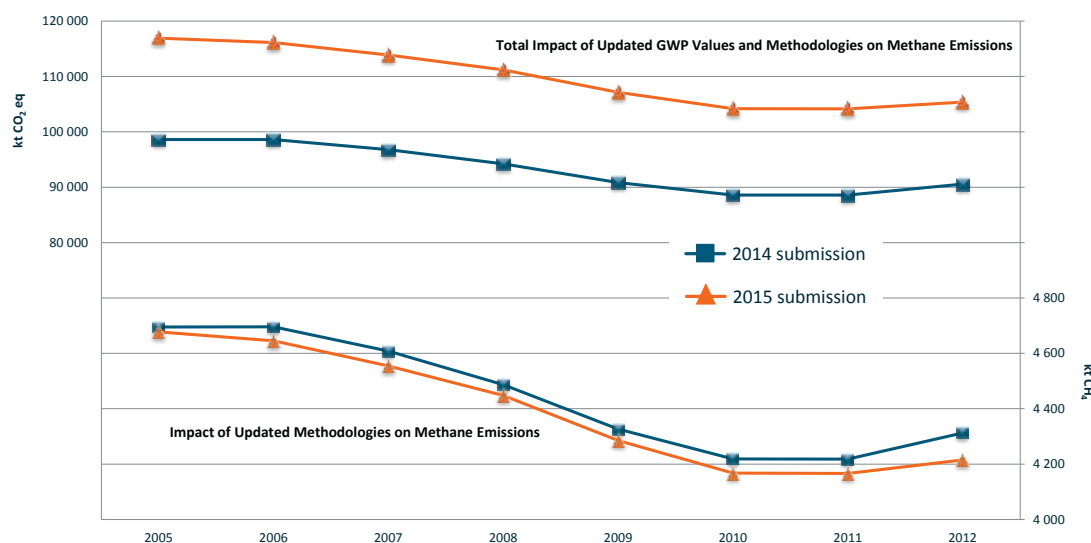
Note: The two bottom lines refer to the right-hand axis and show the impact of methodological changes alone on CH₄ emissions between 2005 and 2012 (overall downward shift in trend line). The two top lines refer to the left-hand axis and show impact on total reported CH₄ emissions (expressed in CO₂ eq) due to use of updated GWPs and methodological improvements (overall upward shift in trend line).

Table 2–3   Recalculations of Methane Emissions and Use of Updated GWPs

	2014 NIR – Previous GWPs				2015 NIR – Updated GWPs			
	Emissions		2005-2012 Trend		Emissions		2005-2012 Trend	
	2005	2012	Absolute	% Diff	2005	2012	Absolute	% Diff
Methane (kt)	4 695	4 313	382	-8.1%	4 677	4 215	462	-9.9%
Methane (kt CO₂ eq)	98 601	90 563	8 038		116 931	105 370	11 561	

2.2.   Emission Trends by Gas

Carbon dioxide (CO_2) is the largest contributor to Canada's GHG emissions (Figure 2–2), and its relative contribution changed slightly between 1990 and 2013 (76% vs. 78%, respectively). The majority of these emissions result from the combustion of fossil fuels. Methane (CH_4) accounted for 15% of Canada's total emissions in 2013, largely from fugitive emissions from oil and natural

Figure 2–3   Relative Contribution of GHGs to Canada's Total Emissions, 1990 and 2013 (excluding LULUCF)
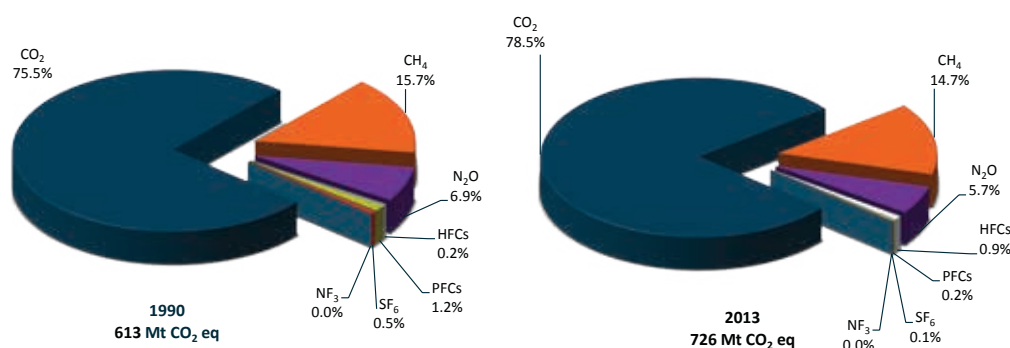
gas systems, as well as Agriculture and Waste. Nitrous oxide (N_2O) emissions from activities such as agriculture soil management and transport accounted for 6% of the emissions, while perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and nitrogen trifluoride (NF_3) accounted for the remainder of the emissions (slightly more than 1%).

2.3. Emission Trends by IPCC Category

Although increases in emissions from the Fossil Fuel Industries and Transport account for most of the emission trends since 1990, emission growth has also occurred in the categories of Fugitives – Oil and Natural Gas Sources (11 Mt), Agriculture (11 Mt), Non-Energy Products from Fuels and Solvent Use (11 Mt), Production and Consumption of Halocarbons, SF_6, and NF_3 (5 Mt), and Commercial/Institutional (3 Mt), while the Manufacturing Industries (Energy) and the Chemical Industry (Industrial Processes) showed emission declines of about 10 Mt each.

2.3.1. Energy Sector (2013 GHG Emissions, 588 Mt)

Energy-related activities are 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 Fuel Combustion Activities (either stationary or transport), Fugitive Emissions from Fuels and CO_2 Transport and Storage (Table 2–4). A detailed description of each category is provided in Chapter 3.

Overall, Fuel Combustion, Fugitive Emissions from Fuels and CO_2 Transport and Storage accounted for 588 Mt or 81% of total Canadian GHG emissions in 2013 (Table 2–4). Emissions from Fuel Combustion (529 Mt) largely dominate the sector. Between 1990 and 2013, fuel combustion-related emissions increased by 93 Mt (which includes 56 Mt in Transport), while emissions from Fugitive Emissions – Oil and Natural Gas rose by about 11 Mt. Combustion emissions in the Mining subcategory increased by about 544% (37 Mt), more rapidly than any other category in the Energy Sector due to increased oil sands mining and extraction activities.

2.3.1.1. Emissions from Fuel Combustion (2013 GHG Emissions, 529 Mt)

GHG emissions from Fuel Combustion activities rose from 436 Mt in 1990 to 529 Mt in 2013, a 21% increase (Table 2–4). The Fuel Combustion activities category is divided into the following IPCC categories: Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors (Table 2–4).

Energy Industries (2013 GHG Emissions, 156 Mt)

GHG emissions from Energy Industries accounts for the second-largest portion (21%) of Canada's fuel combustion-related emissions, behind Transport (28%). GHG emissions included in this category are from stationary sources producing, processing and refining fuels. These sources include Public Electricity and Heat Production, Petroleum Refining, and Manufacture of Solid Fuels and Other Energy Industries. In 2013, combustion emissions from Energy Industries totalled 156 Mt, an increase of 7% from the 1990 level of 146 Mt.

Table 2–4 GHG Emissions form Energy by IPCC Category, Selected Years

GHG Sources/Sinks	GHG Emissions (Mt CO_2 eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Energy	485	606	601	563	573	576	577	588
Fuel Combustion (Sectoral Approach) (1.A)	436	537	539	508	518	520	519	529
Energy Industries (1.A.1)	146	200	193	165	165	157	156	156
Manufacturing Industries and Construction (1.A.2)[1]	58.1	57.3	50.2	41.7	42.8	46.3	46.0	47.6
Mining (1.A.2.F.ii)	6.8	12.2	19.1	31.8	34.8	35.9	42.4	43.8
Transport (1.A.3)	148	182	195	190	200	199	199	204
Other Sectors (1.A.4)[2]	77.2	85.4	81.9	79.2	75.7	81.3	76.0	78.2
Fugitive Emissions (1.B)	49.0	70.0	61.0	56.0	55.0	56.0	57.0	59.0
Solid Fuels (Coal) (1.B.1)	3.0	2.0	2.0	1.0	2.0	2.0	2.0	2.0
Oil and Natural Gas (1.B.2)	46.0	68.0	59.0	54.0	53.0	54.0	56.0	57.0
CO_2 Transport and Storage (1.C)	-	0.09	0.09	0.09	0.09	0.09	0.09	0.09

Note:
Totals may not add up due to rounding.
1. Mining emissions are shown separately because the majority of emissions in this subcategory are from oil and gas extraction.
2. Other Sectors comprise Residential and Commercial emissions, as well as contributions from stationary fuel combustion in Agriculture and Forestry

Table 2–5   GHG Emissions from Public Electricity and Heat Production, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)								Change (%)
	1990	2000	2005	2009	2010	2011	2012	2013	1990–2013
Electricity Generation[1]	94.5	131	124	100	102	94.5	89.0	87.5	-7.4%

Note: Totals may not add up due to rounding.
1.   Currently all Public Electricity and Heat Production is found under the Electricity Generation subcategory.

Public Electricity and Heat Production[3]
(2013 GHG Emissions, 87.5 Mt)

This subcategory accounts for 12% (87.5 Mt) of Canada's 2013 GHG emissions (Table 2–5) and for a 7.4% decrease in emissions between 1990 and 2013.

GHG emissions from the Electricity Generation subcategory are unique in that electricity is generated to meet an instantaneous demand and, depending on the characteristics of that demand, the supply source can fluctuate between non-GHG-emitting and high-GHG-emitting sources. Electricity generation increased by 31% between 1990 and 2013 (Statistics Canada 1990–2004b, 2005–2013a, 2005–2013b); however, a less GHG-intensive mix of sources used to generate electricity in the latter part of the period more than offset this increase in demand so that emissions dropped by 7 Mt over the same period. Likewise, between 2005 and 2013, when generation rose by 2%, emissions fell by 29% (36.6 Mt).

Figure 2–5 shows the net effects of the factors driving Electricity emissions between 1990 and 2013, when emissions fell by 7%. Figure 2–6 demonstrates the strong impact that changes in the generation mix had in the latter part of the period, between 2005 and 2013.

Demand – Demand refers to the level of electricity generation activity in the utility sector, and consists of generation from combustion and non-combustion sources. In 2013, the amount of electricity generated was 31% higher than in 1990. This is due in part to a 270% increase in electricity exports to the United States (Statistics Canada 1990–2004b, 2005–2013a, 2005–2013b), which now accounts for 11% of the overall electricity demand.

Generation mix – The generation mix refers to the relative share of combustion and non-combustion sources in generation activity. Non-combustion sources include renewable generation (wind turbines, solar photovoltaic cells, tidal and hydroelectric generation), as well as nuclear generation. Combustion and noncombustion sources respectively account for 3% and 97% of the increased generation between 1990 and 2013, improving the generation mix to one that is much less GHG-intensive. Renewable sources contributed 65% of the total electricity generated in Canada in 2013. Smaller, distributed renewable generation is becoming part of the generation mix. With over 6.9 gigawatts (GW) of installed wind capacity as of 2013 (CANWEA, 2013), wind power accounts for over 2% of Canada's electricity generation. Solar generation, with an installed capacity of 1.2 GW (CANSIA, 2013), accounts for less than 0.5% of the total generation; however, its contribution to the generation mix increased by 14% between 2012 and 2013. In addition, hydroelectric generation has increased by 36% since 1990 and by 9% since 2005. Overall, renewable generation has increased by 40% since 1990. The increased level of non-combustion sources in the generation mix in 2013 was the largest contributor to emission reductions since 1990 (-19.6 Mt), and 2005 (-27.6 Mt) (Statistics Canada 1990–2004b, 2005–2013a, 2005–2013b).

Fuel mix (combustion generation) – Between 1990 and 2013, the quantity of electricity generated by natural-gas-fired units increased by over 31 terawatt-hours (TWh), while the amount generated by coal and refined petroleum products decreased by about 21 TWh and 13 TWh, respectively. Coal plant electricity generation peaked in 2000 and has since decreased steadily; in 2013, it was 43% less than its 2000 level. Natural gas combustion is about half as carbon-intensive as coal and approximately 25% lower than most refined petroleum products, so the switch from other fuels to natural gas resulted in a decrease in the GHG intensity of combustion from electricity generation. The overall fuel switching impact was -10 Mt between 1990 and 2013 and -4.8 Mt between 2005 and 2013.

Energy efficiency and emission factors – Energy efficiency refers to the efficiency of the equipment used in combustion-related generation of electricity. Changes in fuel energy content over time are reflected in emission factors. The change between 1990 and 2013 largely relates to variations in natural gas emission factors by province, variations in emission factors and energy contents of types of coal, and variations in the petroleum coke emission factor.

For more information on electricity generation and trends, see Annex 11 – Electricity Intensity Tables.

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3   The Public Electricity and Heat Production subcategory corresponds to the IPCC definition (see Section 3.2.1 for a detailed source description). This category includes emissions from utilities and from industrial facilities whose surplus production is supplied to the grid. This allocation is not identical to the allocation used for defining economic categories in Section 2.4. Some utilities are provincially owned, whereas others are privately owned.

Combustion-Based Electricity Generation and GHG Emissions

Emissions of GHGs from electricity generation are primarily driven by demand, by the amount of electricity generated from combustion (the "generation mix") and by the types of fuel used.

Figure 2–4   Public Electricity Generation by Source and GHG Emissions, 1990–2013[1,2]
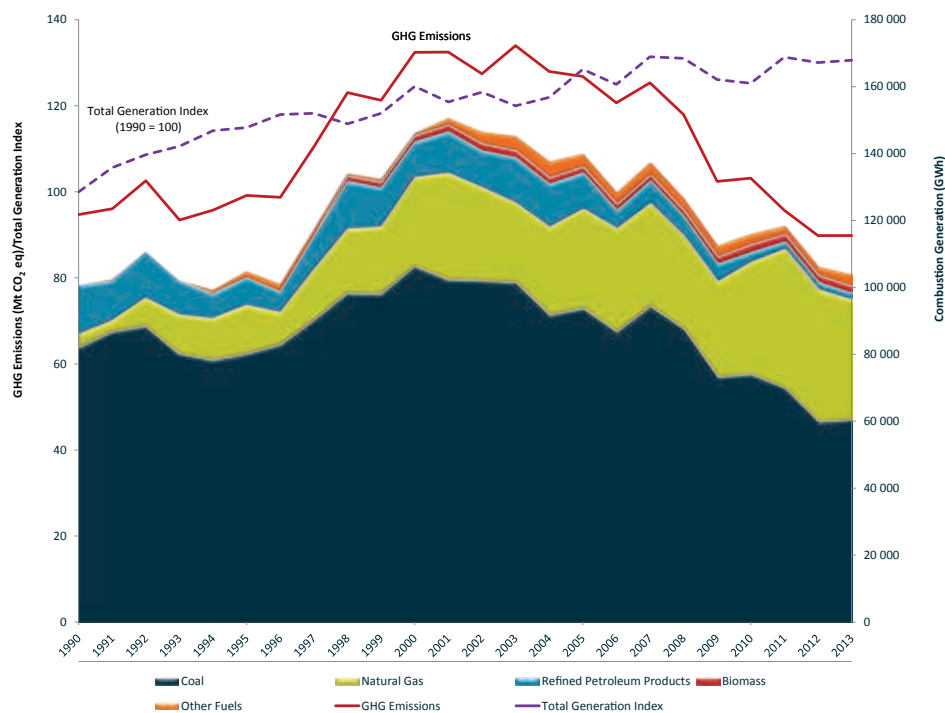
From 1994 to 2000, emissions rose 38%, although generation increased by only about 9%; however, the use of coal, oil and natural gas in generation increased rapidly during that time (36%, 45% and 113%, respectively). Emissions peaked in 2003 and then decreased by 32% over the next 10 years, during which time the use of coal and oil in generation dropped rapidly (-53% and -139% respectively), while the use of natural gas rose by an additional 30%. The shift towards a less carbon-intensive fuel such as natural gas resulted in a decline in emissions. The gradual elimination of coal-fired generation of electricity in Ontario has contributed significantly to this trend. In 2005, the Lakeview coal-fired generating station was shut down, followed by many others. By the end of 2013, all Ontario coal generating stations, except for one (Thunder Bay), had been permanently taken out of service.[3,4,5]

In addition, between 1990 and 2013, the generation mix changed considerably in favour of non-combustion sources (such as hydro, nuclear and other renewables), which has also contributed to the decline in GHG emissions.

Notes:
1.   Generation statistics refer to utility-based generation, which contributes approximately 91% of the total supply.
2.   Electricity subcategory emissions do not include SF_6 emissions associated with transmission and distribution.
3.   Ontario Power Generation. 2014a. OPG's Nanticoke Station Stops Burning Coal. [cited 2015 Feb 3]. Available online at: http://www.opg.com/news-and-media/news-releases/.
4.   Ontario Power Generation. 2014b. Ontario Power Generation Moves to Cleaner Energy Future: Thunder Bay Station Burns Last Piece of Coal. [cited 2015 Feb 3] Available online at: http://www.opg.com/news-and-media/news-releases/.
5.   Ontario Ministry of Energy. 2011. Ontario Shutting Down Two More Coal Units. [cited 2015 Feb 3]. Available online at: http://news.ontario.ca/mei/en/2011/12/ontario-shutting-down-two-more-coal-units.html.

Figure 2–5   Influence of Contributing Factors on Change in Electricity Emissions, 1990–2013 (Mt CO$_2$ eq)
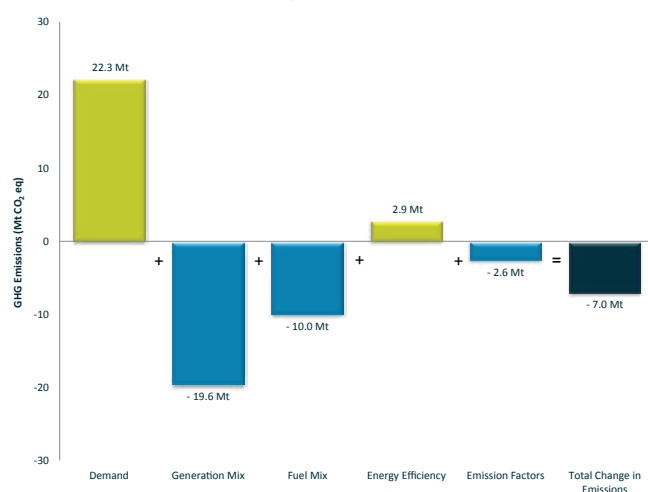
Figure 2–6   Influence of Contributing Factors on Change in Electricity Emissions, 2005–2013 (Mt CO$_2$ eq)
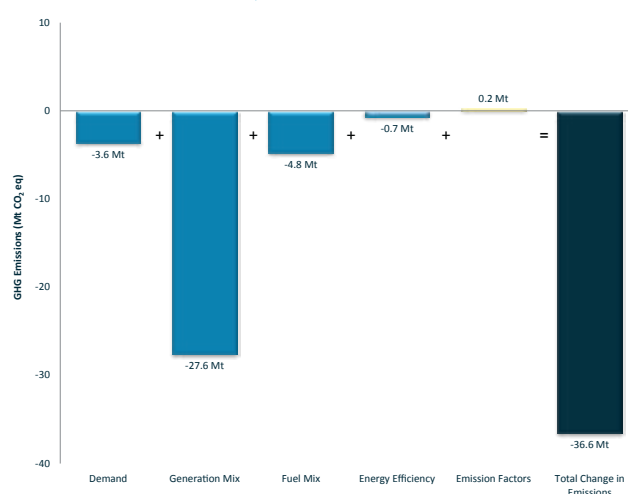
Note: Emissions shown in the figures include those from electricity generation, but exclude SF$_6$ emissions from power transmission and distribution.

Table 2–6   GHG Emissions from Petroleum Refining, Mining and Upstream Oil and Gas Production (Fossil Fuel Industries), Selected Years

GHG Source Category	GHG Emissions (Mt CO$_2$ eq)								Change (%)
	1990	2000	2005	2009	2010	2011	2012	2013	1990–2013
Energy - Fuel Combustion - Energy Industries (CRF Sector: 1.A.1)									
Petroleum Refining (1.A.1.b)	17.1	17.3	20.2	19.0	18.1	17.3	18.7	18.4	8%
Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c)	34.3	51.1	48.7	46.0	45.1	45.7	48.2	49.8	45%
Energy - Fuel Combustion - Manufacturing Industries and Construction (CRF Sector: 1.A.2)									
Other - Mining (1.A.2.g.iii)	6.8	12.2	19.1	31.8	34.8	35.9	42.4	43.8	544%
Total	58	81	88	97	98	99	109	112	93%

Note: Stationary combustion only, excluding fugitive emissions. Totals may not add up due to rounding.

Fossil Fuel Industries
(2013 GHG Emissions, 112 Mt)

Within the Fossil Fuel Industries,[4] Petroleum Refining mainly includes emissions from the combustion of fossil fuels during the production of refined petroleum products, whereas Manufacture of Solid Fuels and Other Energy Industries encompass fuel combustion emissions associated with producers' own use of fuel in the upstream oil and gas (UOG) and coal mining industries. The Mining subsector includes emissions associated with the combustion of purchased fuel in the oil extraction (including crude bitumen from the oil sands), natural gas and coal extraction industries, and non-energy mining, such as iron ore, gold, diamonds, potash and aggregates. As shown in Table 2–6, between 1990 and 2013, emissions from the Petroleum Refining, Manufacture of Solid Fuels and Other Energy Industries and

Mining subsectors increased by about 54 Mt, or 93%. This growth is due to increases in natural gas and oil production, particularly crude bitumen and heavy crude oil, largely for export.

The breakdown of Canada's Fossil Fuel Industries emissions by IPCC categories does not provide a complete and coherent view of trends within Canada's oil and gas sector. A clearer account of emissions from Fossil Fuel Industries is provided in Table 2–14, 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. The data show that the Coal Production and Non-energy Mining industries account for a comparatively small portion of the overall emissions from Fossil Fuel Industries.

In 2013, approximately 87% of the total oil and gas sector emissions can be attributed to the upstream fossil fuel industry, while the downstream portion (oil refining and natural gas

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4   Fossil Fuel Industries encompass the following CRF sectors: Petroleum Refining (1.A.1.b), Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c) and Mining (1.A.2.g.iii).

distribution) contributed the remaining 13% (Table 2–14). The largest contributions to total oil and gas sector emissions were Oil Sands (Mining, Upgrading and In-situ Extraction) (34%), Natural Gas Production and Processing (30%), Conventional Oil Production (18%) and Petroleum Refining (12%), with Oil and Gas Transmission and Natural Gas Distribution making up the remaining 5%. The primary drivers of emissions within the oil and gas sector are production growth and production characteristics (emissions intensity).

Production Growth

From 1990 to 2013, the production of total crude oil (conventional oil plus crude oil from oil sands) increased by 118% (Figure 2–7). The increase in total crude oil production was almost completely driven by Canada's oil sands operations, where total output (non-upgraded bitumen and synthetic crude oil production) has increased by almost 500%, with most of the growth occurring from 1996 onward (AER 2014a). Coinciding with the production increases, emissions from total crude oil production showed an increase of 55 Mt CO_2 eq (about 140%), with oil sands alone increasing by 46 Mt (310%).

Production of conventional crude oil grew from 1990 to peak in 2003, then decreased until 2009, and slowly increased after that time with improvements in extraction technology, including enhanced oil recovery (EOR) operations and multi-stage fracturing. Overall, emissions from conventional oil production increased by 8 Mt (34%) between 1990 and 2013.

In 2013, natural gas production and processing contributed 30% to total emissions in the oil and gas sector. Since 1990, emissions from natural gas production and processing have increased by 50% while production has increased by 45%. Reduced amounts of facilities' own use of natural gas (i.e. raw natural gas consumed by the facility that produced it) has been offset by increased fugitive emissions, largely the result of multi-stage fracturing techniques (Allen et al. 2013).

Production Characteristics (Emission Intensity)

The emission intensity of overall oil production in Canada—defined as the average amount of GHG emissions generated per barrel of oil equivalent—increased by about 12% between 1990 and 2013 (Figure 2–8). Contributors to this emission intensity trend include a reduction in easily removable reserves of conventional crude oil, which are being replaced with more energy- and GHG-intensive sources, including crude bitumen and synthetic crude oil (i.e. oil sands) production and heavier or more difficult-to-obtain conventional oils, such as those from offshore sources or those extracted using EOR 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).

Although increased production in Canada's oil sands has had the largest impact on emission intensity of overall oil production, the emission intensity of oil sands operations declined steadily from 1990 until about 2004, and since that time has remained fairly

Figure 2–7   Canadian Production of Fossil Fuels, 1990–2013
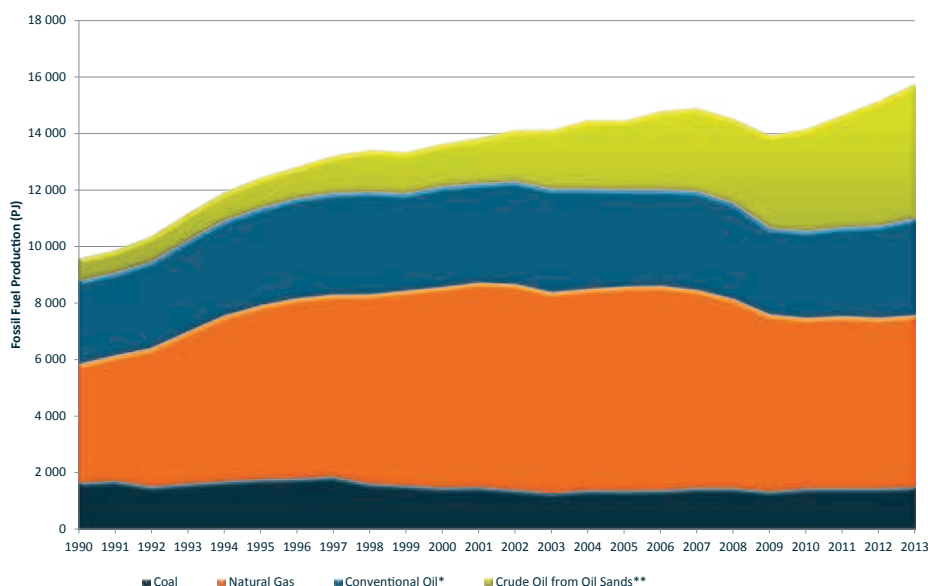
Notes:

* Conventional oil includes light, medium and heavy oil production and pentanes plus or condensates.
** Crude oil from oil sands operations includes non-upgraded crude bitumen and synthetic crude oil.

Figure 2–8   Emission Intensity by Source Type for Oil and Gas (1990, 2002 and 2013)
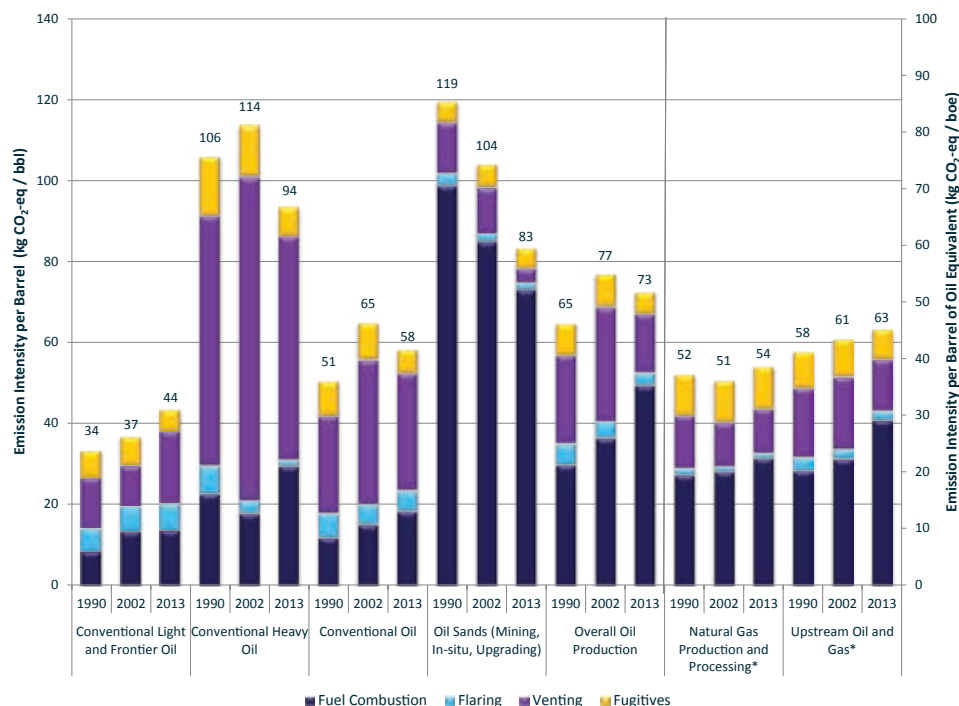
Notes:

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 are calculated on a barrel of oil equivalent (boe) basis. Boe is 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 / 10³ m³).

1 barrel (bbl) = 0.159 m³

Table 2–7   GHG Emissions from Manufacturing and Construction, Selected Years

GHG Source Category	GHG Emissions (Mt CO$_2$ eq)								Change (%)
	1990	2000	2005	2009	2010	2011	2012	2013	1990–2013
Iron and Steel	4.97	6.23	5.57	4.30	4.45	5.29	5.51	5.56	12%
Non-ferrous Metals	3.32	3.59	3.62	2.85	2.99	3.31	2.93	3.20	-4%
Chemicals	8.26	10.82	8.32	8.87	9.91	11.11	10.96	11.42	38%
Cement	3.96	4.63	5.43	4.48	4.07	4.29	4.05	3.89	-2%
Construction	1.88	1.08	1.45	1.22	1.51	1.44	1.46	1.44	-23%
Pulp, Paper and Print	14.6	12.6	8.7	6.4	6.0	6.3	6.0	6.5	-55%
Other Manufacturing[1]	21.2	18.2	17.1	13.5	13.9	14.6	15.1	15.5	-27%
Total	**58.1**	**57.3**	**50.2**	**41.7**	**42.8**	**46.3**	**46.0**	**47.6**	**-18%**

Note: Totals may not add up due to rounding.

1.   Mining emissions have been removed and are included in Fossil Fuel Industries.

static. The initial decline in emission intensity was due to technological innovation, equipment turnover and increased reliability across operations.

Manufacturing Industries and Construction[5]
(2013 GHG Emissions, 47.6 Mt)

Combustion 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, Construction and Other Manufacturing subcategories. In 2013, GHG emissions were 47.6 Mt (Table 2–7). GHG

5   The Mining subsector has been removed from Manufacturing Industries and Construction and included in the Fossil Fuel Industries for the purpose of this analysis, as the majority of emissions in this subsector are from oil and gas extraction.

emissions from the Manufacturing Industries and Construction category declined from 1996 until 2009. Since 2009, GHG emissions from this category have been steadily increasing; however, they still remain 18% (10.6 Mt) below 1990 levels. Overall, this category was responsible for 6.6% of Canada's total GHG emissions in 2013.

The Pulp, Paper and Print subcategory has shown the largest decrease within the Manufacturing Industries and Construction category. Between 1990 and 2013, this subcategory showed a decrease of 8 Mt (55%). In 1990, this subcategory accounted for 25% of the GHG emissions from the Manufacturing Industries and Construction category, but by 2013, it was reduced to 14%, largely due to closures in the industry along with the substitution of biomass-based fuels in place of conventional generation sources (a 57% increase from 1990 to 2013). The only subcategory providing a significant upward trend to balance these decreases is the Chemicals subcategory, which increased by 38% (3.2 Mt). This is largely due to increases in output; the GDP in the Chemicals subcategory increased by 44% in the same period.

Transport (2013 GHG Emissions, 204 Mt)

Transport is a large and diverse subsector. With 204 Mt of GHG emissions, it accounts for 28% of Canada's GHG emissions in 2013 (Table 2–8). This subsector includes emissions from fuel combustion for the transport of passengers and freight in six categories: Road Transportation, Domestic Aviation, Domestic Navigation, Railways, Off-road and Pipeline Transport.

GHG emissions from Transport are primarily driven by energy used for personal transportation (light-duty gasoline vehicles and trucks) and heavy-duty diesel trucks (Table 2–8).

From 1990 to 2013, Transport emissions rose 38% (56 Mt), accounting for almost one half of Canada's emissions growth. The growth in Road Transportation emissions is largely due to more driving: the total vehicle fleet increased by 53% since 1990 (15% since 2005) most notably in the light-duty gas truck (LDGT) and heavy-duty diesel vehicle (HDDV) subclasses (Table 2–9). Consequently, the kilometres travelled for all vehicles increased by 49% over the same time period.

Total passenger vehicle emissions are influenced by such factors as total distance travelled, vehicle type, fuel efficiency, fuel type and emissions control technology. For example, within the light-duty gasoline vehicle (LDGV) subcategory, the total number of light-duty vehicles and associated vehicle kilometres travelled[6] (VKTs) increased, while the fleet average fuel consumption ratio for LDGVs decreased, resulting in a net emissions decrease of 14% (from 45.9 Mt in 1990 to 39.4Mt in 2013).

Figure 2–9: depicts the overall impacts of major drivers for light-duty vehicles (excluding motorcycles):

Total Change is the difference in total emissions over the selected time periods, 1990-2013 and 2005-2013.

Fuel Efficiency effect represents the change in emissions due to the change in fuel consumption ratios (typically expressed as litres/100 km [7]) of the overall light-duty fleet. As reductions in fuel consumption ratios of new model-year vehicles replace less efficient older vehicles, the overall fleet fuel efficiency improves. This gradual improvement offsets emissions increases resulting from increased total kilometres travelled and shifts to the less efficient light-duty truck vehicle class.

Total VKT effect is the change in emissions attributable to the change in the total distance travelled, regardless of the choice of vehicle or fuel. An increase in VKTs is the primary driver of emissions increases between 1990-2013 and 2005-2013.

Vehicle Type effect represents the change in emissions due to the shift in relative share of total VKTs between different vehicle types and their inherent efficiencies. On average, light-duty trucks emit 45% more GHGs per kilometre than cars. Emissions from LDGTs, the subcategory that includes sport utility vehicles (SUVs), many pickups and all minivans, increased 110% between 1990 and 2013 (from 20.4 Mt in 1990 to 42.9 Mt in 2013); while a decrease in the associated fleet fuel consumption ratios was observed between 1990 and 2013, 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.

Fuel Switching effect represents the change in emissions due to the shift between more or less carbon-intense fuels (i.e. motor gasoline vs. diesel fuel). Its overall influence on emissions is minimal.

Overall Emission Factor effect represents the change in emissions due to the change in the aggregate emission factor (CO_2 eq) of the fleet. Since the CO_2 emission factor is constant across the time series, this reflects the impacts of changing emission control technologies on CH_4 and N_2O emissions.

In 2013, emissions from HDDVs contributed 43 Mt to Canada's total GHG emissions (an increase of about 112% 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

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6   Kilometre accumulation rate (KAR) is the average distance travelled by a single vehicle of a given class typically measured over a 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.

7   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).

Table 2–8   GHG Emissions from Transport, Selected Years

GHG Source Category	GHG Emissions (Mt CO$_2$ eq)							
	1990	**2000**	**2005**	**2009**	**2010**	**2011**	**2012**	**2013**
Transport (Total)	**148**	**182**	**195**	**190**	**200**	**199**	**199**	**204**
Domestic Aviation	7.2	7.7	7.6	6.5	6.5	6.2	7.3	7.5
Light-Duty Gasoline Vehicles	45.9	42.4	40.5	40.1	40.4	38.9	38.6	39.4
Light-Duty Gasoline Trucks	20.5	36.7	43.1	42.9	43.3	41.6	41.7	42.9
Heavy-Duty Gasoline Vehicles	7.53	5.53	6.61	6.99	7.10	6.77	6.94	7.31
Motorcycles	0.155	0.164	0.258	0.269	0.275	0.267	0.271	0.279
Light-Duty Diesel Vehicles	0.473	0.470	0.579	0.706	0.756	0.795	0.832	0.877
Light-Duty Diesel Trucks	0.708	1.680	1.940	2.050	2.110	2.070	2.160	2.210
Heavy-Duty Diesel Vehicles	20.2	31.1	38.0	39.4	40.6	42.4	42.1	42.9
Propane & Natural Gas Vehicles	2.20	1.10	0.73	0.79	0.78	0.82	0.88	0.72
Railways	7	7	7	5	7	8	8	7
Domestic Navigation	5.1	5.2	6.7	6.7	7.0	5.9	5.8	5.3
Off-road Gasoline	7.9	8.9	8.4	7.4	8.1	8.2	7.8	8.5
Off-road Diesel	16	23	24	25	30	32	31	32
Pipelines	6.91	11.30	10.20	6.36	5.72	5.65	5.73	6.39

Note: For full details on all years, please refer to Annex 9.

Table 2–9   Trends in Vehicle Populations for Canada, 1990–2013

Year	Number of Vehicles (000s)						
	Light-Duty Vehicles				**All Light-Duty Vehicles**	**Heavy-Duty Vehicles**	**All Vehicles**
	Gas Vehicles	**Gas Trucks**	**Diesel**	**Motorcycles**			
1999	10 646	3 308	221	261	14 437	920	15 356
2005	10 961	7 386	435	437	19 220	1 290	20 510
2009	11 897	8 043	478	475	20 893	1 414	22 308
2010	12 130	8 208	489	484	21 312	1 445	22 757
2011	12 267	8 304	497	490	21 559	1 466	23 025
2012	12 405	8 401	505	495	21 806	1 487	23 293
2013	12 542	8 498	513	501	22 053	1 508	23 561
Change Since 1990	18%	157%	133%	92%	53%	64%	53%
Change Since 2005	12%	12%	14%	12%	12%	14%	12%

Notes:
HDDVs = Heavy-Duty Diesel Vehicles; HDGVs = Heavy-Duty Gasoline Vehicles; LDDTs = Light-Duty Diesel Trucks; LDDVs = Light-Duty Diesel Vehicles; LDGTs = Light-Duty Gasoline Trucks; LDGVs = Light-Duty Gasoline Vehicles; MCs = Motorcycles.

Figure 2–9   Contributing Factors on Change in Light-Duty Vehicle Emissions, 1990-2013 and 2005-2013
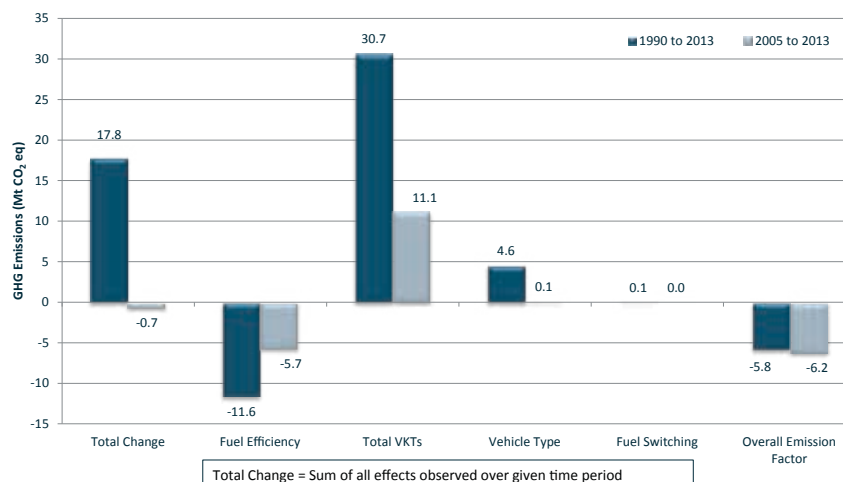
the freight transport mode, the trends in data from major for-hire truck haulers in Canada show conclusively that freight hauling by heavy trucks has increased substantially and that this activity is the primary task performed by HDGVs and HDDVs (Statistics Canada 2013). Further, the adoption of "just-in-time" delivery by many businesses has resulted in reliance on heavy trucks in the freight transportation sector, which sometimes act as virtual warehouses (NRCan 2013).

Off-road fuel combustion emissions[8] (gasoline and diesel combined) increased by 70%, from 24 Mt in 1990 to 41 Mt in 2013. The Domestic Aviation, Domestic Navigation and Railways categories combined contributed to approximately 10% of the Transport subsector emissions in 2013 and overall have been stable over the 1990-2013 time series.

Pipeline emissions are combustion emissions arising primarily from natural gas transport. Since 2005, emissions have been steadily decreasing and have begun to level off in the most recent years, mainly due to a 40% reduction in natural gas throughput volumes (Statistics Canada 2014b).

Residential and Commercial
(2013 GHG Emissions, 74.6 Mt)

Emissions in these subcategories arise primarily from the combustion of fuel to heat residential and commercial buildings, excluding electricity. Fuel combustion in the Residential and Commercial subcategories[9] accounted for 6.3% (46 Mt) and 4.0% (29 Mt), respectively, of all GHG emissions in 2013.

8   Off-road emissions include those from the combustion of diesel and gasoline in a wide variety of applications. Examples include the use of heavy mobile equipment in the construction, mining and logging industries, recreational vehicles such as snowmobiles and all-terrain vehicles (ATVs), and residential equipment such as lawnmowers and trimmers.

9   Commercial subcategory emissions are based on fuel use as reported in the *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada 57-003-X) 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.

Overall, residential emissions decreased by 3.1 Mt (6.4%) between 1990 and 2013, although they fluctuated on an annual basis. Over the short term, residential emissions increased by 1.5 Mt (3.5%) between 2012 and 2013. Commercial emissions increased 3.0 Mt between 1990 and 2013. Combined, emissions from the two subcategories remained relatively stable.

There are several major factors that influenced the changes in energy-related GHG emissions in the Residential and Commercial subcategories (Figure 2–10 and Figure 2–11, respectively).

Floor Space – In the Residential subcategory, both the population and the floor space use per capita are the most significant upward drivers, having increased 27% (Statistics Canada 2015) and 26% respectively between 1990 and 2013, pushing emissions upwards by 11.1 Mt and 10.7 Mt, respectively[10] (the sum of these two drivers represents the total impact of floor space).

In the Commercial subcategory, floor space alone was the most significant upward driver, having increased 45% since 1990,[11] causing a 10-Mt increase in emissions between 1990 and 2013. These impacts have been offset by energy efficiency improvements, changes in the fuel mix and changes in emission factors.

Weather – Fluctuations in weather conditions, particularly outdoor winter temperature, can have a non-negligible effect on emissions as suggested by the close tracking between heating degree-days (HDDs) and emissions (Figure 2–12). The influence that weather can have on space heating requirements and the demand for fuels results in emission patterns that mirror the inter-annual variability of weather. The "Reducing Heating Requirements in Commercial and Residential Buildings" sidebar provides additional information on how HDDs are calculated,

10   See Figure 2-9: Contributing Factors on Change in Light-Duty Vehicle Emissions, 1990-2013 and 2005-2013 for the trend in floor space in Canada.

11   Behidj N. 2015. Personal communication (email from Behidj N to Tracey K, Program Engineer, PIRD dated January 29, 2015). Office of Energy Efficiency, Natural Resources Canada.

Figure 2–10   Major Influences on the Change in Stationary GHG Emissions from the Residential Subcategory Between 1990 and 2013
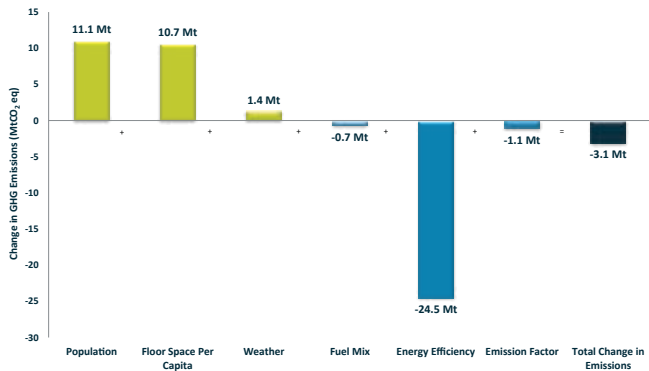
Figure 2–11   Major Influences on the Change in Stationary GHG Emissions from the Commercial Subcategory Between 1990 and 2013
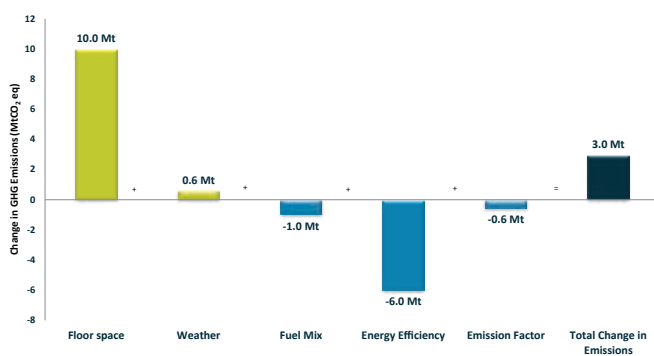
Figure 2–12   GHG Emissions and Heating Degree-Days (HDDs) from Residential and Commercial Subcategories, 1990–2013
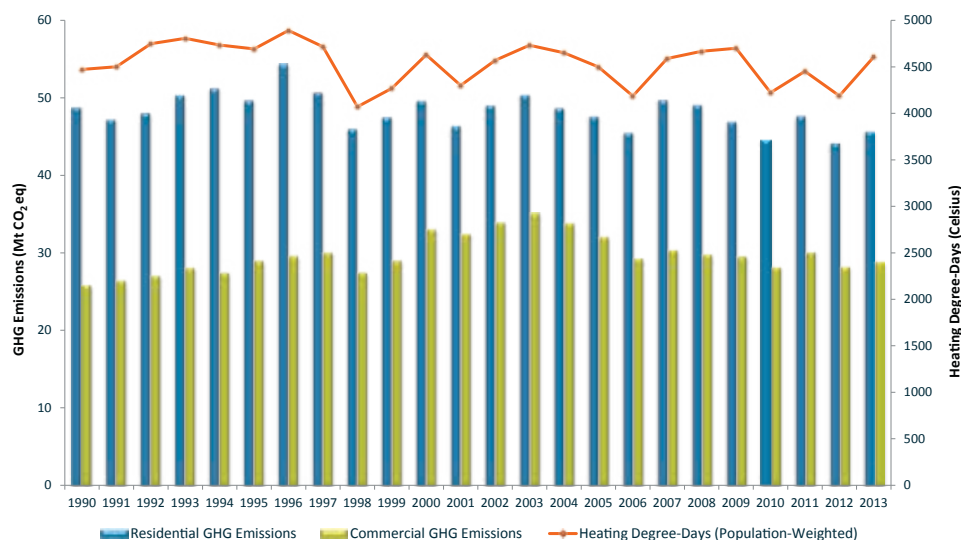
as well as the links between temperature, energy demand and improvements in energy use.

Fuel Mix – In both the Residential and Commercial subcategories, the impact of fuel mix is a result of switches from higher to lower-intensity fuels. This generally means replacing refined petroleum products (RPPs) and coal with natural gas. Since natural gas is the fuel with the lowest emission intensity, switching to natural gas lowers the overall impact of the fuel mix on emissions.

In the Residential subcategory, all fuel use has decreased, with the exception of natural gas. The total use of coal and RPPs has decreased by 54% and 59%, respectively; while the use of natural gas has increased by 26%. In the Commercial subcategory, the use of RPPs has decreased by 60%; while the use of natural gas has increased by 27%. Coal was not historically used in the Commercial subcategory; however a small amount of coal use appeared starting in 2012. This represents only 0.2% of the total energy mix in this subcategory.

Energy Efficiency – Energy efficiency refers to the efficiency of the equipment used in combustion, as well as the energy efficiency of the building as a whole. Improvements are due to better construction methods, increased insulation and higher-efficiency heating systems.

Emission Factor – The emission factor impact is the result of changes to emission factors that are based on the energy contents of fuels over time. This is discussed in 2.3.1.1 under the Public Electricity and Heat Production subcategory.

Agriculture and Forestry
(2013 GHG Emissions, 3.6 Mt)

Stationary fuel combustion-related emissions in Agriculture and Forestry amounted to 3.6 Mt in 2013, an increase of 49% from 1990. Emissions from these categories contributed approximately 0.5% of the total for 2013.

2.3.1.2.   Fugitive Emissions from Fuels
(2013 GHG Emissions, 61 Mt)

Fugitive emissions from fossil fuels are the intentional or unintentional releases of GHGs from the production, processing, transmission, storage and delivery of fossil fuels. Released 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 emissions have two sources: coal mining and handling, and activities related to the oil and natural gas industry. They constituted about 8% of Canada's total GHG emissions for 2013 and alone contributed 9% to the growth in emissions between 1990 and 2013.

In total, fugitive emissions grew by about 20% between 1990 and 2013, from 49 to 59 Mt, with emissions from the Oil and Natural Gas category contributing 97% of the total fugitive emissions in 2013, far overshadowing the 3% contribution from Coal Mining (Table 2–10). Although fugitive releases from the Solid Fuels category (i.e. coal mining) decreased by 1.1 Mt (39%) between 1990 and 2013 as a result of the closing of many mines in eastern Canada, emissions from oil and natural gas increased 24% during the same period. Although rising over the long term, in the period from 2005 to 2013, the total fugitive emissions fell by 2.4 Mt (3.9%).

2

Reducing Heating Requirements in Commercial and Residential Buildings

The amount of energy required to heat and cool a dwelling is closely related to the outside ambient air temperature. Two common indicators that are used to determine the impacts of weather on energy requirements are annual heating degree-days (HDDs) and annual cooling degree-days (CDDs). Annual HDDs are the annual sum of the days when the average daily temperature is below 18°C multiplied by the number of degrees the temperature is below 18°C on each of those days. Annual CDDs are the annual sum of days when the average daily temperature is over 18°C multiplied by the number of degrees above 18°C on each of those days. Since Canada is a northern country, home heating consumes a much greater amount of energy for the average home on an annual basis compared with other countries, and cooling accounts for a much smaller portion of energy.

In the longer-term, GHG emissions remained stable despite increases in floor space, indicating that GHG emissions per amount of floor space requiring heating is decreasing (Figure 2-13). This decoupling has been the result of increases in the efficiency of heating and the thermal envelope of buildings, as well changes in the mix of heating fuels, such as natural gas substituting for light fuel oil.

Figure 2–13   Relationship Between HDDs and Residential GHG Emissions, 1990–2013
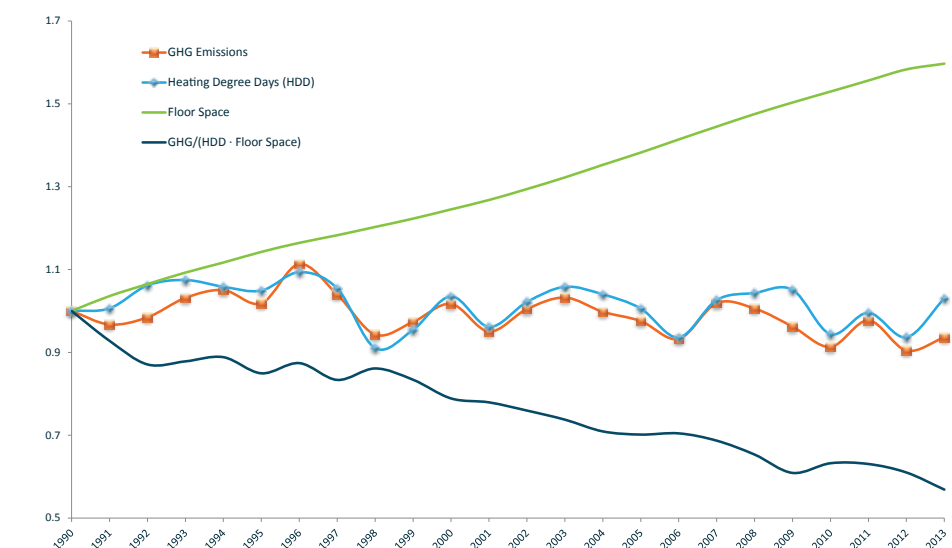
Notes:
1. To remove the effect of climatic and population-related variables, an adjusted GHG emissions trend is measured in terms of GHG emissions divided by the product of floor space and HDDs over the period 1990–2013.
2. Residential floor space data: Liu Y. 2015. Personal communication (email from Liu Y to Tracey K, Program Engineer, PIRD dated January 16, 2015). Office of Energy Efficiency, Natural Resources Canada.

The growth in emissions between 1990 and 2013 is a result of the increased production of natural gas, heavy oil, crude bitumen and synthetic crude oil. Since 1990, net energy exported from Canada has increased by 270% (refer to Section 3.5.3 in Chapter 3 for a discussion of emissions associated with the export of oil and natural gas), accompanied by a 202% increase in GHG emissions associated with those net energy exports.

Although overall fugitive emissions associated with oil and gas production have increased substantially since 1990, the overall fugitive emission intensity (emissions per unit of energy produced) of upstream oil and gas production has decreased by 30% (see Table 2–10). This reduction is due to a 50% decrease in oil sands fugitive emission intensity, which was somewhat offset by a 3% increase in conventional oil production intensity. The increase in conventional oil intensity is indicative of the fact that easily removable reserves of conventional crude oil are being replaced with more high energy-and GHG-intensive sources, including heavier and/or more difficult-to-obtain conventional oils such as those from offshore sources and enhanced oil recovery (EOR) operations. In addition, the increased use of multi-stage fracturing has increased fugitive emissions during the well-completion phase of production (Allen et al. 2013).

Table 2–10   Fugitive GHG Emission Intensity of Fossil Fuel Production by Category, Selected Years

	1990	2000	2005	2009	2010	2011	2012	2013
COAL PRODUCTION								
Fugitive Emissions (Mt CO_2 eq)	3	2	2	1	2	2	2	2
Production (PJ)	1 673	1 510	1 401	1 372	1 483	1 485	1 488	1 526
Fugitive Emissions Intensity (kt CO_2 eq / PJ)	1.69	1.14	1.18	1.03	1.07	1.06	1.07	1.13
UPSTREAM OIL AND GAS PRODUCTION								
Fugitive Emissions (Mt CO_2 eq)	44	65	56	51	50	51	53	54
Production (PJ)	7 958	12 170	13 092	12 594	12 718	13 204	13 704	14 272
Fugitive Emissions Intensity (kt CO_2 eq / PJ)	5.47	5.35	4.30	4.08	3.94	3.89	3.87	3.80
Conventional Oil Production								
Fugitive Emissions (Mt CO_2 eq)	19	29	23	19	19	20	22	22
Production (PJ)	2 973	3 590	3 459	3 090	3 098	3 173	3 287	3 468
Fugitive Emissions Intensity (kt CO_2 eq / PJ)	6.29	8.18	6.53	6.25	6.17	6.33	6.67	6.47
Oil Sands Mining, Extraction and Upgrading								
Fugitive Emissions (Mt CO_2 eq)	2.6	4.6	4.9	6.5	6.7	6.8	7.1	7.5
Production (PJ)	801	1 519	2 441	3 275	3 613	3 968	4 411	4 754
Fugitive Emissions Intensity (kt CO_2 eq / PJ)	3.23	3.02	2.02	1.98	1.85	1.72	1.61	1.58
Natural Gas Production and Processing								
Fugitive Emissions (Mt CO_2 eq)	17	27	27	24	23	23	22	22
Production (PJ)	4 184	7 062	7 192	6 229	6 007	6 062	6 006	6 051
Fugitive Emissions Intensity (kt CO_2 eq / PJ)	4.06	3.82	3.70	3.80	3.77	3.71	3.69	3.69
Natural Gas Transmission								
Fugitive Emissions (Mt CO_2 eq)	5.3	4.2	2.2	1.9	1.7	1.9	1.9	1.9
Throughput x Pipeline Length (trillion m3 km)	3 199	6 853	6 899	5 975	5 613	5 540	5 701	5 759
Fugitive Emissions Intensity (kt CO_2 eq / trillion m^3 km)	1.644	0.615	0.317	0.311	0.294	0.345	0.333	0.338
DOWNSTREAM PRODUCTION								
Fugitive Emissions (Mt CO_2 eq)	2.4	3.0	3.1	2.9	2.9	2.7	2.7	2.7
Production (PJ)	3 907	4 375	4 699	4 525	4 629	4 425	4 513	4 431
Fugitive Emissions Intensity (kt CO_2 eq / PJ)	0.61	0.68	0.67	0.65	0.63	0.61	0.60	0.61
Petroleum Refining								
Fugitive Emissions (Mt CO_2 eq)	0.9	1.7	2.0	1.8	1.8	1.7	1.8	1.7
Production (PJ)	3 907	4 375	4 699	4 525	4 629	4 425	4 513	4 431
Fugitive Emissions Intensity (kt CO_2 eq / PJ)	0.22	0.38	0.42	0.39	0.40	0.38	0.39	0.39
Natural Gas Distribution								
Fugitive Emissions (Mt CO_2 eq)	1.5	1.3	1.2	1.1	1.1	1.0	0.9	1.0
Throughput x Pipeline Length (trillion m^3 km)	2 586	4 432	4 800	5 023	5 209	5 667	5 605	5 995
Fugitive Emissions Intensity (kt CO_2 eq / trillion m^3 km)	0.586	0.288	0.245	0.229	0.210	0.180	0.167	0.167

2

In 1999, Alberta (Canada's largest oil and gas producing province[12]) introduced regulations (called Directive 060) to reduce flaring and venting emissions from its oil and gas industry (AER 2014b). Additionally, in 2006, leak detection and repair (LDAR) best management practices (BMPs) were added to Directive 060 to reduce emissions from fugitive equipment leaks. These measures resulted in a decrease in fugitive emission intensity of the conventional oil production industry by about 24% from 2000 to 2010.

2.3.2.   Industrial Processes and Product Use Sector
(2013 GHG Emissions, 52.2 Mt)

The Industrial Processes and Product Use Sector includes GHG emissions that result from manufacturing processes and use of products. Categories in this Sector include Mineral Products, Chemical Industry, Metal Production, Production and Consumption of Halocarbons, SF_6 and NF_3, Non-Energy Products from Fuels and Solvent Use, and Other Product Manufacture and Use. GHG emissions from the IPPU Sector contributed 52.2 Mt (7.2%) to the 2013 national GHG inventory, compared with 55.1 Mt (9%) in 1990. Total emissions in this Sector result from activities in several diverse industries; trends in emissions reflect the combined effects of multiple drivers on various industries (Figure 2–14 and Table 2–11).

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12   In 2013, Alberta produced approximately 75% of the total oil and gas produced in Canada (Statistics Canada 2014c; 2014d).

Figure 2–14   GHG Emissions from Industrial Processes by Subsector, 1990–2013
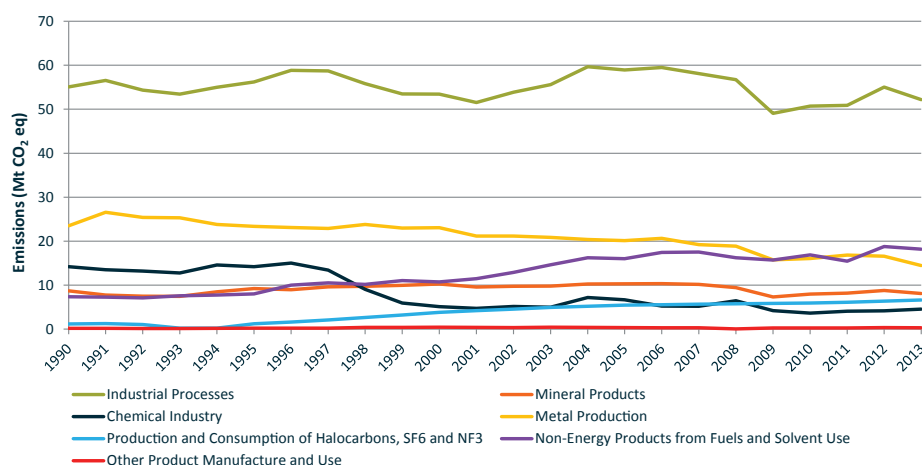
Table 2–11   GHG Emissions from Industrial Processes by Category, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Total - Industrial Processes	**55.1**	**53.4**	**58.9**	**49.1**	**50.7**	**50.9**	**55.0**	**52.2**
Mineral Products	8.7	10.2	10.3	7.3	8.0	8.2	8.8	8.1
Cement Production	5.8	7.2	7.6	5.4	6.0	6.1	6.6	6.0
Lime Production	1.8	1.9	1.7	1.2	1.4	1.4	1.4	1.3
Mineral Product Use	1.20	1.20	1.00	0.72	0.54	0.67	0.77	0.78
Chemical Industry	14.2	5.1	6.6	4.2	3.6	4.1	4.2	4.5
Ammonia Production	2.8	3.0	2.7	2.4	2.5	2.9	3.0	3.5
Nitric Acid Production	0.97	1.18	1.20	1.11	1.06	1.12	1.10	0.99
Adipic Acid Production	10.3	0.9	2.6	0.6	0.0	0.0	0.0	0.0
Petrochemical & Carbon Black Production	0.13	0.11	0.09	0.07	0.07	0.07	0.07	0.08
Metal Production	23.5	23.1	20.1	15.7	16.1	16.9	16.6	14.5
Iron and Steel Production	10.2	11.5	10.2	8.0	9.0	9.9	9.8	7.5
Aluminium Production	10.3	8.9	8.7	7.5	6.9	6.8	6.5	6.7
SF_6 Used in Magnesium Smelters and Casters	2.96	2.66	1.23	0.18	0.18	0.18	0.25	0.21
Production and Consumption of Halocarbons, SF_6 and NF_3	1.2	3.8	5.4	5.8	5.9	6.1	6.4	6.6
Non-Energy Products from Fuels and Solvent Use	7.4	10.8	16.0	15.7	16.9	15.5	18.8	18.2
Other Product Manufacture and Use	0.17	0.43	0.36	0.25	0.24	0.26	0.33	0.30

Note: Totals may not add up due to rounding.

Overall, IPPU emissions decreased by 2.9 Mt (5.3%) between 1990 and 2013. Emission reductions in Adipic Acid Production (N_2O), Aluminium Production (PFCs), Magnesium Production (SF_6), and Iron and Steel Production (CO_2) since 1990 were partially offset by increases observed in Non-Energy Products from Fuels and Solvent Use (CO_2),[13] and Production and Consumption of Halocarbons, SF_6 and NF_3, and to a lesser degree by increases in Ammonia Production (CO_2) and Cement Production (CO_2).

2.3.2.1.   Mineral Products

Mineral Products include cement production, lime production, and uses of carbonates in various processes in the iron and steel industry, pulp and paper mills, and glass manufacturers. The subsector experienced a decrease in emissions of 0.6 Mt CO_2 eq (7%) from 1990 to 2013.

Emissions from the Cement Production category peaked in 2007 at 7.8 Mt CO_2 eq and reached 6.0 Mt CO_2 eq in 2013, or 4% (0.2 Mt CO_2 eq) above 1990 levels, mirroring changes in Canadian clinker production, which peaked at 14.2 Mt in 2007 and declined thereafter to 11.0 Mt in 2013 (Statistics Canada 19902004a, 2004–

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13   Non-Energy Products from Fuels and Solvent Use is an aggregate emission subsector that includes emissions from petrochemical production and use of petroleum products as lubricants and solvents.

2013a, 2004–2013b). Similarly, emissions from Lime Production fluctuated along with production levels and decreased by 0.44 Mt CO_2 eq (25%) compared to 1990.

A significant decline in pulp and paper production, increased use of recycled glass (NRCan 2007), and a moderate decrease in steel output resulted in the declining use of carbonates and their associated emissions. Since 1990, emissions from the use of limestone and dolomite have declined by 0.23 Mt (29%) and emissions from the use of soda ash have decreased by 0.13 Mt (54%). Canada's emissions resulting from magnesite use are purely from magnesia production for industrial, environmental and agriculture applications (Baymag 2011). As a result of declining magnesia production, emissions from magnesite use in 2013 decreased by 0.06 Mt CO_2 eq (38%) compared to 1990.

2.3.2.2. Chemical Industry

A decrease of 9.6 Mt CO_2 eq (68%) from 1990 to 2013 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; this alone represents a decrease of 10.3 Mt CO_2 eq from 1990.[14]

In contrast, emissions from ammonia production increased by 0.7 Mt CO_2 eq (26%) from 1990 to 2013 in step with a general increase in production of ammonia (Statistics Canada 2008-2013).

2.3.2.3. Metal Production

Emissions reductions in the production of magnesium, aluminium, and iron and steel contributed to the overall reduction of 8.0 Mt CO_2 eq (36%) in emissions from Metal Production between 1990 and 2013. Magnesium production in Canada ceased in 2009 and accounted for 2.7 Mt CO_2 eq of the reductions in Metal Production.

The aluminium industry successfully decreased its PFC emissions by 4.9 Mt CO_2 eq (76%), while increasing production by 89% between 1990 and 2013 (AAC 2013). Reductions in PFC emissions have been achieved through the incorporation of computerized sensors and automated alumina feeders. However, the increase in aluminium production also gave rise to an increase in CO_2 emissions of 2.4 Mt CO_2 eq (or 89%) over the same period. Net emissions from aluminium production therefore decreased by 2.6 Mt CO_2 eq (28%) between 1990 and 2013.

From 1990 to 2013 the iron and steel industry experienced an emission decrease of 2.7 Mt CO_2 eq (26.1%). 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 1990-2012, CSPA 2013).

[14] Invista 2012, provided by Joe Hendriks from Invista via email to Pollutant Inventories and Reporting Division, dated November 22, 2013.

2.3.2.4. Production and Consumption of Halocarbons, SF$_6$ and NF$_3$

The consumption of HFCs accounts for a 5.4 Mt CO_2 eq (450%) 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 (AC) markets since the Montreal Protocol came into effect in 1996. The 1990 emissions from the Production and Consumption of Halocarbons in Table 2–11 represents only HFC-23 emissions from the production of HCFC-22, as emissions from the consumption of HFCs were negligible in 1990. Production of HCFC-22 ceased in 1992, and HFC emissions reported after this year are only from consumption. The other sources of emissions (PFCs, SF_6, NF_3) in this subsector do not have a significant effect on emission trends, as the next largest source of emissions (SF_6) is only equal to approximately 3% of the HFC emissions value.

2.3.2.5. Non-energy Products from Fuels and Solvent Use
(2013 GHG Emissions, 18.2 Mt)

Non-energy Products from Fuels and Solvent Use is the largest category in the sector, with an increase in emissions of 10.8 Mt CO_2 eq (147%) from 1990 to 2013. The increase can be attributed to the greater use of petroleum fuels as feedstock to meet increased demand for petrochemical products. CO_2 emissions from feedstock use of waxes, paraffin and unfinished petrochemical derivatives increased by 7.9 Mt CO_2 eq (1700%) (Statistics Canada 1990-2013), the use of ethane increased by 1.6 Mt CO_2 eq (130%), and the use of petrochemical feedstock increased by 0.58 Mt CO_2 eq (30%).

2.3.3. Agriculture Sector
(2013 GHG Emissions, 60 Mt)

The main sectors in Canadian agriculture are livestock and crop production. The livestock sector is dominated by beef, dairy, poultry and swine production, while crop production is mainly dedicated to the production of cereals and oil seeds. Canada also produces a wide variety of specialty crops and animals, but these represent a very small portion of the overall agricultural economy. Agricultural production is highly regionalized; approximately 75% of beef cattle and more than 90% of wheat, barley and canola are produced in the semi-arid to subhumid ecozones of the Prairies. On the other hand, approximately 75% of dairy cattle, 60% of swine and poultry, 95% of corn and 90% of soybeans are produced in the humid Mixedwood Plains ecozone in eastern Canada (Statistics Canada 2014e, 2014f, 2014g). Traditionally Canada's Agriculture Sector has been composed of small family farms, but over the past 30 years, intensification has occurred in the Agriculture Sector and as a consequence, the number of farms has decreased and farm size and productivity have increased (Statistics Canada 2007).

2

Non-energy emissions directly related to animal and crop production accounted for 60 Mt CO_2 eq, or 8% of total 2013 GHG emissions for Canada, an increase of 11 Mt CO_2 eq or 23% since 1990. Agriculture accounted for 27% and 70% of national CH_4 and N_2O emissions, respectively; all of these emissions are from non-energy sources. Generally, agricultural emissions result from losses and inefficiencies in production processes, i.e., either losses of nutrition energy during animal digestion or losses of nutrient nitrogen to the atmosphere or surface waters. Emissions from energy used during the agricultural production process and the energy and fugitive emissions occurring during the production of nitrogen fertilizers and other agricultural chemicals are discussed in Chapter 3 (Energy) and Chapter 4 (Industrial Processes and Product Use) of this report.

Agricultural GHG emissions from the livestock sector include enteric fermentation emissions (CH_4) and all emissions (CH_4 and N_2O) from the storage and application of manure. The crop production sector includes N_2O emissions from the application of synthetic nitrogen fertilizers, crop residue decomposition, the burning of agricultural residues (CH_4 and N_2O), and CO_2 emissions from agricultural use of lime and urea-based N fertilizers (Table 2–12).

In 2013, livestock emissions consisted of 25 Mt CO_2 eq from enteric fermentation and 12 Mt CO_2 eq from manure management, storage and application (68% and 32% of livestock emissions, respectively). Crop production produces N_2O and CO_2 emissions from the application of inorganic nitrogen fertilizers and agricultural use of lime (16 Mt CO_2 eq,) and from the decomposition of crop residues (7.7 Mt CO_2 eq), representing 67% and 33%, respectively, of crop production emissions (Table 2–12).

GHG trends in agricultural production reflect the complex interconnections between the two dominant branches of agriculture: livestock and crop production. These two sub-industries compete for the same land base and contribute resources to and from that land base. For instance, high beef prices may stimulate more conversion of marginally arable annual cropland to perennial pasture, and vice versa. Over the past decades, agriculture has undergone a gradual intensification of production per unit land area. The intensification in the crop production industry has involved an increased reliance on off-farm inputs such as fertilizers, herbicides and pesticides and has resulted in increased productivity per hectare and reduction of summerfallow. In the livestock industry this has also involved increased reliance on processed feeds and medicinal and non-medicinal supplements that have also increased output per animal. At the same time, over the past 30 years, there has been an increased focus on soil conservation through conservation tillage and crop rotation. For these reasons, a comprehensive discussion of trends in emissions from agricultural production must at least touch on the dominant emissions from production practices, farm inputs, land manage-

ment practices and land-use change (Statistics Canada 2007).

The main drivers of the emission trend in the Agriculture Sector are the expansion of beef cattle and swine populations and increases in the application of inorganic nitrogen fertilizers in the Prairies. Beef, swine and poultry populations in Canada are 14%, 26% and 39% higher, respectively, than in 1990. The increase in livestock populations, a result of strong commodity prices from 1990 to 2003 (Statistics Canada, 2009), largely accounts for the 10% increase, from 33 to 37 Mt CO_2 eq, in emissions associated with animal production over the 1990–2013 period (Table 2–12). In the case of beef cattle, emissions increased at greater rates than cattle populations as herd improvements resulted in an increase in live weight; consequently, an average animal now consumes more feed and also emits more GHGs.

Increases from beef production were, however, partially offset by a 30% reduction in the dairy population (Statistics Canada 2007). The dairy quota systems encouraged the dairy industry to invest in herd improvement in order to increase profitability. Emissions associated with dairy cows have fallen by approximately 19% since 1990, but the decline in the dairy herd has also been partly offset by a 40% increase in average milk productivity, due to improved genetics and changes in feeding and/or management practices. Therefore, even though the decrease in dairy population is driving the emission decline in this category, an average cow produces more milk today than in 1990, and also emits more GHGs.

Overall, during the 1990–2005 period, the combination of increased livestock populations and increasing emissions per animal in some cattle subcategories resulted in a change in the relative proportion from 68% to 73% of GHGs originating from the livestock sector (Figure 2–15).

Emissions attributed to crop production are due mainly to either the application of inorganic nitrogen fertilizers or to crop residue decomposition, which is directly proportional to crop yields. Emissions from crop residue decomposition varied between 3.7 Mt CO_2 eq (in 2002, a drought year) and 7.3 Mt CO_2 eq (in 2013). However, from 1990 to 2013, the use of inorganic nitrogen fertilizer increased steadily from 1.2 Mt N to 2.5 Mt N. Two periods showed the sharpest increases: 1991–1997 and 2007–2013. 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 a dramatic increase in grain price, which encouraged farmers to use more nutrient inputs, and saw an increase in the area of land planted to annual crops. As a consequence, emissions from inorganic nitrogen fertilizer application increased substantially, from 9.8 Mt CO_2 eq in 1990 to 16 Mt CO_2 eq in 2013. Notably, a decrease in the carbon sink in soils reported in the LULUCF sector also parallels this second period of increased inorganic fertilizer use as perennial crops were converted to annual production.

Table 2–12   GHG Emissions from Agriculture by Production Systems for Selected Years[1]

Production System	GHG Emissions (Mt CO_2 eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Livestock	33	41	45	39	38	37	37	37
Dairy Cows	6.9	6.0	5.7	5.4	5.5	5.4	5.4	5.6
Beef Cattle	22	30	33	28	27	26	26	26
Swine	2.6	3.3	3.7	3.0	3.1	3.1	3.1	3.1
Other Livestock[2]	1.6	2.3	2.5	2.3	2.3	2.2	2.2	2.2
Crop	16	17	16	19	19	19	21	24
Inorganic Nitrogen Fertilizers[3]	9.8	10	10	12	12	13	14	16
Crop Residue Decomposition	5.2	5.2	5.7	6.2	6.4	5.8	6.0	7.3
Other Management Practices[4]	2.6	1.9	1.1	0.9	0.8	0.8	0.8	0.7
Agriculture (Total)	**49**	**59**	**62**	**58**	**57**	**56**	**58**	**60**

1. Totals may not add up due to rounding.
2. Other livestock includes sheep, lamb, goat, horse, bison, poultry, fur-bearing animals, wild boar, deer and elk, llamas and alpacas.
3. Inorganic Nitrogen Fertilizers includes emissions of N_2O from the soil and CO_2 emissions from the hydrolysis of carbon stored in urea.
4. Other Management Practices includes summerfallow, conservation tillage practices, irrigation, cultivation of organic soils, the mineralization of soil carbon, the use of lime and field burning of crop residues..

Figure 2–15   The GHG Contribution from Livestock, Crop Production and Total Agricultural Emissions, 1990–2013
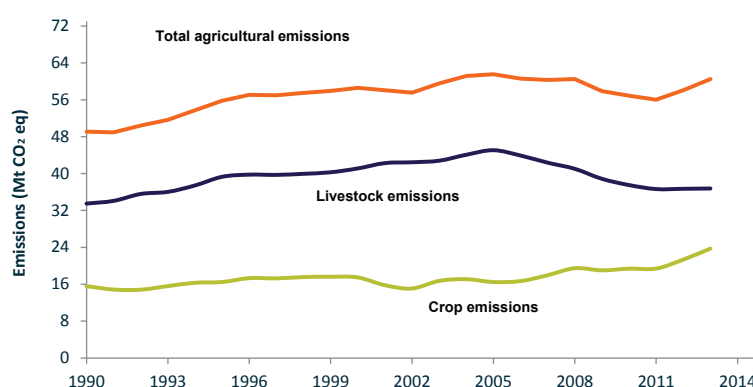
Recent Trends

The outbreak of bovine spongiform encephalopathy (BSE, or mad cow disease) in 2003 resulted in a worldwide ban on Canadian beef products. A sudden 9% increase in domestic animal populations occurred between January 2003 and January 2004. The BSE crisis was not completely resolved until 2005. Since then, beef populations have decreased by 20%. Swine populations also followed trends in prices, peaking in 2005 and declining since then by 15% (Statistics Canada, 2009). These population declines since 2005, combined with decreasing dairy cattle populations, have resulted in a reduction in emissions from livestock by 18%, or 8.3 Mt CO_2 eq. For the past two years, animal commodity prices have increased, animal populations have stabilized and livestock emissions have stabilized as well.

From 2005 to 2013, agricultural emissions fluctuated depending on crop production, the rate of decline in animal populations and the rate of increase in fertilizer use. For example, from 2008

to 2011, livestock emissions continued to decrease, fertilizer use increased at a slower rate and crop production was low. As a result, by 2011 emissions dropped to 6 Mt CO_2 eq below the average emissions from 2005 to 2008. Since 2011, fertilizer use has increased sharply by 25%, animal populations remained stable and record crop production resulted in an emissions increase of 4 Mt CO_2 eq in 2013, to levels similar to those observed in the period 2005–2008 (Figure 2–15).

As a result of the decline in animal populations and continued increase in fertilizer use the proportion of emissions from livestock in 2013 dropped to its lowest proportion of total agriculture emissions (61% of total emissions) of the reporting period, considerably lower than the proportion in 2005 (73% of total emissions). The increasing emissions from crop production are notable, not only in emissions of N_2O, but are also observed in a decreased carbon sink in soils reported in the LULUCF sector due to a shift from perennial crop production to annual production.

2.3.4. Land Use, Land-use Change and Forestry Sector (2013 Net GHG Removals, 15 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 and emissions from the pool of long-lived harvested wood products.

The net LULUCF flux, calculated as the sum of CO_2 emissions and removals and non-CO_2 emissions, displays high interannual variability over the reporting period. In 2013, this net flux amounted to removals of 15 Mt (Figure 2–16).

All emissions and removals in the LULUCF Sector are excluded from the national totals. In 2013, the estimated 15 Mt would, if included, decrease the total Canadian GHG emissions by about 2.1%.

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 the new Harvested Wood Products (HWP) category, which is closely linked to Forest Land.

The Forest Land category includes GHG emissions from and removals by Canada's managed forests. Due to a methodological artefact, the net flux in forest land displays an important annual variability reflecting the erratic pattern of forest wildfires, which are random natural events; wildfires alone represented annual emissions of between 11 and 280 Mt CO_2 eq over the 1990–2013 period (Figure 2–17).

Underlying the interannual variability of wildfires, net removals by managed forests have decreased since 2002, due to the long-term impacts of unprecedented forest insect epidemics in western Canada. The immediate and long-term effect of the catastrophic Mountain Pine Beetle infestation in western Canada

Figure 2–16   Net Flux from LULUCF Relative to Total Canadian Emissions, 1990–2013
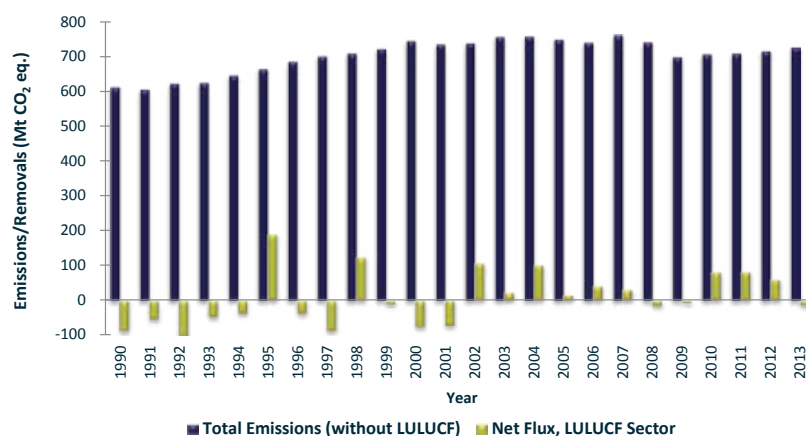
Figure 2–17   LULUCF Sector Net GHG Flux and Major Emission and Removal Components, 1990–2013
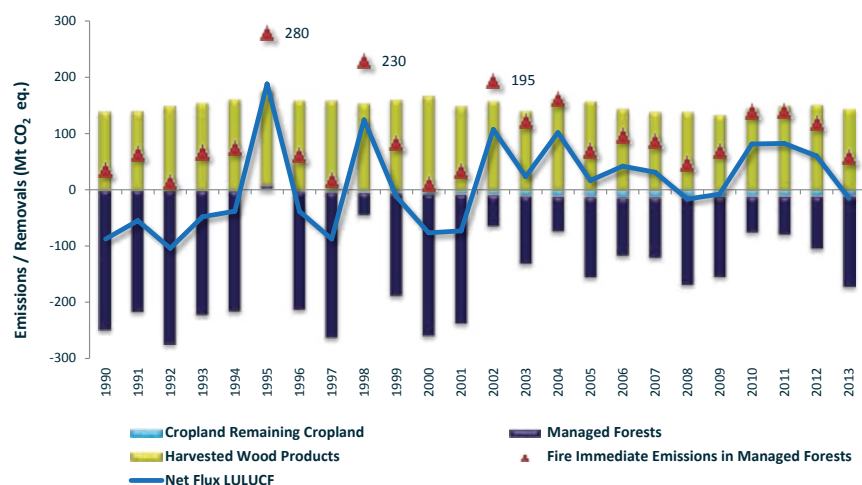
will undoubtedly continue to influence the net flux from forests due to tree mortality and residual decay of dead organic matter. In general, the large impacts of natural disturbances on the net flux in managed forests mask underlying patterns associated with direct human interventions in forests that are of interest in the sector.

Important subsectoral trends directly associated with human activities in managed forests include a 28% increase in the carbon removed from forests and transferred to HWP between 1990 and 2004, the peak harvest year. Since then, significant reductions in harvesting have occurred, with 2009 harvest levels reaching the lowest point in the 24-year period covered in this report. Even though the last three years show a modest increase, harvest levels in 2013 are still 27% below the peak year of 2004. This trend reflects a deep restructuring of the Canadian forest economic sector, aggravated by the consequences of the economic recession in the United States, Canada's main export market.

The new approach to estimating emissions from the use of HWP better reflects the long-term storage of carbon in HWP from wood harvested from Canada's managed forests. The inclusion of HWP more accurately reflects the effect of harvest on emissions/ removals from forests since the carbon is emitted at the end of the useful product life, not at the time of harvest. Emissions are notably influenced by the trend in forest harvest rates during the reporting period and also by the long-term impact of forest harvest since 1941. Emissions fluctuate between 134 Mt in 2009, the lowest harvest year, and 168 Mt in 2000 (Figure 2–17).

The Cropland subcategory includes the effect of agricultural practices on CO_2 emissions from, and removals by, arable soils and the immediate and long-term impacts of forest and grass-land conversion to cropland. The trend shows a steady decline

in emissions from Cropland, notably in the period 1990–2006, going from a net source of 10.3 Mt in 1990 to a net sink of 9.6 Mt CO_2 eq in 2006. This trend is a result of changes in agricultural land management practices in western Canada (Statistics Canada 2007), such as the extensive adoption of conservation tillage practices (over 13 million hectares of cropland since 1990) and a 79% reduction in summerfallow by 2013. Since 2006, net removals have gradually declined to 7.4 Mt, due to the soil carbon approaching equilibrium and an increase in the conversion of perennial to annual crops. The net CO_2 removals due to conservation tillage and summerfallow on mineral soils increased from a small source of 150 kt in 1990 to a removal of 11 Mt in 2013. A decline in emissions from the conversion of forest land to crop-land has also contributed to this trend.

The Wetlands category includes emissions from peatlands managed for peat extraction and from land flooding (hydroelectric reservoirs). Emissions from peat extraction increased 74% from 1990 to 2000, but subsequently decreased to 2.3 Mt in 2013. Emissions from land conversion to flooded lands do not show a consistent trend. The creation of large reservoirs before 1990 influenced emissions over the period 1990–1993; since then, emissions have generally declined, reaching a low of 1.3 Mt in 2013.

The conversion of forests to other land is a prevalent yet declining practice in Canada. It is driven by a variety of circumstances across the country, including policy and regulatory frameworks, market forces and resource endowment. The economic drivers of forest conversion are diverse and result in heterogeneous spatial and temporal patterns of forest conversion (Kurz et al. 2013). Since 1990, 1.3 million hectares of forest have been lost in Canada. GHG emissions from forest conversion dropped from 19.2 Mt CO_2 eq in 1990 to 13.5 Mt CO_2 eq in 2013. Geographically, the highest average rates of forest conversion occur in the Boreal

Figure 2–18   Trends in Annual Rates of Forest Conversion due to Agricultural Expansion, Oil and Gas Extraction and Hydroelectric Developments

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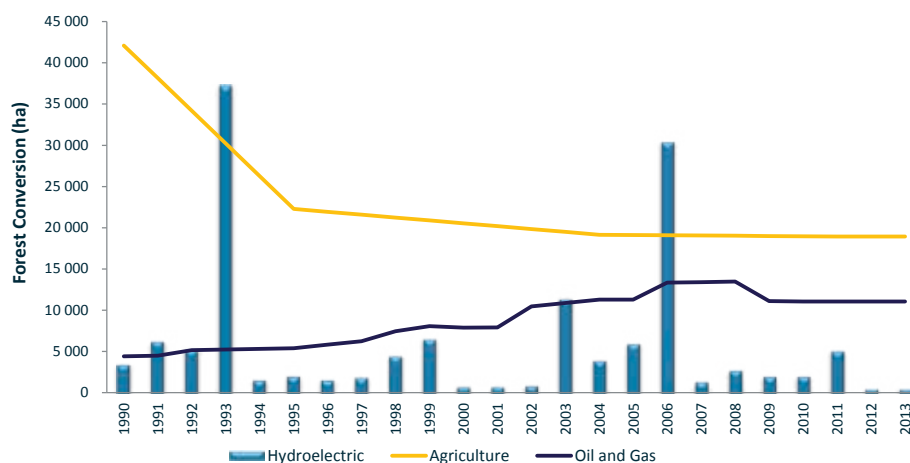
Plains (24 kha per year) and the Boreal Shield East (8 kha per year), which account for 46% and 16% of the total loss of forest area in Canada since 1990, respectively.

Primary drivers of forest conversion include agricultural expansion, resource extraction and hydroelectric development. Forest conversion for agricultural expansion accounted for 44% of the total cumulative area of forest conversion since 1990. Annual rates, however, dropped from 42 kha in 1990 to 19 kha in 2013 (Figure 2–18). This decrease predominantly took place in the Boreal Plains, Subhumid Prairies and Montane Cordillera of western Canada, following a period of active agricultural expansion in previous decades.

Forest clearing for resource extraction, which includes oil and gas extraction, forestry roads, mining and peat extraction, is the second-largest driver of forest conversion. Resource extraction expanded at the expense of over 365 kha of forests and accounted for 29% of the total cumulative area of forest conversion since 1990. Forest clearing for oil and gas extraction more than doubled, from 4.4 kha per year in 1990 to 11 kha per year in 2013 (Figure 2–18) and occurred largely in the Boreal Plains of the northern Prairies.

Forest conversion due to hydroelectric development is episodic, corresponding to the occasional impoundment of large reservoirs (e.g. LaForge-1 in 1993 and Eastmain1 in 2006) (Figure 2–18). Cumulative areas of forest converted for the creation of hydro reservoirs and associated infrastructure equal 142 kha, accounting for 11% of total forest conversion areas over the reporting period. Hydroelectric development occurs mainly in the Taiga Shield East and the Boreal Shield East. Other rates of forest conversion due to the development of built-up lands and transportation routes have remained relatively constant, at approximately 8 kha per year.

2.3.5. Waste Sector
(2013 GHG Emissions, 25 Mt)

From 1990 to 2013, GHG emissions from the Waste Sector increased by 5.9% (Table 2–13 and Figure 2–19), which is much less than the 27% population growth. Per capita emissions from the Waste Sector decreased by 7% from 1990 to 2013, and the

contribution of this Sector to total national GHG emissions in 2013 was 3.5%, compared to 3.9% in 1990. Of the 25 Mt total emissions from this Sector in 2013, Solid Waste Disposal, which includes municipal solid waste (MSW) landfills and wood waste landfills, accounted for 24 Mt (Table 2–13), while Wastewater Treatment and Discharge contributed 1.05 Mt and Incineration and Open Burning of Waste (excluding emissions from incineration of biomass material) contributed 0.55 Mt. CH_4 emissions, produced by the decomposition of biomass in MSW landfills, represent 82% of the emissions from the Waste Sector. The tables in Annex 9 summarize this information nationally by CO_2 eq and by category (i.e. individual gas and source).

GHG emissions from landfills were estimated for two solid waste types: MSW disposal and wood waste landfills, both of which produce CH_4 anaerobically.[15] The CH_4 production rate at a landfill is a function of several factors, including the mass and composition of biomass being landfilled, the landfill temperature, and the moisture entering the site from rainfall.

The quantity of CH_4 captured at MSW landfills for flaring or combustion for energy recovery purposes in 2013 amounted to 36% of the total generated emissions from this source, as compared to 20% in 1990. Hence, of the 33 Mt CO_2 eq of CH_4 generated by MSW landfills in 2013, only 21 Mt were actually emitted to the atmosphere, with the difference (12 Mt) being collected. The number of landfill sites collecting gas since facility data collection was initiated in 1997 has increased from 32 to 81 (Figure 2–20); landfill gas capture therefore contributed to containing the growth in CH_4 emissions from MSW landfills to 8% above their 1990 levels and to actual emission reductions in this category between 2006 and 2013.

Of the total amount of CH_4 collected in 2013, 49% (5.7 Mt CO_2 eq) was utilized for various energy purposes and the remainder

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15 When waste consists of biomass, the CO_2 produced from burning or aerobic decomposition is not accounted for in the Waste Sector. This is because, in the case of agricultural biomass, it is deemed to be a sustainable cycle (carbon in CO_2 will be sequestered when the biomass regenerates in crop reproduction). In the case of biomass from forest products, the emissions of CO_2 are accounted for as part of the LULUCF Sector (forest harvests). However, waste that decomposes anaerobically produces CH_4, which is not used photosynthetically and therefore does not sequester carbon in biomass regeneration and is not accounted for in forest harvest estimates. The production and release of unburned CH_4 from waste are therefore accounted for in GHG inventories.

Table 2–13   GHG Emissions from Waste, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Waste Sector	24	26	28	28	27	26	26	25
Solid Waste Disposal on Land	22	25	26	27	25	25	24	24
Wastewater Treatment and Discharge	0.87	0.95	0.98	1.02	1.03	1.04	1.04	1.05
Incineration and Open Burning of Waste	0.73	0.74	0.69	0.64	0.66	0.64	0.71	0.55
Note: Totals may not add up due to rounding.								

Figure 2–19   GHG Emissions from Waste, 1990–2013
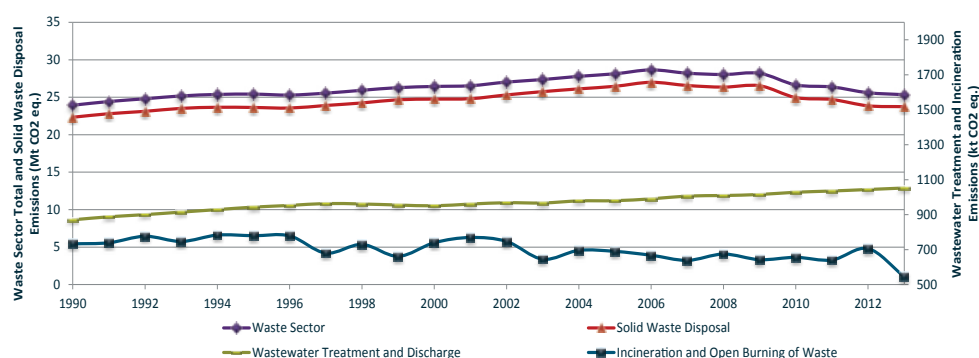
Figure 2–20   Number of Active MSW Gas Collection Landfill Sites in Canada
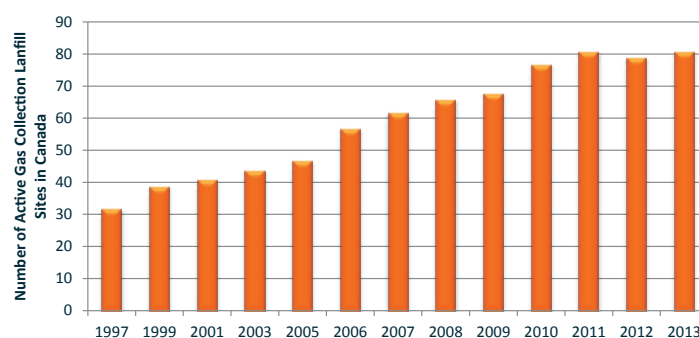
Source: Environment Canada 2014b

Figure 2–21   Proportion of Landfill Gas Utilized vs Flared
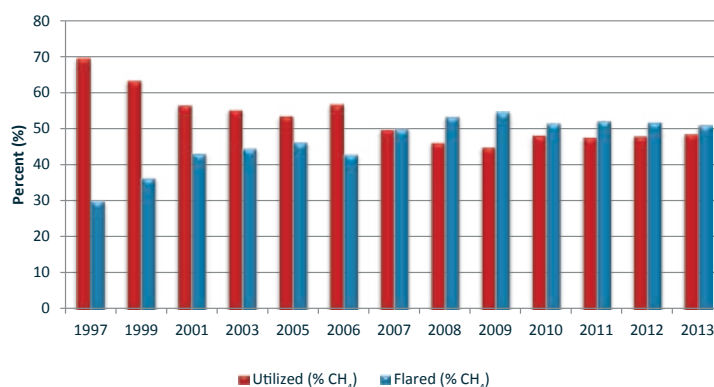
Source: Environment Canada 2014b.

was flared. Typically, a facility will start by installing the collection system and will flare the gas. Utilization systems are installed subsequently, once the capture system proves itself as reliable and stable. The decline in relative gas utilization from 70% to 48% between 1997 and 2013 (Figure 2–21) is due to a growing number of recently installed facilities initiating gas collection where the gas is flared.

The quantity of waste placed in MSW landfills[16] increased by 34% from 1990 to 2013, peaking in 2002 and subsequently plateauing. The amount of waste diverted, as a percentage of the waste generated, fluctuated from 22% to 25% over the period 1998–2010 (Statistics Canada 2000, 2003, 2004, 2007, 2008, 2010, 2013b). For this reason, and due to the presence of the waste export activity

16   The quantity of wastes placed in landfills is calculated as the waste disposed less the amounts incinerated and exported from Canada.

Figure 2–22   Per Capita GHG Emission Trend for Waste, 1990–2013

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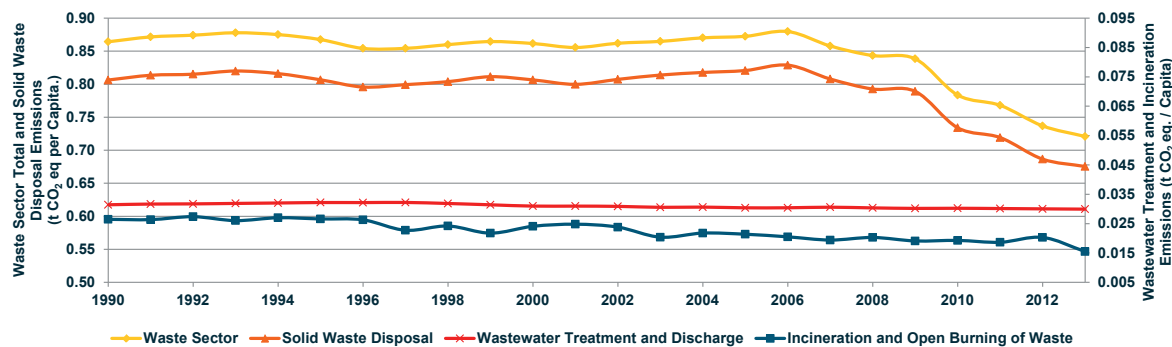
since the mid-1990s, the landfilled quantity per capita peaked in 2000, at approximately 0.7 tonnes per person, then followed a decreasing trend to 0.6 tonnes per person by 2013. The amount of residential and non-residential waste exported from Canada to the United States increased from 13kt in 1990 to 3394 kt in 2013.

Per capita emissions in the Wastewater Treatment and Discharge and Incineration and Open Burning subsectors showed decreases in GHG emissions over the 1990–2013 time series (Figure 2–22). Total incineration emissions (MSW, sewage sludge and hazardous waste) per capita decreased by 41% over the time series, due mainly to declines in emissions from the closure of aging MSW incinerators.

2.4.   Economic Sector Emission Tables

In this report, emissions estimates are primarily grouped into the activity sectors defined by the IPCC (i.e. Energy; Industrial Processes and Product Use; Agriculture; Land-Use, Land-use Change and Forestry; and Waste). While this categorization is consistent with the UNFCCC reporting guidelines, it is also useful to reallocate emissions into economic sector definitions since most people associate GHG emissions with a particular economic activity (e.g. producing electricity, farming, or driving a car.). This section reports emissions by the following economic sectors: oil and gas, electricity, transportation, emissions intensive trade exposed industries,[17] buildings, agriculture, and waste and other.

This reallocation takes the relevant proportion of emissions from various IPCC sub-categories to create a comprehensive emission profile for a specific economic sector. This is the approach taken for reporting against Canada's Copenhagen target in the annual Canada's Emissions Trends Report. Table 2–14 details the relationship between economic sectors and IPCC categories. Examining the historical path of Canadian GHG emissions by economic sec-

tors facilitates the identification of pressure points and emerging issues with respect to emissions growth. Moreover, this allows for a better understanding of the connection between economic activities and GHG emissions for the purposes of analyzing trends and for policy and public analysis.

For example, the transportation economic sector represents emissions arising from the cars, trucks, trains, aircraft and ships fulfilling mobility requirements of people, and also includes the mobility service emissions from heavy-duty trucks and other commercial vehicles. However, unlike the IPCC categorization, the transportation economic sector does not contain offroad transportation emissions related to farming, mining, construction, forestry, pipelines or other industrial activities. Excluding off-road in the transportation economic sector ensures that emissions related to industrial activities do not appear as trends associated with on-road passenger and freight transportation requirements. For example, if there were any upward trend in farming or mining activity, emissions arising from the increased use in mobile farming machinery or mining trucks would be reflected in the economic sector estimates for agriculture or mining.

This re-allocation simply re-categorizes emissions under different headings but does not change the overall magnitude of Canadian emissions estimates. Table 2–14 shows the distribution of emissions allocated on the basis of the economic sector from which they originate. 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 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 building sector represents emissions arising directly from residential homes and

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17   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.

commercial buildings; the waste and other sector represents emissions that arise from solid and liquid waste, waste incineration, and from 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.

Table 2–14   Details of Trends in GHG Emissions by Sector

	1990	2000	2005	2009	2010	2011	2012	2013
NATIONAL GHG TOTAL	**613**	**745**	**749**	**699**	**707**	**709**	**715**	**726**
Oil and Gas	107	158	157	158	160	161	174	179
Upstream Oil and Gas	87	137	133	135	138	140	151	156
Natural Gas Production and Processing	36	60	58	52	50	49	53	54
Conventional Oil Production	25	38	31	28	29	30	32	33
Conventional Light Oil Production	12	13	12	12	12	13	15	15
Conventional Heavy Oil Production	12	25	17	15	15	15	15	16
Frontier Oil Production	0*	1	2	2	2	2	2	2
Oil Sands (Mining, In-situ, Upgrading)	15	24	32	46	51	54	58	62
Mining and Extraction	4	6	10	13	15	15	16	16
In-situ	4	7	10	17	20	21	25	27
Upgrading	6	11	13	16	17	17	18	18
Oil and Natural Gas Transmission	12	15	12	8	7	7	8	8
Downstream Oil and Gas	20	20	23	23	22	21	23	23
Petroleum Refining	18	19	22	22	21	20	22	22
Natural Gas Distribution	2	1	1	1	1	1	1	1
Electricity	95	130	121	98	99	91	86	85
Transportation	130	157	169	164	169	167	168	170
Passenger Transport	78	93	98	97	97	94	95	97
Cars, Trucks and Motorcycles	70	84	88	88	89	86	86	88
Bus, Rail and Domestic Aviation	8	9	9	8	8	8	9	10
Freight Transport	39	48	57	57	60	62	62	62
Heavy Duty Trucks, Rail	33	42	50	50	52	55	55	56
Domestic Aviation and Marine	6	7	8	7	8	7	7	6
Other: Recreational, Commercial and Residential	12	16	14	10	11	12	11	11
Emissions Intensive & Trade Exposed Industries	95	92	89	73	75	79	77	76
Mining	6	6	6	7	7	7	7	7
Smelting and Refining (Non Ferrous Metals)	17	16	14	12	11	11	10	11
Pulp and Paper	15	13	9	7	7	7	7	7
Iron and Steel	16	19	20	15	16	17	16	14
Cement	10	12	13	10	10	10	11	10
Lime & Gypsum	3	3	3	2	3	3	3	2
Chemicals & Fertilizers	28	23	24	21	22	24	24	25
Buildings	76	88	87	85	82	87	85	86
Service Industry	27	38	40	38	37	39	40	40
Residential	49	50	48	47	45	48	45	46
Agriculture	57	69	71	68	70	70	72	75
On Farm Fuel Use	8	10	10	10	13	14	14	15
Crop Production	16	17	16	19	19	19	21	24
Animal Production	33	41	45	39	38	37	37	37
Waste & Others	54	52	54	52	53	53	53	54
Waste	24	26	28	28	27	26	26	25
Coal Production	4	3	3	4	5	4	4	5
Light Manufacturing, Construction & Forest Resources	26	23	23	20	22	23	23	24

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

2.4.1. Emission Trends by Economic Sector

In 2013, the oil and gas economic sector produced the largest share of GHG emissions in Canada (25%). Between 1990 and 2013, emissions from this sector increased by 72 Mt. The majority of this increase (50 Mt) occurred between 1990 and 2005 as the sector expanded and adopted new extraction processes. However, growth in GHG emissions from the oil and gas sector slowed between 2005 and 2013, due to several factors including the economic downturn that resulted in a lower global demand for petroleum products, and the gradual exhaustion of traditional natural gas and oil resources in Canada.

Canada's transportation economic sector is the second-largest contributor to Canada's GHG emissions, representing 23% of total emissions in 2013. Although there was a small increase in GHG emissions arising from transportation between 2009 and 2013 (6 Mt), the rate of growth in emissions has not returned to its trend prior to 2009. Emissions rose by 40 Mt between 1990 and 2005, an increase of around 31% over the period. These trends in GHG emissions in the overall transportation sector are driven by differing trends in subsectors such as heavy-duty vehicles and light-duty vehicles. For example, although the average fuel consumption ratios (FCR) of light-duty vehicles have been decreasing, the number of light trucks on the road continues to rise. Other factors affecting these emissions include changing demographics, changes in personal travel demand, higher gasoline prices, and government policies.

In 2013, the electricity sector contributed 12% to total Canadian emissions. Emissions from the electricity sector increased in parallel to rising demand for electricity both domestically and to satisfy export to the United States over the earlier years of the time period. Additionally, prior to 2005, fossil fuel power generation increased its share over non-emitting sources such as hydro and nuclear power in the generating portfolio. Emissions from the electricity sector increased by 26 Mt (28%) over the 1990–2005 time period. More recently, electricity-related emissions have declined because of measures such as a return to service of a number of nuclear units and fuel switching to natural gas, as well as the closure of a number of coal-fired electricity generation facilities. Further measures such as incremental fuel switching to natural gas and efficiency incentives coupled with the economic downturn saw emissions decrease by a further 37 Mt (30%) between 2005 and 2013.

The emissions-intensive trade-exposed industry sector experienced some fluctuation in emissions over the time period. Emissions from this sector were responsible for 15.4% of total Canadian emissions in 1990, falling to 12% in 2005. In more recent years, emissions have fallen further as a result of the economic downturn and the continued evolution of Canadian production towards other sectors and services, representing a decrease of 12 Mt between 2005 and 2013. GHG emissions from the buildings sector had increased with population and commercial development, but like all sectors of the economy fell marginally in the recessionary period. Emissions from the agriculture sector and the waste and other sector generally continued a slow upward or relatively stable trend throughout the time period, respectively.

The relationship between economic sectors and IPCC categories is shown in Table 2–15.

2.5. Emission Trends per Capita

While Canada represented less than 2% of total global GHG emissions in 2011 (CAIT 2015), it is one of the highest per capita emitters, largely as a result of its size, climate (i.e. energy demands due to climate), and resource-based economy. In 1990, Canadians released 22.1 tonnes (t) of GHGs per capita. In 2005, this indicator had risen to 23.2 t; however, by 2009, it had dropped to 20.8 t and has remained at historic lows ever since (Figure 2–23).

Figure 2–23   Canadian per Capita Greenhouse Gas Emissions (1990-2013)

Population data source: Statistics Canada (2014h)

2
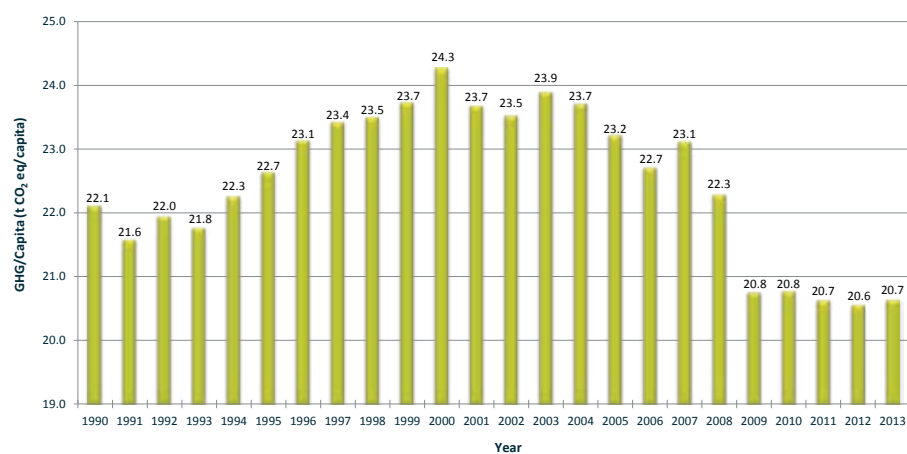
Table 2–15   2013 GHG emissions by national inventory and and economic categories

ECONOMIC CATEGORY	Economic Category Total	Energy: Fuel Combustion — Stationary Combustion — Stationary	Energy: Fuel Combustion — Stationary Combustion — Industrial Cogeneration — Electricity[c]	Energy: Fuel Combustion — Stationary Combustion — Industrial Cogeneration — Steam for Sale	Energy: Fuel Combustion — Transport	Energy: Fugitive — Fugitive (Unintentional)	Energy: Fugitive — Flaring	Energy: Fugitive — Venting	Energy Total	Industrial Processes — Mineral Products[d]	Industrial Processes — Chemical Industry[e]	Industrial Processes — Metal Production[f]
						Mt CO_2 equivalent						
National Inventory total [a,b]	**726**	**309**	**14.8**	**1.6**	**204**	**21.4**	**5.4**	**31.9**	**588**	**8.1**	**4.5**	**14.5**
Oil and Gas	**179**	**98.3**	**9.3**	**0.1**	**12.6**	**19.7**	**5.4**	**31.9**	**177.3**			
Upstream Oil and Gas	156	80.5	8.9	-	12.5	18.7	5.2	30.4	156.1			
Natural Gas Production and Processing	54	25.8	4.3	-	1.1	10.4	1.2	10.8	53.6			
Conventional Oil Production	33	7.7	0.6	-	2.1	3.3	2.9	16.2	32.9			
Conventional Light Oil Production	15	2.5	0.1	-	1.5	2.1	2.1	7.1	15.5			
Conventional Heavy Oil Production	16	4.4	-	-	0.6	1.2	0.2	9.2	15.6			
Frontier Oil Production	2	0.8	0.5	-	0.0	0.0	0.5	0.0	1.8			
Oil Sands (Mining, In-situ, Upgrading)[c]	62	46.9	4.0	-	3.0	3.7	1.2	2.7	61.4			
Mining and Extraction	16	7.7	1.9	-	3.0	3.4	0.2	-	16.2			
In-situ	27	25.6	0.7	-	-	0.2	0.1	0.1	26.7			
Upgrading	18	13.6	1.4	-	-	0.1	0.8	2.6	18.5			
Oil and Natural Gas Transmission	8	-	-	-	6.3	1.2	0.0	0.7	8.2			
Downstream Oil and Gas	23	17.9	0.4	0.1	0.1	1.0	0.2	1.5	21.2			
Petroleum Refining	22	17.9	0.4	0.1	-	0.1	0.2	1.4	20.1			
Natural Gas Distribution	1	-	-	-	0.1	0.9	0.0	0.1	1.1			
Electricity	**85**	**83.5**		**0.8**					**84.3**			
Transportation[h]	**170**				**168.1**				**168.1**			
Passenger Transport	97				95.8				95.8			
Cars, Light Trucks and Motor-cycles	88				86.4				86.4			
Bus, Rail and Domestic Aviation	10				9.4				9.4			
Freight Transport	62				61.0				61.0			
Heavy-duty Trucks, Rail	56				54.9				54.9			
Domestic Aviation and Marine	6				6.2				6.2			
Other: Recreational, Commercial and Residential	11				11.2				11.2			
Emissions Intensive & Trade Exposed Industries	**76**	**32.5**	**4.2**	**0.6**	**3.3**				**41**	**7.9**	**4.5**	**14.5**
Mining	7	3.5	0.7	-	3.0				7.3			
Smelting & Refining (Non-ferrous Metals)	11	2.9	0.0	0.3	0.1				3.3	0.0		6.9
Pulp & Paper	7	5.3	1.6	0.1	0.1				7.0	0.0		
Iron & Steel	14	5.5	0.0	0.0	0.1				5.6	0.3		7.5
Cement	10	3.9	-	-	0.0				3.9	6.0		
Lime & Gypsum	2	1.0	-	-	0.0				1.1	1.3		
Chemicals & Fertilizers	25	10.3	1.9	0.2	0.0				12.5	0.3	4.5	
Buildings	**86**	**74.2**	**0.6**						**74.8**			
Service Industry	40	28.5	0.6						29.1			
Residential	46	45.8							45.8			
Agriculture	**75**	**3.4**	**0.0**		**11.5**				**14.9**			
On-farm Fuel Use[i]	15	3.4	0.0		11.5				14.9			
Crop Production	24											
Animal Production	37											
Waste	**25**								**-**			
Solid Waste	24								-			
Waste Water	1								-			
Waste Incineration	1								-			
Coal Production	**5**	**1.3**	**-**	**-**	**1.6**	**1.7**	**-**	**-**	**4.6**			
Light Manufacturing, Construction & Forest Resources	**24**	**15.6**	**0.6**	**0.1**	**7.0**				**23.3**	**0.2**	**-**	**-**
Light Manufacturing	16	14.0	0.6	0.1	0.8				15.5	0.2		
Construction	6	1.4	-	-	5.0				6.4			
Forest Resources	1	0.1	0.0	-	1.2				1.4			

Notes: Totals may not add up due to rounding. Economic category totals rounded to nearest megatonne (Mt).

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.

a.   Categorization of emissions is consistent with the IPCC's sectors following the reporting requirement of the UNFCCC.

b.   National totals exclude all GHGs from the Land Use, Land-use Change and Forestry Sector.

c.   Industrial cogeneration includes emissions associated with the simultaneous production of heat and power. At some facilities, a portion of this power is generated by onsite utility-owned generators. As such, the cogeneration emissions for these specific facilities are included under the Public Electricity and Heat Generation category in the National Inventory (UNFCCC) format.

d.   Mineral products includes cement production, lime production and mineral product use.

| | National Inventory Category[a] | | | | | | | | | | | | | |
| Industrial Processes | | | | Agriculture | | | | Waste | | | | | |
Consumption of Halocarbon, SF$_6$ and NF$_3$	Non-Energy Products from Fuels and Solvent Use[g]	Other Product Manufacture and Use	Total	Manure Management	Enteric Fermentation	Agriculture Soils	Total	Solid Waste Disposal on Land	Waste Water Handling	Waste Incineration	Total	LULUCF[b]	ECONOMIC CATEGORY
6.6	18.2	0.3	52.2	8.4	25.2	26.8	60.5	23.7	1.1	0.5	25.3	-15.0	**National Inventory total** [a,b]
	2.2		2.2										**Oil and Gas**
	0.1		0.1										Upstream Oil and Gas
													Natural Gas Production and Processing
													Conventional Oil Production
													Conventional Light Oil Production
													Conventional Heavy Oil Production
													Frontier Oil Production
	0.1		0.1										Oil Sands (Mining, In-situ, Upgrading)[c]
	0.1		0.1										Mining and Extraction
													In-situ
													Upgrading
													Oil and Natural Gas Transmission
	2.1		2.1										Downstream Oil and Gas
	2.1		2.1										Petroleum Refining
													Natural Gas Distribution
0.2			0.2										**Electricity**
2.2	0.1		2.3										**Transportation**[h]
1.4	0.0		1.4										Passenger Transport
1.3	0.0		1.3										Cars, Light Trucks and Motorcycles
0.1	0.0		0.1										Bus, Rail and Domestic Aviation
0.8	0.1		0.8										Freight Transport
0.7	0.1		0.8										Heavy-duty Trucks, Rail
0.1	0.0		0.1										Domestic Aviation and Marine
													Other: Recreational, Commercial and Residential
0.0	8.7		35.6										**Emissions Intensive & Trade Exposed Industries**
	0.1		0.1										Mining
-	0.5		7.4										Smelting & Refining (Non-ferrous Metals)
	0.0		0.0										Pulp & Paper
	0.8		8.7										Iron & Steel
	0.0		6.0										Cement
	0.0		1.3										Lime & Gypsum
0.0	7.2		12.0										Chemicals & Fertilizers
3.9	7.0	0.3	11.2										**Buildings**
3.5	7.0	0.3	10.8										Service Industry
0.4		-	0.4										Residential
	0.0		0.0	8.4	25.2	26.8	60.5						**Agriculture**
	0.0		0.0				-						On-farm Fuel Use[i]
						23.7	23.7						Crop Production
				8.4	25.2	3.1	36.8						Animal Production
								23.7	1.1	0.5	25.3		**Waste**
								23.7			23.7		Solid Waste
									1.1		1.1		Waste Water
										0.5	0.5		Waste Incineration
													Coal Production
0.3	0.2	-	0.7										**Light Manufacturing, Construction & Forest Resources**
0.3	0.2		0.7										Light Manufacturing
	0.0		0.0										Construction
	0.0		0.0										Forest Resources
												-15.0	

e. Chemical industry includes ammonia production, nitric acid production, petrochemical production (CH_4 and N_2O only), and adipic acid production.

f. Metal production includes iron and steel production, aluminium production, and SF_6 used in magnesium smelters and casters.

g. Non-energy Products from Fuels and Solvent Use includes N_2O use in anaesthetics and aerosols.

h. Emissions from the consumption of propane and natural gas in Transportation are allocated to Cars, Light Trucks and Buses.

i. On-farm Fuel Use includes emissions associated with the use of lube oils and greases.

* Less than 0.5 Mt CO_2 eq

Chapter 3

Energy (CRF Sector 1)

3.1. Overview

In 2013, the Energy Sector accounted for 588 Mt (or 81%) of Canada's total greenhouse gas (GHG) emissions (Table 3–1). The Energy Sector includes all GHG (CO_2, CH_4 and N_2O) emissions from stationary and transport fuel combustion activities as well as fugitive emissions from the fossil fuel industry.[1]

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_4 and N_2O emissions resulting from the combustion of biomass fuels, such as residential fuel wood and spent pulping liquor, are accounted for in the Energy Sector, whereas CO_2 emissions resulting from the combustion of biomass are reported as a memo item in the Common Reporting Format (CRF) tables.

GHG emissions from the combustion (and evaporation) of fuel for all transport activities, such as Domestic Aviation, Road Transportation, Railways, Domestic Navigation, Pipeline Transport

and Other (Off-road), are included in the Transport subsector. 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 (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, revised activity data, and new United Nations Framework Convention on Climate Change (UNFCCC) reporting requirements. These new requirements include the use of the 2006 IPCC Guidelines for National GHG Inventories (2006 IPCC Guidelines) and new global warming potentials (GWPs) (UNFCCC-Decision 24/CP.19, IPCC 2006). Table 3–2 presents a summary of the GHG magnitude change due to recalculations, by IPCC category, for the Energy Sector.

Overall, recalculation activities contributed to an increase of 10.8 Mt compared to last year's submitted value for 2012. The total change was due mainly to the incorporation of new GWPs and revised energy data as shown in Figure 3–1. 'Revised energy data' represents the final 2012 data which has (as per standard practice) been incorporated as an update to the preliminary data

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

Table 3–1   GHG Emissions from Energy, Selected Years

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Energy Sector	485 000	606 000	601 000	563 000	573 000	576 000	577 000	588 000
Fuel Combustion (1.A)	436 000	537 000	539 000	508 000	518 000	520 000	519 000	529 000
Energy Industries (1.A.1)	146 000	200 000	193 000	165 000	165 000	157 000	156 000	156 000
Manufacturing Industries and Construction (1.A.2)[1]	64 900	69 500	69 300	73 500	77 500	82 200	88 400	91 300
Transport (1.A.3)	148 000	182 000	195 000	190 000	200 000	199 000	199 000	204 000
Other Sectors (1.A.4)	77 200	85 400	81 900	79 200	75 700	81 300	76 000	78 200
Fugitive Emissions from Fuels (1.B)	49 000	70 000	61 000	56 000	55 000	56 000	57 000	59 000
CO_2 Transport and Storage (1.C)	NO	0	0	0	0	0	0	0

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.
Totals may not add up due to rounding.
NO = Not Occuring
0 value indicates emissions truncated due to rounding.

Table 3–2   GHG Emission Change due to Recalculation

IPCC Categories	1990	2000	2005	2009	2010	2011	2012
1 Energy Sector			*Overall GHG Emissions (Mt CO$_2$ eq)*				
2014 Inventory Submission	469	591	595	560	570	573	566
2015 Inventory Submission	485	606	601	563	573	576	577
Total change due to recalculations	15.5	15.6	5.5	3.4	3.2	3.0	10.8
1.A. Energy Sector – Fuel Combustion	9.0	8.8	7.8	6.6	7.1	7.0	14.5
1.A.1., 1.A.2. and 1.A.4. – Stationary Combustion	7.7	7.2	6.1	4.8	5.2	5.3	10.7
CO$_2$	2.3	2.5	3.0	2.0	2.1	2.1	7.4
CH$_4$ kt CO$_2$ eq	4.9	4.4	2.9	2.6	2.9	2.9	3.0
N$_2$O kt CO$_2$ eq	0.4	0.3	0.2	0.2	0.2	0.2	0.3
1.A.3. – Transport	1.4	1.6	1.7	1.8	1.8	1.8	3.8
CO$_2$	1.5	1.8	2.0	1.9	2.0	2.0	3.9
CH$_4$ kt CO$_2$ eq	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N$_2$O kt CO$_2$ eq	-0.2	-0.4	-0.4	-0.3	-0.3	-0.3	-0.2
1.B. – Fugitive and 1C – CO$_2$ Transport & Storage	6.4	6.8	-2.3	-3.2	-3.9	-4.0	-3.7
CO$_2$	0.1	0.2	-0.7	-1.1	-1.5	-1.8	-1.9
CH$_4$ kt CO$_2$ eq	6.3	6.6	-1.6	-2.1	-2.4	-2.2	-1.9
N$_2$O kt CO$_2$ eq	0.001	0.001	0.001	0.000	0.000	0.000	0.000

Note: Totals may not add up due to rounding.

Figure 3–1   Changes to 2012 GHG Emissions Due to Recalculation Activities
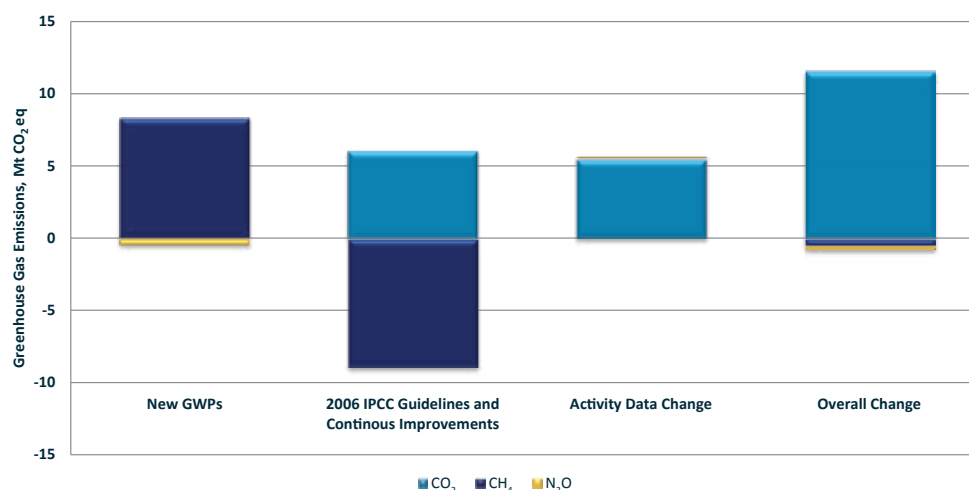
utilized in last year's inventory.[2] Implementation of the 2006 IPCC Guidelines for the Energy Sector includes the application of the assumption that carbon in fuels is 100% oxidized during combustion and the estimation of fugitive emissions from two new sources: abandoned coal mines and CO$_2$ transport in Canada. Additional recalculation discussions on new emission factors, new residential biomass data and improved estimates of fugitive emissions are presented in sections 3.2 (Fuel Combustion) and 3.3 (Fugitive Emissions) of Chapter 3. Recalculation due to new GWPs is discussed in Chapter 2. A summary of recalculations for all sectors is provided in Chapter 8.

3.2.   Fuel Combustion (CRF Category 1.A)

Fuel Combustion sources include all emissions from the combustion of fossil fuels. Major categories include Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors (which include the residential and commercial subcategories). Methods used to calculate emissions from fuel combustion are consistent throughout and are presented in Annex 3.1: Methodology and Data for Estimating Emissions from Fossil Fuel Combustion. The estimation methodologies are consistent with the 2006 Intergovernmental Panel on Climate Change (IPCC) Tier 2 approach, with country-specific emission factors and parameters.

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2   Statistics Canada annually publishes a revised, final version of the previous year's (preliminary) energy data. Currently, energy data for 2013 represents preliminary data (which will be revised in 2016).

Figure 3–2   GHG Emissions from Fuel Combustion, 1990–2013
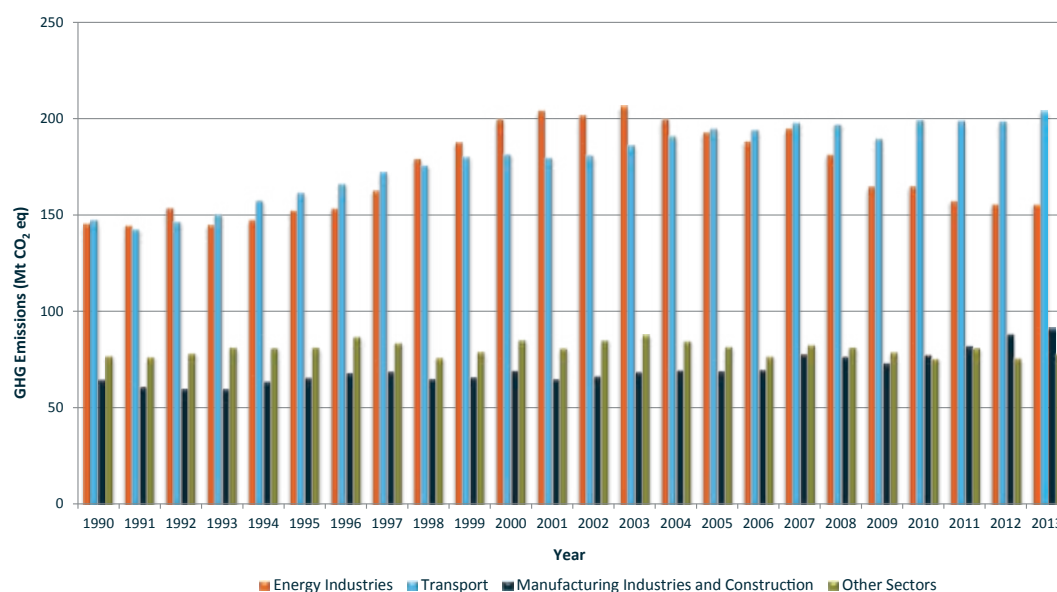
In 2013, about 529 Mt (73%) of Canada's GHG emissions were from the combustion of fossil fuels (Table 3–1). Overall GHG emissions from Fuel Combustion Activities have increased by 21% since 1990. Between 1990 and 2013, emissions from the Stationary Combustion Sources subsector (i.e. Energy Industries (1.A.1), Manufacturing Industries and Construction (1.A.2) and Other Sectors ((1.A.4)) and Transport subsector increased by about 13% (37.8 Mt) and 38% (56.2 Mt), respectively (Figure 3–2).

3.2.1.   Comparison of the Sectoral Approach with the Reference Approach

An anlysis of the Comparison of Sectoral and Reference Approaches, which presents a full discussion of this topic, is included within 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 (RESD) (Statistics Canada 57-003-X) 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.

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

Emissions (Table 3–4) have been calculated using the same methods listed in the Domestic Navigation section (see Section 3.2.6.2). Fuel-use data are reported as foreign marine in the RESD (Statistics Canada 57-003-X). 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 emissions 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

Table 3–3   GHG Emissions from Domestic and International Aviation

GHG Source Category	GHG Emissions (kt CO$_2$ eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
International Aviation	6 200	9 300	10 100	8 900	9 400	9 500	10 900	11 300
Domestic Aviation	7 200	7 700	7 600	6 500	6 500	6 200	7 300	7 500
Total	13 300	17 000	17 800	15 300	15 900	15 700	18 200	18 900

Note: Totals may not add up due to rounding.

Table 3–4   GHG Emissions from Domestic and International Navigation

GHG Source Category	GHG Emissions (kt CO$_2$ eq)							
	1990	2000	2005	2008	2009	2010	2011	2012
International Navigation	**3 100**	**3 200**	**3 100**	**2 300**	**2 400**	**1 700**	**1 400**	**1 400**
Domestic Navigation	5 100	5 200	6 700	6 700	7 000	5 900	5 800	5 300
Total	8 200	8 400	9 800	9 000	9 400	7 600	7 300	6 700

Note: Totals may not add up due to rounding.

Table 3–5   Energy Industries GHG Contribution

GHG Source Category	GHG Emissions (kt CO$_2$ eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Energy Industries TOTAL (1.A.1)	146 000	200 000	193 000	165 000	165 000	157 000	156 000	156 000
Public Electricity and Heat Production	94 500	131 000	124 000	100 000	102 000	94 500	89 000	87 500
Petroleum Refining	17 100	17 300	20 200	19 000	18 100	17 300	18 700	18 400
Manufacture of Solid Fuels and Other Energy Industries[1]	34 300	51 100	48 700	46 000	45 100	45 700	48 200	49 800

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 category.

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 2013, the Energy Industries category accounted for 156 Mt (over 21%) of Canada's total GHG emissions, with an increase of over 6.7% in total emissions since 1990. The Public Electricity and Heat Production subcategory accounted for 56% (87.5 Mt) of the Energy Industries' GHG emissions, while Petroleum Refining and the Manufacture of Solid Fuels and Other Energy Industries contributed 12% (18.4 Mt) and 32% (49.8 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 emissions from stationary fuel combustion sources related to utility electricity generation and many of the emissions from the production, processing and refining of fossil fuels. Specifically, the Manufacture of Solid Fuels and Other Energy Industries subcategory includes 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 the Manufacturing Industries and Construction/ Mining and the Other Transportation and Pipeline Transport subcategories. 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 emissions associated with the production of electricity and heat from the combustion of fuel in public utility thermal power plants.[3] The estimated GHG emissions from this subcategory do not include emissions from industrial generation; rather, these emissions have been allocated to the 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 are not direct emitters of GHGs; therefore, GHG estimates reflect emissions from combustion-derived electricity only. Steam generation and internal combustion engines are the primary systems used to generate electricity through thermal processes. Steam turbine boilers are fired with coal, petroleum coke, heavy fuel oil, natural gas or biomass. Reciprocating engines can use natural gas and/or a combination of refined petroleum products (RPPs). Gas turbines are also fired with natural gas or RPPs.

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

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

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

The Manufacture of Solid Fuels and Other Energy Industries subcategory comprises own fuel combustion emissions associated with the crude oil, natural gas, oil sands mining, bitumen extraction and upgrading, and coal mining industries. Emissions

from purchased fuel associated with coal mining and oil and gas extraction (which includes oil sands mining, extraction and upgrading) are reported 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 57-003-X). 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. Industrial electricity generation emissions 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 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

3   Category as defined by Statistics Canada.

these subcategories, but aggregate the data into one category titled Electricity by Utilities. All GHG emissions from the Statistics Canada Electricity by Utilities area were reported under the Electricity Generation CRF category.

Statistics Canada fuel-use data include industrial wood wastes and spent pulping liquors combusted for energy purposes, aggregated into one national total. GHG emissions of CH_4 and N_2O from the combustion of biomass were reallocated to their respective categories using the RESD input data. CO_2 emissions from biomass combustion are not included in totals but are 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 fueluse 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 fueluse 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 (NGLs) 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.

3.2.4.3. Uncertainties and Time-Series Consistency

The estimated uncertainty range for the Energy Industries category is ±7% for all gases and ±7% for CO_2 alone.

Uncertainties for the Energy Industries category are dependent on activity data collection procedures and the representativeness of specific fuels' emission factors. Commercial fuel volumes and properties are generally well known, while greater uncertainty surrounds both the reported quantities and properties of non-marketable fuels (e.g. own use of natural gas from the producing wells and the use of still gas). For example, in the Petroleum Refining subcategory, the CO_2 emission factors for non-marketable fuels, such as still gas, petroleum coke and catalytic coke, have a greater impact on the uncertainty estimate than

the CO_2 factors for commercial fuels. Coal CO_2 emission factors were developed using statistical methods and 95% confidence intervals.

The estimated uncertainty for CH_4 (±21%) and N_2O (±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_4 and N_2O 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 82% of the 2013 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_2 (±6%) and CH_4 (0% to +240%) emission factors for the consumption of unprocessed natural gas. Provincially weighted natural gas emission factors were used to estimate emissions for the natural gas industry since plant-level information on the physical composition of unprocessed natural gas (which will vary from plant to plant) is unavailable.

3.2.4.4. QA/QC and Verification

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

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 new UNFCCC reporting guidelines. As detailed below, revised activity data and emission factors, along with new 2006 IPCC Guidelines, contributed to improved emission estimates from fuel combustion. Table 3–6, presents the overall change in GHG emissions as a result of recalculation activities for Energy Industries, Manufacturing Industries and Construction, and Other Sectors. In 2012, the overall emission increased by 10.7 Mt CO_2 eq as a result of methodological improvements, activity data updates and revised GWPs. The GHG impacts on the entire inventory due to revised CH_4 and N_2O GWPs (as called for in the new UNFCCC reporting guidelines) are presented in Chapter 2. The recalculation resulting from the adoption of a new residential fuelwood method is discussed in Section 3.2.7.5 and in Annex 3.1.

Table 3–6   Overall GHG Impact Due to Recalculations for Categories 1A1 –Energy Industries, 1A2 – Manufacturing Industries and Construction and 1A4 – Other Sectors

IPCC Categories	1990	2000	2005	2009	2010	2011	2012
Previous submission (2014 NIR); kt CO_2 eq	280 000	347 000	338 000	313 000	313 000	316 000	309 000
Current submission (2015 NIR); kt CO_2 eq	288 000	355 000	344 000	318 000	318 000	321 000	320 000
Total change:	Categories 1A1, 1A2, and 1A4						
kt CO_2 eq	7 660	7 240	6 060	4 850	5 230	5 260	10 710
Percentage change	2.7%	2.1%	1.8%	1.5%	1.7%	1.7%	3.5%
Change due to new GWPs:	GWPs						
CH_4 kt CO_2 eq	1 390	1 450	1 170	1 090	1 130	1 140	1 170
N_2O kt CO_2 eq	-105	-123	-119	-109	-111	-113	-114
Change due to new methods:	Oxidation Factor, Residential Fuelwood, Coal Coke EF, Still Gas EF						
CO_2	2 280	2 520	3 010	2 010	2 120	2 120	3 800
CH_4 kt CO_2 eq	3 540	2 930	1 680	1 550	1 760	1 760	1 780
N_2O kt CO_2 eq	550	460	320	300	340	340	350
Change due to updates in activity data:	RESD						
CO_2	-	-	-	-	-	-	3 650
CH_4 kt CO_2 eq	-	-	-	-	-	-	54
N_2O kt CO_2 eq	-	-	-	-	-	-	31

Note: Totals may not add up due to rounding.
Impact of Residential Firewood does not include CO_2 emissions.
Totals may not add up due to rounding.
- Indicates no emissions.

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

- 2012 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):

- 100% oxidation factor has been applied to all combustion based CO_2 emission factors according to the default recommendation provided by the 2006 IPCC Guidelines. Refer to Annex 6, Emission Factors, for details.

- Revised CO_2 emission factor for coke based on specific coking coal characteristics from all four Canadian integrated steel plants. Refer to Annex 6, Emission Factors, for details.

- Revised 2010 to 2012 CO_2 emission factor for still gas based on updated industry data (CIEEDAC 2014).

3.2.4.6.   Planned Improvements

The 2006 IPCC Guidelines requires the Public Electricity and Heat Production subcategory to be divided into Electricity Generation, Combined Heat and Power Generation and Heat Plants. However, the current Statistics Canada fuel-use data in the RESD do not differentiate based on these subcategories. Additional data sources and methods are being investigated with the eventual goal of reallocating the data, as required. Increases in the usage of privately-owned combined heat and power plants (and co-generation systems) require additional research and investigation to ensure that emissions are appropriately allocated.

Work is under way to investigate the possibility of developing a bottom-up inventory for the Public Electricity and Heat Production category, consistent with Tier 3 methods. It will be necessary to first complete research and investigation to ensure that emissions from 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, and these are presented separately in the following subsections.

In 2013, the Manufacturing Industries and Construction category accounted for 91.3 Mt (12.6%) of Canada's total GHG emissions, with a 41% (26.4 Mt) increase in overall emissions since 1990 (refer to Table 3–7 for more details). Within the Manufacturing Industries and Construction category, 60.7 Mt (67%) of the GHG emissions are from the Others subcategory. The Others subcategory is made up of mining, construction and other manufacturing activities. This subcategory is followed by (in order of decreasing contributions) the Chemical Industries; Pulp, Paper and Print; Iron and Steel; Cement; and Non-ferrous Metals subcategories, at 11.4 Mt (12.5%), 6.52 Mt (7.1%), 5.56 Mt (6.1%), 3.89 (4.3%) and 3.2 Mt (3.5%), respectively. Emissions from Food Processing,

Table 3–7   Manufacturing Industries and Construction GHG Contribution

GHG Source Category	GHG Emissions (kt CO$_2$ eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Manufacturing Industries and Construction TOTAL (1.A.2)	64 900	69 500	69 300	73 500	77 500	82 200	88 400	91 300
Iron and Steel	4 970	6 230	5 570	4 300	4 450	5 290	5 510	5 560
Non-ferrous Metals	3 320	3 590	3 620	2 850	2 990	3 310	2 930	3 200
Chemicals	8 260	10 800	8 320	8 870	9 910	11 100	11 000	11 400
Pulp, Paper and Print	14 600	12 600	8 660	6 410	5 990	6 260	6 040	6 520
Food Processing, Beverages and Tobacco[1]	IE	IE	IE	IE	IE	IE	IE	IE
Cement	3 960	4 630	5 430	4 480	4 070	4 290	4 050	3 890
Others	29 900	31 600	37 700	46 500	50 100	52 000	58 900	60 700
Mining[2]	6 800	12 200	19 100	31 800	34 800	35 900	42 400	43 800
Construction	1 880	1 080	1 450	1 220	1 510	1 440	1 460	1 440
Other Manufacturing	21 200	18 200	17 100	13 500	13 900	14 600	15 100	15 500

Note:
1. Note that Food Processing, Beverages and Tobacco emissions are included under Other Manufacturing.
2. Mining is included with 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.

Beverages and Tobacco are included in the Other Manufacturing subcategory due to fuel-use data not being available at the appropriate level of disaggregation.

Industrial emissions resulting from fuel combustion for the generation of electricity or steam for sale have been assigned to the corresponding industrial subcategory. 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 Sector to ensure that the emissions are not double counted.

3.2.5.2.   Methodological Issues

Fuel combustion emissions 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. 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)). GHG emissions of CH$_4$ and N$_2$O from the combustion of biomass were included in the subcategory. CO$_2$ emissions from biomass combustion are not included in totals, but are reported separately in the UNFCCC CRF tables as a memo item.

Methodological issues specific to each manufacturing subcategory are identified below.

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

In 2013, Canada had four integrated iron and steel facilities that manufacture all the coal-based metallurgical coke. All these facilities are structured in such a way 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 way the fuel consumption is reported by the iron and steel industry, determining the amount of coke oven gas lost as fugitive emissions through flaring is difficult. However, Statistics Canada indicates that the amount of fuel flared is included in the energy statistics, indicating that fugitive emissions are being captured as well.

Emissions associated with the use of metallurgical coke as a reagent for the reduction of iron ore in blast furnaces have been allocated to the Industrial Processes Sector.

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

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

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

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

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

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

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

All fuel-use data for this category were 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 ±1% for all gases.

The underlying fuel quantities and CO_2 emission factors have low uncertainty because they are predominantly commercial fuels, which have consistent properties and a more accurate tracking of quantity purchased for consumption. Coal CO_2 emission factor uncertainties were updated with 95% confidence intervals (see Section 3.2.4.3).

As discussed in the Energy Industries category uncertainty discussion, additional expert elicitation is required to improve the CH_4 and N_2O uncertainty estimates for some of the emission factor uncertainty ranges and probability density functions developed by the ICF Consulting study (ICF Consulting 2004), 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_2, CH_4 and N_2O estimates for the entire time series. No mathematical or reference errors were found during the QC checks. The data, methodologies and changes related to the QC activities are documented and archived in both paper and electronic form.

3.2.5.5. Recalculations

Revised emission factors and 2012 RESD data contributed to recalculations and improved accuracy of the emission for the Manufacturing Industries and Construction subcategory. Refer to Section 3.2.4.5, Recalculations for more details.

3.2.5.6. Planned Improvements

As this is an activity that is continuously being improved, Environment Canada, Natural Resources Canada and Statistics Canada are working jointly to improve the underlying quality of the national energy balance and to further disaggregate fuel-use information.

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

Transport-related emissions account for 204 Mt, 28% of Canada's total GHG emissions (Table 3–8). The greatest emission growth since 1990 has been observed in light-duty gasoline trucks (LDGTs) and heavyduty diesel vehicles (HDDVs), with growth amounting to 110% (22.4 Mt) for LDGTs and 112% (22.7 Mt) for HDDVs. A longterm decrease in some Transport categories has also been noted: specifically, reductions in emissions from lightduty gasoline vehicles (LDGVs, i.e. cars), propane and natural gas vehicles, pipelines and heavy-duty gasoline vehicles (HDGVs), for a combined decrease of 8.7 Mt since 1990. Generally, emissions from the Transport subsector have increased 38% and have contributed the equivalent of 50% of the total overall growth in emissions observed in Canada.

3.2.6.1. Source Category Description

The Transport subsector comprises the combustion of fuel by all forms of transportation in Canada. The subsector has been divided into six distinct categories:

- Domestic Aviation;
- Road Transportation;
- Railways;
- Domestic Navigation;
- Pipeline Transport; and
- Other (Off-road).

3.2.6.2. Methodological Issues

Fuel combustion emissions associated with the Transport subsector 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). Please refer to Annex 3.1 for a detailed description of Transport methodologies.

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

This category 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 category 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 57-003-

X). Aircraft fuel sales reported in the RESD represent aircraft fuels sold to Canadian airlines, foreign airlines, 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_2 emissions and an IPCC Tier 1 for CH_4, and N_2O emissions), as outlined in IPCC (2006). MGEM disaggregates vehicle data and calculates emissions of CO_2, CH_4, and N_2O from all mobile sources except pipelines.

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

The procedure used to estimate GHG emissions from railways adheres to an IPCC Tier 2 methodology (IPCC 2006). Emission estimates are performed within MGEM. Fuel sales data from the RESD (Statistics Canada 57-003-X) reported under railways are multiplied by country-specific emission factors.

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

This category 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).

Table 3–8   Transport GHG Contribution

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Transport TOTAL (1.A.3.)	148 000	182 000	195 000	190 000	200 000	199 000	199 000	204 000
Civil Aviation (Domestic Aviation)	7 200	7 700	7 600	6 500	6 500	6 200	7 300	7 500
Road Transportation	97 700	119 000	132 000	133 000	135 000	134 000	134 000	137 000
Light-duty Gasoline Vehicles	45 900	42 400	40 500	40 100	40 400	38 900	38 600	39 400
Light-duty Gasoline Trucks	20 500	36 700	43 100	42 900	43 300	41 600	41 700	42 900
Heavy-duty Gasoline Vehicles	7 530	5 530	6 610	6 990	7 100	6 770	6 940	7 310
Motorcycles	155	164	258	269	275	267	271	279
Light-duty Diesel Vehicles	473	470	579	706	756	795	832	877
Light-duty Diesel Trucks	708	1 680	1 940	2 050	2 110	2 070	2 160	2 210
Heavy-duty Diesel Vehicles	20 200	31 100	38 000	39 400	40 600	42 400	42 100	42 900
Propane & Natural Gas Vehicles	2 200	1 100	730	790	780	820	880	720
Railways	7 000	6 600	6 700	5 100	6 600	7 600	7 600	7 400
Navigation (Domestic Marine)	5 100	5 200	6 700	6 700	7 000	5 900	5 800	5 300
Other Transport	31 000	43 000	43 000	38 000	44 000	46 000	45 000	47 000
Off-road Gasoline	7 900	8 900	8 400	7 400	8 100	8 200	7 800	8 500
Off-road Diesel	16 000	23 000	24 000	25 000	30 000	32 000	31 000	32 000
Pipelines	6 910	11 300	10 200	6 360	5 720	5 650	5 730	6 390

Note: Totals may not add up due to rounding.

The methodology complies with IPCC Tier 2 technique for CO_2 emissions and IPCC Tier 1 for CH_4, and N_2O 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[4] represent the only non-vehicular transport in this sector. They use fossil-fuelled combustion engines to power motive compressors that propel hydrocarbon-based products. 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.

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

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

This category comprises vehicles and equipment that are not licensed to operate on roads or highways. Non-road or off-road transport[5] (ground, non-rail vehicles and equipment) includes GHG emissions resulting from both gasoline and diesel fuel combustion. Vehicles in this category include farm tractors, logging skidders, construction vehicles and mobile mining vehicles as well as off-road recreational vehicles. Equipment in this 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 subsector 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 subsector, the ICF Consulting study incorporated uncertainty values for CO_2, CH_4 and N_2O emission factors from two other

reports: McCann (2000) and SGA Energy Ltd. (2000). The ICF Consulting study included values determined in these reports, along with expert elicitations addressing the uncertainty of the activity data contributing to the Transport subsector estimates within its Monte Carlo analysis.

Modifications to the original assessment include the addition of biofuel emission factor uncertainties based on the assumption of similarities in emission control technologies between conventional transport fuels and biofuels. Biofuel activity data uncertainties were based on expert judgement. Aviation turbo fuel CH_4 and N_2O emission factor uncertainties have been updated to better reflect the improvements made by implementing AGEM. A number of on-road CH_4 and N_2O emission factor uncertainties have also been modified based on recent laboratory data. Additionally, a thorough verification of the 2004 ICF Consulting report revealed a number of discrepancies in referenced uncertainty ranges. In these instances, the discrepancy was corrected to coincide with the original reference.

Transport

The Transport subsector comprises 1) mobile sources of transport, including on-road and off-road vehicles, railways, domestic aviation and navigation; and 2) pipeline transport. The overall uncertainty of the 2013 estimates for the mobile subsector (not including pipelines) was estimated to be between -1.9% and +5.0%.

The uncertainty for Transport fuel combustion CO_2 emissions was ±0.4%. In contrast, and similar to the stationary fuel combustion sources, CH_4 and N_2O emission uncertainty ranges were two to three orders of magnitude greater than that of CO_2. Hence, the overall uncertainty for the Transport subsector reflects the predominance of CO_2 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 high uncertainties associated with jet kerosene CH_4 (-50% to +50%) and N_2O emission factors (-70% to +150%) resulted in a downward bias on the inventory. These effects were somewhat reduced by the large contribution of jet kerosene CO_2 emissions and its comparatively low emission factor uncertainty. The Domestic Aviation category only contributed approximately 4% to total Transport GHG emissions and therefore did not greatly influence overall uncertainty levels.

Emissions from Road Transportation

The uncertainty related to the overall emissions from on-road vehicles was estimated to be within the range of ±1%, driven

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

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

primarily by the relatively low uncertainties in gasoline and diesel fuel activity data and their related CO_2 emissions. Conversely, the high uncertainties associated with CH_4 and N_2O emissions, as well as biofuel activity data, did not greatly 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 between -11% and +31%, indicating that this category was potentially underestimated. The greatest influence was exerted by the high N_2O emission factor uncertainty (-90% to +900%), whereas the relatively low uncertainties in diesel fuel activity data and CO_2 emission factors contributed very little. It is important to note that railway emissions only accounted for approximately 4% of the Transport subsector GHG inventory and therefore did not greatly influence the overall uncertainty results.

Emissions from Domestic Navigation

The uncertainty associated with emissions from the domestic navigation source category ranged from -7% to +14%, suggesting that GHGs were potentially underestimated. The high N_2O emission factor uncertainty (-90% to +900%) represented the largest contribution to uncertainty, while CO_2 emission factor uncertainties were insignificant. Since domestic navigation emissions only made up 3% of the Transport subsector GHG inventory, they did not substantially alter the overall uncertainty results.

Emissions from Pipeline Transport

In general, the CH_4 emission uncertainty for pipeline transport ranges from ±40%. Specific uncertainties from pipelines by GHGs can be found in Table A -1 and Table A -2 – Uncertainty Assessment with and without LULUCF.

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 ranged from -8% to +25%, indicating that the 2015 submission is more likely to underestimate total emissions from this subcategory. 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 employed in the off-road uncertainty analysis and did not greatly contribute to the results mentioned above since they were relatively low. Of greater influence was the N_2O emission uncertainty for gasoline and diesel fuel (-90% to +900%), which suggested a downward bias in the GHG estimate. Approximately 20% of the Transport subsector'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 whose data are expected to be incorporated into MGEM in the coming years.

3.2.6.5. Recalculations

Transportation estimates were revised for the 1990–2012 period. Revised guidelines, revised activity data, a new method for Aviation Gasoline and an emission factor correction for gasoline all contributed to recalculations in the Transport subsector. The detailed impacts of the recalculations are summarized in Table 3–9.

The changes in the Transport subsector can be described as the following:

- *Incorporation of New UNFCCC Reporting Guidelines*: To reflect the adoption of the updated UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3) and by extension, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006), CO_2 emission factors and GWPs were updated. The CO_2 emission factors now assume full oxidation (100%) of the carbon in the fuel. These updates affect the entire time series.
- *Activity Data*: The fuel-use data were revised for 2012 based on Statistics Canada data, and estimates were recalculated accordingly. Refer also to Section 3.2.4.5. Biofuel consumption data were also revised for 2011 and 2012.
- *Tier 3 for Aviation Gasoline*: The method for Aviation Gasoline was changed from a Tier 1 to a Tier 3 approach. The method change resulted in recalculations for the entire time series. For further information on the method, please refer to Annex 3.1.

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Table 3–9   Summary of Recalculations in the Transport Subsector

	Year						
	1990	2000	2005	2009	2010	2011	2012
Previous submission (2014 NIR); kt CO_2 eq	147 000	180 000	194 000	188 000	198 000	198 000	195 000
Current submission (2015 NIR); kt CO_2 eq	148 000	182 000	195 000	190 000	200 000	199 000	199 000
Total change:							
kt CO_2 eq	1 360	1 560	1 720	1 760	1 830	1 750	3 800
Percentage change of previous submision	0.93%	0.87%	0.89%	0.93%	0.93%	0.89%	1.95%
Change due to New UNFCCC Reporting Guidelines:							
CH_4 kt CO_2 eq	100	100	100	100	100	100	100
N_2O kt CO_2 eq	-200	-400	-400	-300	-300	-300	-300
Change due to 2006 IPCC Guidelines:							
kt CO_2 eq (CO_2 only)	1 360	1 660	1 800	1 780	1 880	1 870	1 880
Change due to continuous improvement or refinement:							
kt CO_2 eq[1]	109	141	155	156	161	156	164
Change due to updates in activity data:							
CO_2	-	-	-	-	-	-77.4	1 810
CH_4 kt CO_2 eq	-	-	-	-	-	0.1	2
N_2O kt CO_2 eq	-	-	-	-	-	4	100

Note:
Totals may not add up due to rounding.
1. Primarily composed of CO_2. Includes a negligle contribution from CH_4 and N_2O.
- Indicates no emissions.

- *Gasoline CO_2 Emission Factor*: A correction was made to the previous gasoline EF, which was miscalculated based on the ethanol content in the fuel samples when it was originally developed. This correction better represents the base gasoline CO_2 emission factor, as CO_2 emissions from ethanol are calculated distinctly with an ethanol-specific CO_2 emission factor. For further documentation on emission factors, refer to Annex 6.

These improvements have increased the transparency, accuracy and representativeness of fuel consumption at the sectoral and subsectoral levels.

3.2.6.6.   Planned Improvements

Planned improvements have been identified for the Transport subsector. Current high priorities include the development of a bottom-up, Tier 3 methodology for off-road emissions estimates using the NONROAD model and replacing 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. An update on these projects will be provided in the next inventory submission.

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/Fisheries. The Commercial/Institutional subcategory also includes emissions from the public administration subcategory (i.e. federal, provincial and municipal establishments) Emissions are from fuel combustion, primarily related to space and water heating. 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_2 as well as CH_4 and N_2O emissions, which are considered technology-dependent. The main types of residential wood combustion devices are stoves, fireplaces, furnaces and other equipment (e.g. pellet stoves). Biomass used to generate electricity is a small source of emissions in the Commercial subcategory. Emissions from CH_4 and N_2O were included in the subcategory estimates, while CO_2 emissions were reported separately in the CRF tables as memo items and were not included in Energy Sector totals.

In 2013, the Other Sectors category contributed 78.2 Mt (10.8%) of Canada's total GHG emissions, with an overall growth of about 1.4% (1.1 Mt) since 1990. Within the Other Sectors category,

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residential emissions contributed about 45.8 Mt (58.5%), followed by a 28.9 Mt (or 36.9%) contribution from the Commercial/Institutional subcategory. Since 1990, GHG emissions have grown by 11.7% in the Commercial/Institutional subcategory, while GHG emissions in the Residential subcategory have declined by about 6.4%. Refer to Table 3–10 for additional details. Additional trend discussion 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 subsector.

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_4 and N_2O emissions from the combustion of LFG are included, while CO_2 emissions are excluded from totals but reported separately in the UNFCCC CRF tables as a memo item.

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_2 emissions are not accounted for in the national residential GHG total (but reported as a memo item), the CH_4 and N_2O 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 reported typically under either the Transportation 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 ±6% for all gases and ±2% for CO_2.

The underlying fossil fuel quantities and non-biomass CO_2 emission factors have low uncertainties, since they are predominantly commercial fuels that have consistent properties and accurate tracking as compared to residential biomass information. The overall non-CO_2 emissions uncertainty were 12% for the Residential subcategory due to higher uncertainty associated with biomass emission factors (CH_4 with -90% to +1500% and N_2O with -65% to +1000%) as compared to fossil-fuel-based CH_4 and N_2O emission factors (ICF Consulting 2004). As stated in the Energy Industries category, for some of the emission factor uncertainty ranges and probability density functions, additional expert elicitation will improve the associated CH_4 and N_2O uncertainty estimates.

These estimates use the same methodology and are consistent over the time series. A discussion of fuel-use data is presented in Section 3.2.4.3, Recalculations.

Table 3–10   Other Sectors GHG Contribution

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Other Sectors TOTAL (1.A.4)	77 200	85 400	81 900	79 200	75 700	81 300	76 000	78 200
Commercial/Institutional	25 800	33 100	32 100	29 600	28 200	30 100	28 200	28 900
Commercial and Other Institutional	23 900	30 800	30 000	27 500	26 300	28 200	26 400	27 200
Public Administration	1 990	2 300	2 070	2 040	1 820	1 920	1 760	1 630
Residential	48 900	49 700	47 700	47 100	44 700	47 800	44 200	45 800
Agriculture/Forestry/Fishing	2 410	2 570	2 110	2 550	2 900	3 460	3 560	3 580
Forestry	58	77	159	169	189	136	137	166
Agriculture	2 350	2 490	1 950	2 380	2 710	3 320	3 420	3 410

Note: Totals may not add up due to rounding.

3.2.7.4. QA/QC and Verification

The Other Sectors category underwent QC checks in a manner consistent with 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 both paper and electronic form.

3.2.7.5. Recalculations

In addition to revised emission factors and new 2012 energy data for the Other Sectors category (refer to Section 3.2.4.5), new residential fuelwood and combustion technology data also contributed to improved accuracy:

Revised 1990 to 2012 residential fuel wood data based on new fuel wood consumption survey results; the new approach incorporates additional information on the type and density of wood consumed, as well as fuel wood consumed at secondary residences (i.e. cottages).

Revised residential fuelwood combustion equipment parameters to reflect change in combustion technology over time.

The residential fuelwood methodology is discussed in detail in Annex 3.1.

3.2.7.6. Planned Improvements

Future improvement plans for the Other Sectors category include updating the uncertainty associated with the activity data based on the recent improvements discussed in Section 3.2.7.5, Recalculations.

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

The UNFCCC reporting guidelines assign military fuel combustion to this subsector. 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 subsector, whereas stationary military fuel use has been included under the Commercial/Institutional category (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_2 eq in 2013.

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 2013, the Fugitive Emissions from Fuels category accounted for about 59 Mt (8.1%) of Canada's total GHG emissions, with 20% growth in emissions since 1990. Between 1990 and 2013, fugitive emissions from oil and natural gas increased 23.9% to 57 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 97% of the fugitive emissions. Refer to Table 3–11 for more details.

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

3.3.1.1. Source Category Description

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

Coal Mining and Handling

Sources of mining emissions include exposed coal surfaces, coal rubble and the venting of CH_4 from within the deposit. Post-mining activities such as preparation, transportation, storage and final processing prior to combustion also release CH_4.

Abandoned Underground Mines

Abandoned underground coal mines are sites where active mining and ventilation management have ceased but fugitive methane emissions continue to occur. In Canada, emissions from abandoned mines were 333 kt CO_2 eq in 2013, while emissions

Table 3–11   Fugitive GHG Contribution

GHG Source Category	GHG Emissions (kt CO$_2$ eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Fugitive Emissions from Fuels (1.B)	49 000	70 000	61 000	56 000	55 000	56 000	57 000	59 000
Solid Fuels—Coal Mining (1.B.1)	2 800	1 700	1 600	1 400	1 600	1 600	1 600	1 700
a. Coal Mining and Handling	2 600	1 200	1 200	1 100	1 200	1 200	1 300	1 400
b. Abandoned Underground Mines	200	500	400	400	400	300	300	300
Oil and Natural Gas (1.B.2)	46 000	68 000	59 000	54 000	53 000	54 000	56 000	57 000
a. Oil[1]	5 000	6 500	6 400	5 900	6 000	6 200	6 800	7 200
b. Natural Gas[1]	13 000	18 000	14 000	13 000	12 000	12 000	12 000	13 000
c. Venting and Flaring[2]	28 000	44 000	39 000	36 000	35 000	36 000	37 000	37 000
Venting	23 000	38 000	34 000	31 000	30 000	31 000	32 000	32 000
Flaring	4 600	5 700	5 300	4 900	4 700	4 900	4 900	5 400
CO$_2$ Transport and Storage (1.C)[3,4]	-	0	0	0	0	0	0	0

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.

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from the two active underground mines were estimated at only 90 kt CO$_2$ eq. See Table 3–11 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 located in Annex 3.2: Additional Methodologies – Fugitive Emissions.

A field testing campaign to measure fugitive emissions of CH$_4$, CO$_2$, and VOCs was performed on four coal mines in late February 2014:

• Sites 1 & 2: two subbituminous coal mines in central Alberta;

• Site 3: one bituminous coal mine in northeast BC; and

• Site 4: one bituminous coal mine in northwest Alberta.

Methane (CH$_4$) emissions were measured remotely using a ground-based mobile plume transect system (MPTS) for area sources and tracer tests for volume and point sources (Cheminfo

et al. 2014). Data from this field testing was used to modify the CH$_4$ emission factors of 7 of the 23 producing mines in Canada. Additional discussion of the methodology can be found in Annex 3.2, Additional Methodologies – Fugitive Emissions.

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

5.   Openings and restrictions such as vent holes and mine seals

Yearly variations in emissions are driven by changes in number of abandoned mines and the effects of the applied decline curve. Further discussion of the methodology can be found in Annex 3.2, Additional Methodologies – Fugitive Emissions.

3.3.1.3. Uncertainties and Time-Series Consistency

Coal Mining and Handling

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

Abandoned Underground Mines

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

3.3.1.4. QA/QC and Verification

The CH_4 emissions from coal mining were identified as a key category and underwent QC checks in a manner consistent with the 2006 IPCC Guidelines. Checks included a review of activity data, time-series consistency, emission factors, reference material, conversion factors and units labelling, as well as sample emission calculations. No mathematical errors were found during the QC checks. The data and methods related to the QC activities are documented and archived in paper and electronic form. Abandoned underground mines were also subject to QC checks as noted above.

3.3.1.5. Recalculations

Coal Mining and Handling

Estimates for fugitive emissions from coal mining were revised based on a new study of emissions at several mines in Alberta and British Columbia. See section 3.3.2.5 for more details.

Abandoned Underground Mines

Emissions reported for the first time.

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

Future improvement plans for this sector include a review of the activity data and assumptions underlying the emissions estimates for abandoned underground mines.

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 categories.

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/m3). 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^3. 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 (CHOPS)), cyclic steam stimulation (CSS), steam-assisted gravity drainage (SAGD), and experimental methods, such as toe-to-heel air injection (THAI), vapour extraction process (VAPEX) and combustion overhead gravity drainage (COGD). The sources of emissions are wells, flow lines, satellite batteries and cleaning plants. The main source of emissions is the venting of casing gas.

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

Natural Gas Transmission: Virtually all of the natural gas produced in Canada is transported from the processing plants to the gate

of the local distribution systems by pipelines. The volumes transported by truck are insignificant and assumed to be negligible. The gas transmission system emission sources are from equipment leaks and process vents. Process vents include activities such as compressor start-up and purging of lines during maintenance. The largest source of emissions is equipment leaks.

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

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

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

Oil Sands / Bitumen

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

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

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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 subsector.

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

3.3.2.2. Methodological Issues

Upstream Oil and Gas

Fugitive emission estimates from the UOG industry are based on two separate studies that follow the same methodology: the Canadian Association of Petroleum Producers' (CAPP) study of the industry titled A *National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emissions by the Upstream Oil and Gas Industry* (CAPP 2005)—referred to here as the CAPP study—and an update to this inventory which was completed in 2014 for Environment Canada by Clearstone Engineering Ltd. and which is referred to here as the UOG study (EC 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 that delivered to 150 tank terminals, all of which are interconnected by tens of thousands of kilometres of pipeline carrying hydrocarbons from wells to batteries to plants and ultimately markets. The resulting 2011 inventory database contains more than 7.5 million point-source emission records. Emissions from flaring, venting, equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses and accidental releases were estimated.

A multitude of data were collected and used in both studies. These included activity data from the facilities, such as production accounting (e.g. volumes flared and vented) and equipment data. Emission factors were obtained from a variety of sources, including published reports, equipment manufacturers' data, observed industry values, measured vent rates, simulation programs, and other industry studies. A list of data and emission factors can be found in Volume 5 of the CAPP study (CAPP 2005) and Volume 4 of the UOG study (EC 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 (EC 2014) emission results along with annual industry activity data and interpolation techniques. Similarly, the 2006–2010 emissions were estimated using the 2005 and 2011 (EC 2014) emission results with annual industry activity data and interpolation techniques. From 2012 on, the 2011 (EC 2014) emission results are used in conjunction with annual activity data to estimate emissions. A more detailed description of the methodology can be found in Annex 3.2.

Natural Gas Transmission

Fugitive emissions from natural gas transmission for 1990–1996 are from the study titled *CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP 1999). This study is considered to follow a rigorous IPCC Tier 3 approach in estimating GHG emissions. Fugitive emission estimates for 1997–1999 were estimated based on length of natural gas pipeline and leakage rates, as developed based on the results from the original study. For the year 2000 onwards, emissions are based on data from the UOG study (EC 2014), following an IPCC Tier 3 approach that rolled up the reported GHG emissions from individual natural gas companies. 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 H₂S 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 CAPP's UOG study (CAPP 2005a) (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 reports: *Alberta Mineable Oil Sands Plant Statistics* from the Alberta Energy Regulator (AER 2014) and the National Energy Board's (NEB 1998–2013) 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 (2014) 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 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 published by Statistics Canada (57-003-X).

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 upon emission factors from the U.S. EPA, other published sources and engineering estimates. The activity data in the study were obtained from published sources and from specialized surveys of gas distribution system companies. The surveys obtained information on schedules of equipment, operation parameters of equipment, pipeline lengths used in the Canadian distribution system, etc. In the year 2000, the Gas Research Institute (GRI) reviewed and revised the 1997 CGA study, with more accurate and better substantiated data for station vents (GRI 2000). General emission factors were developed for the distribution system based on the study data (CGA 1997; GRI 2000) and gas distribution pipeline distances by province provided by Statistics Canada.

For the year 2000 onwards, emissions are based on data from the UOG study (EC 2014), following an IPCC Tier 3 approach that rolled-up the reported GHG emissions from individual natural gas companies. 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 2013 upstream oil and gas fugitive emissions is -11.4% to + 13.3%. The uncertainties for specific UOG categories are listed in Table 3–12. Note that the gas transportation industry includes natural gas transmission, storage and distribution. Accidents and equipment failures has the highest uncertainty, while oil production and transport has 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

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

GHG Source Category	Uncertainty (%)				
	Oil Production and Transport	Gas Production / Processing	Gas Transportation	Accidents and Equipment Failures	Well Drilling, Servicing and Testing
Flaring	±7.6	-6.5 to + 6.4	-17.2 to +16.2	—	-21.3 to +19.3
Fugitive	±15.9	± 29.2	-22.0 to +23.6	± 52.6	-28.4 to +31.1
Venting	-14.0 to +14.1	-23.6 to +38.5	-14.9 to +17.6	—	-33.1 to +38.0
Total	**-10.4 to + 10.5**	**-18.6 to +29.6**	**-16.4 to +17.8**	**± 52.6**	**-20.0 to +18.2**

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 2013 oil sands/bitumen fugitive emission estimates has been estimated to be ± 6.1%, on the basis of a study conducted on 2006.[6] An IPCC Good Practice Guidance Tier 1 uncertainty assessment was conducted for each oil sands mining and upgrading facility, with full details of the assessment contained in 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 3–13.

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 were performed, for comparison purposes, of the emission factors and activity data, for an overall CO_2 uncertainty in the 2002 data (CPPI 2004).

The results of these analyses are as follows: For the Tier 1 analysis, the overall uncertainty was ±8.3%. The Tier 2 analysis determined

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

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

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

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 3–14.

3.3.2.4.   QA/QC and Verification

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

3.3.2.5.   Recalculations

Fugitive emissions from oil and natural gas and coal mining activities were revised for the 1990–2012 period. Revised guidelines, revised activity data, and the updated Upstream Oil and Gas study (EC 2014) all contributed to recalculations. The detailed

Table 3–14   Uncertainty in Oil Refining Fugitive Emissions

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

Table 3–15   Summary of Recalculations in the Fugitive category

	1990	2000	2005	2009	2010	2011	2012
Previous submission (2014 NIR); kt CO_2 eq	42 400	63 000	63 400	58 800	58 500	59 600	61 100
Current submission (2015 NIR); kt CO_2 eq	48 800	69 900	61 100	55 700	54 600	55 600	57 400
Total change:							
kt CO_2 eq	6 400	6 800	-2 300	-3 200	-3 900	-4 000	-3 700
Percentage change	15%	11%	-4%	-5%	-7%	-7%	-6%
Change due to new GWPs:							
CH_4 kt CO_2 eq	5 900	8 600	7 400	6 700	6 600	6 800	7 100
N_2O kt CO_2 eq	-1.3	-1.5	-1.5	-1.8	-1.7	-1.7	-1.6
Change due to 2006 IPCC Guidelines, continuous improvement or refinement:	Abandoned Coal Mines, CO_2 Transport and Storage, Fugitive Coal Efs						
CO_2	-	0.1	0.1	0.1	0.1	0.1	0.1
CH_4 kt CO_2 eq	170	470	380	330	320	330	330
N_2O kt CO_2 eq	-	-	-	-	-	-	-
Change due to continuous improvement or refinement:	Upstream Oil and Gas, Natural Gas Transmission and Distribution						
CO_2	140	230	-670	-1 100	-1 500	-1 800	-1 900
CH_4 kt CO_2 eq	170	-2 500	-9 400	-9 100	-9 300	-9 300	-9 300
N_2O kt CO_2 eq	2	3	2	2	2	2	2
Change due to updates in activity data:							
CO_2	0.0	0.0	0.0	0.0	0.1	0.0	18
CH_4 kt CO_2 eq	1.1	1.6	6.0	9.0	10.4	0.6	4.9
N_2O kt CO_2 eq	1.1	1.6	6.0	9.1	10.4	0.6	22

Note:
Totals may not add up due to rounding.

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impacts of the recalculations are summarized in Table 3–15. The GHG impacts on the entire inventory due to revised CH_4 and N_2O GWPs (as called for in the new UNFCCC reporting guidelines) are presented in Chapter 2.

The changes in the Fugitive Sources category were caused by the following:

- *Incorporation of New UNFCCC Reporting Guidelines*: To reflect the adoption of the updated UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3) and by extension, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006), GWPs were updated. This update affects the entire time series.

- *2006 IPCC Guidelines*: Implementation of the 2006 IPCC Guidelines for the Fugitive Sources category includes the estimation of fugitive emissions from abandoned coal mines, which were previously not included in the inventory.

- *Updated Fugitive Coal Emission Factors*: Updated emission factors for five mines in Alberta and British Columbia (Cheminfo et al. 2014) resulted in small changes throughout the time series.

- *Updated Upstream Oil and Gas Study*: The updated inventory of fugitive emissions from the Upstream Oil and Gas industry (EC 2014) resulted in significant changes to the entire time series. Changes in the 1990-1999 time period were minimal, while from 2000-2012 the updated inventory (EC 2014) resulted in large changes. The large reduction in CH4 emissions is mainly the result of three changes that impacted emission estimates:

  1. Improvements to the natural gas transmission, storage, and distribution emission estimates. Previously, studies that were completed in the mid-1990s were used to estimate emissions for the entire time series. The estimates for these industries are now based on the results contained in the updated UOG study (EC 2014), taking into account changing practices and technology used in the industry.

  2. Around the year 2000, Alberta introduced regulations for venting and flaring, called Directive 060 (AER 2014), which have reduced emissions from these sources significantly. The CAPP (2005) study, previously used to estimate emissions, did not fully capture the affects of this regulation.

  3. In 2006, Best Management Practices (BMP) for fugitive equipment leaks were incorporated into Alberta's Directive 060, which have had an impact on fugitive emissions. In order to evaluate the impact of the BMPs, CAPP completed an update of fugitive equipment leak emission factors (EF) in facilities where such practices were implemented (CAPP 2014). These updated EFs were applied to all facilities in the UOG study (EC 2014) for the 2011 data year and resulted in updated emission estimates.

- *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 (EC 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.

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_2 Transport and Storage (CRF 1.C)

Carbon dioxide transport and storage involves the capture of anthropogenic CO_2 and its transport to a storage facility. The IPCC previously provided no default method for calculating these emissions. With the adoption of the 2006 IPCC Guidelines, these emissions are reported in the NIR for the first time.

While a CO_2 pipeline exists in Canada, it is associated with the use of carbon dioxide in an enhanced oil recovery (EOR) process. All CO_2 from this process is recovered for reuse and therefore no estimates are provided for emissions from storage. Any net emissions from these operations are included in Canada's inventory as part of the Energy Industries (1A.1) and Oil and Natural Gas and Other Emissions from Energy Production (1B.2) categories. Further discussion of this facility can be found in Section 3.5.2.

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

Carbon dioxide captured at Dakota Gasification Company's Great Plains Synfuels Plant in North Dakota (in the United States) is transported by pipeline to the Cenovus EOR facility at Weyburn, Saskatchewan.

3.4.1.1. Source Category Description

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

3.4.1.2. Methodological Issues

The 2006 IPCC Guidelines provide a Tier 1 methodology for emissions from pipeline transport of CO_2. Pipeline length from the Canada/United States border to the Cenovus Weyburn facility at Weyburn is approximately 61 km. Emissions are calculated using the IPCC default medium EF of 0.0014 kt CO_2/km pipeline length/per year.

3.4.1.3. Uncertainties and Time-Series Consistency

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

3.4.1.4. QA/QC and Verification

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

3.4.1.5. Recalculations

No recalculations required for the first year of reporting.

3.4.1.6. Planned Improvements

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

3.5. Other Issues

3.5.1. CO_2 Emissions from Transport Biomass

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

3.5.1.1. Fuel Ethanol

Quantities of fuel ethanol used in transportation are presented in Table 3–16. Ethanol properties were developed according to chemistry and resulted in a higher heating value (HHV)[7] of 24.12 TJ/ML, 52.14% carbon content and 789.2 kg/m3 density.

Based on feedback from Statistics Canada, ethanol is included in RESD gasoline fuel consumption data. Fuel ethanol is therefore introduced and modelled as if it were mixed into the total gasoline for the region(s). Total fuel ethanol available per province was allocated to each mode (on-road, by vehicle technology classes, and offroad as a whole) as per the percentage of total gasoline. In lieu of developing specific emission factors for CH_4 and N_2O for ethanol, the representative gasoline emission factor was applied

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7   Higher Heating Value and Lower Heating Value are technical terms identifying the energy content of a specific fuel and differ depending on whether the water in the combustion products is in the liquid or gaseous phase respectively. Synonyms for Higher heating value include Gross heating value or Gross calorific value while synonyms for Lower Heating Value include Net Heating Value or Net Calorific Value.

Table 3–16 Ethanol Used for Transport in Canada

Year	1990	2000	2005	2009	2010	2011	2012	2013
Ethanol Consumed (ML)	7	227	267	1 529	1 874	2 753	2 876	2 659

Table 3–17 Biodiesel Used for Transport in Canada

Year	1990	2000	2005	2009	2010	2011	2012	2013
Biodiesel Consumed (ML)	0	0	4	164	394	583	621	648

as per mode and technology class. CO_2 emission factors used are those based upon true chemical characteristics mentioned previously and a 100% oxidation rate.

3.5.1.2. Fuel Biodiesel

The quantities of biodiesel fuel used in transportation are presented in Table 3–17. The properties used for biodiesel were extracted from a biodiesel study conducted between 2004 and 2005 (BioMer 2005). The higher heating value (HHV)[7] used is 35.18 TJ/ML, with a 76.5% carbon content and 882 kg/m3 density.

Unlike fuel ethanol, biodiesel is not considered by Statistics Canada to be reported within the diesel fuel energy statistics, and therefore the volumes of biodiesel consumed are in addition to the volumes of diesel fuel reported in the RESD. Biodiesel was introduced and modelled as if it were mixed into the total fossil fuel-based diesel for the region(s). Total fuel available per province was allocated to each mode (on-road, by vehicle technology classes, and off-road, railways and domestic marine as a whole) as per the percentage of total fossil fuel-based diesel fuel. In lieu of developing specific emission factors for CH_4 and N_2O for biodiesel, the representative fossil fuel-based diesel emission factor was applied as per mode and technology class. CO_2 emission factors used are those based upon true chemical characteristics mentioned previously and a 100% oxidation rate.

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

In Canada, CO_2 captured during coal gasification is used as a flooding agent in EOR operations to increase crude oil production volume at two depleting oil reservoirs. Carbon dioxide is used as a flooding agent in EOR since it acts as a solvent while increasing reservoir pressure, resulting in the release of trapped hydrocarbons to production wells. The high pressure flooding process also results in CO_2 being trapped in the voids previously occupied by hydrocarbon molecules. This process is commonly known as geological storage of CO_2.

CO_2 flooding started in 2000 at the Weyburn site and in 2005 at the Apache Midale site in order to extend the life of these mature reservoirs by another 30 years. Carbon dioxide purchased from the Dakota Gasification Company located in North Dakota (U.S.) is transported via pipeline to the field. This fresh supply and CO_2 recovered from previous flooding cycles are combined and injected into the reservoir. Currently about 2.8 Mt per year of CO_2 is injected at the Weyburn-Midale operations.[8] From 2000 to 2013, the Weyburn site injected over 25 Mt of fresh CO_2 purchased from the Dakota gasification plant with an injection rate of 7000 t of CO_2 per day (PTRC 2011). Since 2005, the Midale site has injected more than 2 Mt of fresh CO_2, with an injection rate of 1800 t of CO_2 per day (PTRC 2004).

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

The final phase (from 2005 to 2011) of the IEA Weyburn-Midale research project outlined on the PRTC website focused on developing a best practice manual for future projects on the geological storage of CO_2, drawing from technical and non-technical components such as site characterization, selection, well bore integrity, monitoring and verification, risk assessment, regulatory issues, public communication and outreach, and business environment policy .

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

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

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

Canada exports a large proportion of its produced fossil fuel resources, mostly to the United States. In 2013, Canada exported approximately 65% (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 2013, emissions associated with the production of oil and gas for exports have increased by approximately 170%, coinciding with an increase of over 200% in total exported oil and gas (Table 3–18). 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 almost tripled (Table 3–19). 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 3–22). For natural gas, emissions associated with exports have increased by approximately 45%, coinciding with an increase of over 100% in natural gas exports (almost 2.5 times the rate of growth of natural gas production) (Table 3–20).[9]

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. Following this, the exports of conventional crude oil and the emissions associated with their export have also increased (Table 3–21). In contrast to the trend in conventional crude oil, production of unconventional crude oil[10] from Canada's oil sands has been consistently increasing (Table 3–22). In 2013, production was almost six times higher than in 1990, while exports were over seven times higher than in 1990. Whereas exports have grown seven-fold, the emissions associated with these exports are only five and a half times larger, reflecting improved efficiencies in extracting oil sands products.

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9 The source for all export and energy production data is Statistics Canada's *Report on Energy Supply and Demand in Canada* (RESD, 57003-X). The 1990–2013 GHG emissions associated with net exports are from Smyth (2010).

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

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

Crude Oil & Natural Gas Trends	1990	2000	2005	2009	2010	2011	2012	2013
Domestic Production (PJ)	7 958	12 170	13 092	12 594	12 718	13 204	13 704	14 272
Energy Exported (PJ)	3 068	7 068	7 870	7 954	8 256	8 583	8 909	9 246
Emissions Associated with Gross Exports (Mt CO_2 eq.)	39.2	90.9	91.8	91.7	94.3	98.0	106.7	106.6

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

Crude Oil Trends	1990	2000	2005	2009	2010	2011	2012	2013
Domestic Production (PJ)	3 774	5 108	5 899	6 365	6 711	7 142	7 699	8 222
Energy Exported (PJ)	1 531	3 222	3 804	4 294	4 582	5 020	5 516	6 077
Emissions Associated with Gross Exports (Mt CO_2 eq.)	22.4	52.8	54.8	58.6	61.9	67.8	76.0	82.6

Table 3–20   Natural Gas: Production, Export and GHG Emission Trends, Select Years

Natural Gas Trends	1990	2000	2005	2009	2010	2011	2012	2013
Domestic Production (PJ)	4 184	7 062	7 192	6 229	6 007	6 062	6 006	6 051
Energy Exported (PJ)	1 537	3 846	4 066	3 660	3 673	3 563	3 393	3 169
Emissions Associated with Gross Exports (Mt CO_2 eq.)	16.8	38.1	37.0	33.0	32.4	30.2	30.7	24.0

Table 3–21   Conventional Crude Oil: Production, Export and GHG Emission Trends, Select Years

Crude Oil Trends	1990	2000	2005	2009	2010	2011	2012	2013
Domestic Production (PJ)	2 973	3 590	3 459	3 090	3 098	3 173	3 287	3 468
Energy Exported (PJ)	1 112	2 433	2 293	2 310	2 315	2 608	2 623	3 035
Emissions Associated with Gross Exports (Mt CO_2 eq.)	13.6	39.0	33.4	26.6	25.0	28.2	28.6	33.0

Table 3–22   Unconventional Crude Oil: Production, Export and GHG Emission Trends, Select Years

Crude Oil Trends	1990	2000	2005	2009	2010	2011	2012	2013
Domestic Production (PJ)	801	1 519	2 441	3 275	3 613	3 968	4 411	4 754
Energy Exported (PJ)	418	789	1 511	1 984	2 268	2 412	2 894	3 042
Emissions Associated with Gross Exports (Mt CO_2 eq.)	8.8	13.8	21.4	32.1	36.8	39.5	47.4	49.6

3

Chapter 4

Industrial Processes (CRF Sector 2)

4.1. Overview

This chapter covers GHG emissions produced from various industrial processes that chemically or physically transform materials. These processes include: production and use of mineral products; metal production; chemical production (including CH_4 and N_2O from petrochemicals); consumption of SF_6; halocarbon production and use as alternatives to ozone-depleting substances (ODS); and non-energy products from fuels and solvents.

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.

The Non-energy Products from Fuels and Solvent Use subsector (Section 4.12) includes CO_2 emissions resulting from the use of fossil fuels as feedstock in the production of chemicals and from other non-energy uses of fuels in the mining and processing of metals; two exceptions are CO_2 emissions from ammonia production (covered in section 4.5) and from the use of coke in iron and steel (Section 4.9).

Emissions of other substances (such as CO, non-methane volatile organic compounds (NMVOC) and SO_2) from industrial process activities, including asphalt roofing, road paving with asphalt, pulp and paper production, and production of food and drink are reported in Annex 7 of this Report.

Greenhouse gas emissions from IPPU contributed 52.2 Mt to the 2013 national GHG inventory (Table 4–1), compared with 55.1 Mt in 1990. The 2013 IPPU emissions represented 7.2% of the total Canadian GHG emissions in 2013. The contributing factors of the long-term and short-term trends in this Sector are discussed in detail 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 and rectification of transcription and calculation errors identified in the 2014 submission.

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

GHG Source Category	GHG Emissions (kt CO_2 eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Industrial Processes TOTAL	55 100	53 400	58 900	49 100	50 700	50 900	55 000	52 200
a. Mineral Products	8 700	10 200	10 300	7 300	8 000	8 200	8 800	8 100
Cement Production	5 800	7 200	7 600	5 400	6 000	6 100	6 600	6 000
Lime Production	1 800	1 900	1 700	1 200	1 400	1 400	1 400	1 300
Mineral Product Use	1 200	1 200	1 000	720	540	670	770	780
b. Chemical Industry	14 200	5 100	6 600	4 200	3 600	4 100	4 200	4 500
Ammonia Production	2 800	3 000	2 700	2 400	2 500	2 900	3 000	3 500
Nitric Acid Production	970	1 200	1 200	1 100	1 100	1 100	1 100	990
Adipic Acid Production	10 000	870	2 600	640	0	0	0	0
Petrochemical and Carbon Black Production	130	110	90	68	68	69	71	84
c. Metal Production	23 500	23 100	20 100	15 700	16 100	16 900	16 600	14 500
Iron and Steel Production	10 200	11 500	10 200	8 000	9 000	9 900	9 800	7 500
Aluminium Production	10 300	8 900	8 700	7 500	6 900	6 800	6 500	6 700
SF_6 Used in Magnesium Smelters and Casters	3 000	2 700	1 200	180	180	180	250	210
d. Production and Consumption of Halocarbons, SF_6 and NF_3	1 200	3 800	5 400	5 800	5 900	6 100	6 400	6 600
e. Non-Energy Products from Fuels and Solvent Use	7 400	10 800	16 000	15 700	16 900	15 500	18 800	18 200
f. Other Product Manufacture and Use	170	430	360	250	240	260	330	300

Note: Totals may not add up due to rounding. Also, because of number rounding, some slight emission decreases or increases discussed in the paragraphs above many not be reflected in this table.

Detailed explanations for the changes in estimates as a result of the improvements are described in the recalculation sections of the respective categories in this chapter and are summarized in Table 4–2 below.

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

4.2.1. Category Description

Portland cement constitutes more than 90% of the cement produced in Canada, while the rest is masonry and other cement (Statistics Canada 44-001 and CANSIM tables 303-0060 and 3030061). 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. Additional details on cement kilns are provided in Annex 3.3. In 2013, the category accounted for 6.0 Mt (or 0.82%) of Canada's total emissions, with about a 4% 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_2 emissions from cement production were calculated using a Tier 2 method (Eq. 4-1) that incorporates country-specific emission factors. Previous NIR submissions used a Tier 2 method based on IPCC 2000 Good Practice Guidance (IPCC 2000).

Table 4–2   Impact of Recalculations from Revisions and Improvements (kt CO_2 eq)

GHG Source Category	IPPU GHG Emissions per Year							
	1990	2000	2005	2008	2009	2010	2011	2012
Current (kt CO_2 eq)	55 100	53 400	58 800	57 000	49 100	50 700	50 900	55 000
2014 Submission (kt CO_2 eq)	55 900	54 200	60 800	59 300	52 000	54 300	54 900	56 800
Total Net Change	-800	-800	-2 000	-2 300	-3 000	-3 600	-4 000	-1 800
Change (%)	-1.4%	-1.5%	-3.3%	-3.9%	-5.7%	-6.6%	-7.3%	-3.1%
a. Impact due to update in GWP (kt CO_2eq)	600	900	1 000	900	1 000	1 000	1 000	1 000
b. Impact of implementing 2006 IPCC GL (kt CO_2 eq)	-1 400	-2 300	-2 200	-2 400	-2 500	-2 500	-2 500	-2 500
Cement Production	300	400	400	400	300	300	300	300
Ammonia Production	-1 700	-2 800	-2 600	-2 800	-2 800	-2 800	-2 900	-2 800
Integrated Circuit or Semiconductor	-9	-7	-6	-3	-1	-3	-3	-2
Other Product Manufacture and Use (Use of Urea in SCR Vehicles)	0	0	0	0	2	9	23	37
c. ERT recommendations	0	0	0	0	0	0	0	0
d. Continuous improvements	0	-100	-600	-1 000	-1 100	-1 300	-1 500	-1 600
Magnesium Production	0	0	0	-6	0	0	0	0
Petrochemicals	-1	-2	-2	-6	-5	-6	-5	-4
Product Uses as Substitutes for Ozone Depleting Substances	0	-100	-600	-1 000	-1 100	-1 300	-1 500	-1 600
e. Revised activity data	0	800	-200	200	-300	-800	-1 000	1 300
Lime Production	0	0	0	0	0	0	1	8
Mineral Product Use	0	0	0	0	0	0	0	150
Magnesium Casting	0	0	0	0	0	0	-8	3
Production and Consumption of Halocarbons, SF_6 and NF_3	0	310	-140	220	-300	-800	-950	-830
Product Uses as Substitutes for Ozone Depleting Substances	0	310	-140	200	-300	-810	-950	-840
Electrical Equipment	0	0	0	0	0	0	0	7
Integrated Circuit or Semiconductor	0	0	0	0	0	3	3	2
Non-Energy Products from Fuels and Solvent Use	0	444	-49	-11	-10	-2	-29	1 990
f. Reporting of new greenhouse gases	0	0	0	1	1	3	3	3
NF_3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
HFCs	0	0	0	1	1	3	3	3

Note:
1.   Totals may not add up due to rounding.
2.   Changes due ERT recommendations have been included in other categories: updates to emission factors for ODS substitutes are included under "Continuous Improvement".

Equation 4–1:

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

where:

EF_{cl}	=	annual emission factor based on clinker production, 0.5270 kt CO_2/kt clinker
EF_{toc}	=	Emission factor for CO_2 emissions from organic carbon in the raw feed, 0.0115 kt CO_2/kt clinker
M_{cl}	=	clinker production data, kt
CF_{ckd}	=	factor that corrects for the loss of cement kiln dust and bypass dust, fraction (1.013)

Disaggregated data are not publically available on the composition of raw materials and clinker, the calcination degree of cement kiln dust (CKD), and the amount of bypass dust and CKD. However, the Cement Association of Canada (CAC) has provided national aggregated data expressed as an annual calcination emission factor (EFcl), and annual amounts of by-pass dust and CKD for recent years (2002-2013) and 1990. The CAC receives plant-based data from the member companies in accordance with the quantification method published by the World Business Council for Sustainable Development (WBCSD): Cement Sustainability Initiative, CO_2 Emissions Inventory Protocol, Version 2.0.

The calcination CO_2 emission factor (EF_{cl}) varies from year to year and is based on the available data for years 1990, 2000, and 2002-2013. 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/bypass 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_2 to C (44.01/12.01), result in the organic carbon emission factor (EF_{toc}) of 0.0115 (kt CO_2/kt clinker).

Clinker production data for 1990–1996 were obtained from A Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry, 1990 to 2008 (CIEEDAC 2010). Clinker production data for 1997–2004 were obtained from Statistics Canada (44-001) and for 2005–2013 from CANSIM tables 303-0060 and 303-0061 (Statistics Canada 2005–2013).

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, information was provided directly by Natural Resources Canada via personal communication.[1]

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1   Panagapko D. 2008–2014. Personal communications (emails from Panagapko D. to Environment Canada). The latest update was received on September 16, 2014.

4.2.3.   Uncertainties and Time-Series Consistency

A Tier 1 uncertainty 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_2 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 are 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 elaborated in the Quality Manual of the Pollutant Inventories and Reporting Division PIRD (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

New country-specific emission factors have been used to recalculate emissions over the 1990–2012 time series. The recalculations resulted in increases of 0.3 Mt (5.2%) for 1990 and 0.4 Mt (6.1%) for 2012.

4.2.6.   Category-Specific Planned Improvements

There are currently no improvements planned for this category.

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

4.3.1.   Category Description

Dolomitic lime and high-calcium lime are both produced in Canada and emissions from their production are accounted for in this inventory submission. Table 4–3 indicates the proportion of Canadian lime production that is dolomitic and high-calcium for all inventory years. There 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_2 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_2 emissions from lime production where the country-specific emission factors were applied to national activity data. The country-specific emission factors for high-calcium lime and dolomitic lime were developed based on the information on Canadian lime compositions collected from the Canadian Lime Institute,[2] 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_2 emissions were calculated by applying the Canadian emission factors to the estimated yearly national lime production data, by lime type.

The water content of Canadian hydrated lime is 28.25%.[3] Water content of hydrated lime is deducted from national lime production to derive "dry" lime production amount, which is broken down into the two lime types: high calcium and dolomitic. Corresponding emission factors are then applied.

Provincial CO_2 emissions are derived from national emissions based on the calcining capacity of each province/territory.

The large decline in the share of dolomitic lime during 1999–2000 is caused by two major changes in Ontario plants in that period. First, Guelph DoLime Limited, which produced only dolomitic lime up to 1999, ceased operations in 2000. Second, the Lafarge Canada quarry in Dundas switched from producing only dolomitic lime to both high-calcium and dolomitic lime in 1999–2000.[4] 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.

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

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

4   Confirmed by D. Panagapko (email to Edalatmanesh M, Environment Canada, dated November 6, 2013).

Table 4–3   Split between Dolomitic and High-Calcium Lime Production in Canada (1990–2013)

Year	% Split	
	Dolomitic Lime	High-Calcium Lime
1990	14%	86%
1991	14%	86%
1992	14%	86%
1993	16%	84%
1994	16%	84%
1995	16%	84%
1996	16%	84%
1997	16%	84%
1998	16%	84%
1999	16%	84%
2000	8%	92%
2001	8%	92%
2002	8%	92%
2003	9%	91%
2004	9%	91%
2005	9%	91%
2006	9%	91%
2007	9%	91%
2008	9%	91%
2009	7%	93%
2010	7%	93%
2011	7%	93%
2012	7%	93%
2013	7%	93%

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 ±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, source of activity data, and estimation method, are consistent throughout the time series.

4.3.4. Category-Specific QA/ QC and Verification

The Lime Production category has undergone Tier 1 QC checks as elaborated in the Quality Manual of the PIRD. The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

4.3.5. Category-Specific Recalculations

Updates to the activity data for 2012 resulted in the recalculation of emissions for that year.

4.3.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

4.4. Production and Other Process Uses of Carbonates (CRF Categories 2.A.4 & 2.B.7)

4.4.1. Category Description

The categories discussed here, under the aggregate title Production and Other Process Uses of Carbonates include: Limestone and Dolomite Use, Soda Ash Production and Use, and Magnesite Use.

In 2013, the aggregate category accounted for 780 kt (or 0.11%) of Canada's total GHG emissions, with a decrease of about 35% in total emissions since 1990. Limestone and Dolomite use accounted for 74% (or 570 kt) of the subsector's emissions, while Soda Ash Production and Use, and Magnesite Use contributed 15% (114 kt) and 12% (91kt), respectively (Table 4–1).

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

Limestone and dolomite are used in a number of industries in Canada: glass manufacture as a raw material, iron and steel as flux stone, and in pulp and paper as makeup lime. They also have other chemical uses such as wastewater treatment and flue gas desulphurization (FGD).

Emissions from limestone and dolomite used to produce cement and lime are accounted for under the Cement Production and Lime Production categories, respectively.

Soda Ash Production and Use (CRF Categories 2.A.4.b and 2.B.7)

In Canada, soda ash is mainly used in the glass products manufacturing industry (AMEC 2006, Statistics Canada 44-250). Second to glass production, soda ash is used in the production of chemicals. Other uses include soaps and detergents, pulp and paper and water treatment.

Canadian soda ash production halted in 2001. For the operational years between 1990 and 2001, the net CO_2 emissions are assumed to be minimal because the CO_2 coming from the Solvay process was recovered for re-use (AMEC 2006).

Magnesite Use (CRF Category 2.A.4.c)

Three facilities in Canada reported use of magnesite in their processes in different periods during the years 1990–2008, and two of them were closed in 1991 and 2007, one facility remains in production.

4.4.2. Methodological Issues

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

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

The emission factor used for Canadian limestone use is derived from the process stoichiometric ratio of 440 g of CO_2 per kilogram of pure limestone used, and adjusted to consider a purity fraction of 95% (Ministry of Northern Development and Mines 1989). The Canadian emission factor is therefore 418 g CO_2/kg of limestone used (AMEC 2006).

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

For the years 1990 to 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 (the major user of dolomite). National CO_2 emissions are estimated by multiplying the quantities of limestone and dolomite consumed by the corresponding emission factors.

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 merely crushed and sieved to

Table 4–4   High Calcium and Dolomite Consumption Split in the Canadian Iron and Steel Sector

Year	Total Limestone (kt)	High Calcium (kt)	Dolomite (kt)
1990	656	459	197
1991	491	344	147
1992	562	393	169
1993	198	139	59
1994	190	133	57
1995	307	215	92
1996	297	208	89
1997	332	232	100
1998	392	274	118
1999	392	274	118
2000	680	476	204
2001	477	334	143
2002	258	181	77
2003	282	197	85
2004	209	146	63
2005	216	151	65
2006	200	140	60
2007	99	69	30
2008	318	223	95
2009	260	182	78
2010	313	219	94
2011	501	350	150
2012	760	532	228
2013	759	531	228

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,[5] 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, iron and steel, non-ferrous metal, glass and chemical sectors).

Soda Ash Production and Use (CRF Categories 2.A.4.b and 2.B.7)

National CO_2 emissions are calculated using a Tier 1 method that applies the stoichiometry-based emission factor of 415 g CO_2/kg soda ash to the national consumption data, assuming 100% purity of soda ash used in Canada.

Soda ash consumption data were estimated based on soda ash production, import and export data. Canada stopped its soda ash production in 2001. Production before 2002 was assumed to be equal to the capacity of the only soda ash plant in Canada, which produced soda ash using the Solvay process. Most CO_2 emitted from this facility was recovered for reuse; net CO_2 emissions from soda ash production in Canada were therefore assumed to be negligible (AMEC 2006).

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 2010–2013). 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 apportioning the national emissions according to the respective provincial gross output values of the same sectors.

Magnesite Use (CRF Category 2.A.4.c)

A Tier 1 method is applied by using national consumption data and an emission factor derived from the stoichiometry of the process. An overall emission factor of 506 g CO_2/kg magnesite was derived and applied to estimation of CO_2 emissions from magnesite use, taking into account 97% purity of magnesite (AMEC 2006).

Magnesite use activity data were obtained or derived from various sources. For the plant that only operated between 1990 and 1991, magnesite use data was unavailable and it was back-calculated from the amount of magnesium produced, which was assumed to be half of the 1990 capacity reported in the Minerals and Metals Foundation Paper, 1999 (AMEC 2006).

For the other two plants, the 1990–2005 facility-specific magnesite use data came from British Columbia's Ministry of Energy, Mines and Petroleum Resources (2006) and Environment Canada, Quebec Region, Environmental Protection Branch.[6] For 2006 and 2007, activity data were not available; hence, to estimate the use of magnesite for these two plants, some assumptions were made.

For the plant that was closed in 2007, the ratio of magnesite use to magnesium production was first calculated for each year of the 1990–2005 period.[7] The average of the calculated (magnesite use / magnesium production) ratios was then taken. This average was

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5   Cook S. (CEA). Personal communication to Edalatmanesh M, Environment Canada, November 18, 2013.

6   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.

7   Banville J. 2007. Personal communication (email from Banville J to Pagé M, Environment Canada, dated October 4, 2007). Environment Canada, Environmental Protection Branch, Quebec Region.

multiplied by the plant's 2006 and 2007 magnesium production to yield the 2006 and 2007 magnesite use, respectively.

For the other plant (the only one still in operation in 2013), the 2006–2013 magnesite use data came from British Columbia's Ministry of Energy, Mines and Petroleum Resources.[8,9]

Finally, multiplying the consumption data (either actual or estimated, depending on the years) by the above-mentioned emission factor gave the national and provincial emission estimates for this subsector.

4.4.3. Uncertainties and Time-Series Consistency

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

A Tier 1 uncertainty assessment has been performed for the category of Limestone and Dolomite Use. It took into account the uncertainties associated with the use of data by use type and emission factors. The uncertainty associated with the category as a whole for the time series ranged from ±11% to ±34%, with data on the use of limestone and dolomite in the chemical sector and as flux in iron and steel furnaces being the largest contributors.

The same emission factors were consistently applied over the time series. The activity data source is provided in Section 4.4.2.

Soda Ash Production and Use (CRF Categories 2.B.7 and 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 data (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 4.5.2.

Magnesite Use (CRF Category 2.A.4.c)

A Tier 1 uncertainty assessment has been performed for the category of Magnesite Use. It took into account the uncertainties associated with the activity data (for years before 2001) and emission factor. The uncertainty associated with the category as a whole for the time series ranged from ±4% 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 is provided in Section 4.6.2.

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8   Meredith-Jones S. 2012. Personal communication (email from Meredith-Jones S to Edalatmanesh M, Environment Canada, dated October 30, 2013).

9   B.C. Ministry of Energy, Mines and Petroleum Resources. (Also, see link: http://www.empr.gov.bc.ca/mwg-internal/de5fs23hu73ds/progress?id=gOiReM321H).

4.4.4. Category-Specific QA/QC and Verification

A Tier 1 QC checklist was completed for the categories included in Production and Other Process Uses of Carbonates as developed in the Quality Manual of the PIRD. The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC 2006 Guidelines.

4.4.5. Category-Specific Recalculations

The 2012 emissions estimate for Limestone and Dolomite Use was recalculated as a result of an update in activity data.

4.4.6. Category-Specific Planned Improvements

Limestone and soda ash are both consumed in the production of glass in Canada. The CO_2 emissions associated with glass production are currently included in the estimates for Limestone and Dolomite Use and Other Uses of Soda Ash. In order to improve transparency, glass production emissions will be reported separately in the next NIR. Likewise, historical emissions from soda ash production will be reported under the Chemical Industry subsector.

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

4.5.1. Category Description

The Ammonia Production category accounted for 3.48 Mt (0.48%) of Canada's emission in 2013 and has increased by 25% since 1990.

Currently, there are 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 and also recover CO_2 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_2 emissions.

4.5.2. Methodological Issues

The Ammonia Production category estimates CO_2 emissions resulting from the feedstock use of natural gas and considers emissions that are recovered for use in urea production. A Tier 2 country-specific method is applied in accordance with IPCC Guidelines (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 (FF). 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 2008–2013 were obtained from the data of Statistics Canada's Industrial Chemical and Synthetic Resin Survey (Statistics Canada 2008–2013). 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_i) to determine the resulting CO_2 emissions generated. The amount of CO_2 recovered for urea production is then subtracted from the process-related emissions (Equation 4–2). Using the IPCC 2006 Guidelines, it is assumed that the urea production process consumes a stoichiometric quantity of CO_2, and that 5 kg of CO_2 are emitted per tonne of urea produced. The resulting recovery factor ($RFCO_2$) is therefore 0.728 kg CO_2 / kg urea.

Equation 4–2: CO_2 Emissions from Ammonia Production

$$E_{CO2} = \sum_i AP_i \cdot FF_i \cdot CC_j - R_{FCO2} \cdot UP_i$$

where:

ECO_2	=	emissions of CO_2, kt
AP_i	=	ammonia production of facility i, kt
FF_i	=	ammonia-to-feed fuel conversion factor of facility i, m3 natural gas/ t NH_3
CC_j	=	carbon content factor of the fuel in province j, kt CO_2/m³ of natural gas
RF_{CO2}	=	Factor for CO_2 recovered for urea production, 0.728 kg CO_2/ kg urea
UP_i	=	urea production of facility i, kt

Assuming a complete conversion of NH_3 and CO_2 to urea, the stoichiometric mass ratio of CO_2:urea (0.733 tonnes CO_2 per tonne urea) is used to convert urea production to the CO_2, as recovered from ammonia process emission. Using an CO_2 release rate of 5 kg per tonne of urea production, the net emissions recovered (RCO_2) is calculated at 0.728 tonnes CO_2/ tonne urea.

Urea production data for years 2008 through 2013 where retrieved from Statistics Canada's Industrial Chemical and Synthetic Resin 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 subsector.

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 the Quality Manual of the PIRD. The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Guidelines 2006 (IPCC 2006).

4.5.5. Category-Specific Recalculations

Emissions for the whole time series have been recalculated in order to account for emissions recovered for urea production. Previous submissions assumed that emissions were not recovered.

4.5.6. Category-Specific Planned Improvements

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

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

4.6.1. Category Description

The Nitric Production category accounted for 0.99 Mt (0.14%) of Canada's emission in 2013 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

Table 4–5   Nitric Acid Industry-Typical Emission Factors

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

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

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 NO_x. In contrast, a "selective" catalytic reduction (SCR) uses ammonia, which selectively reacts only with NO and NO_2 gases, and not with N_2O (hence a higher N_2O 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_2O 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_2O emissions from nitric acid production for 1990–2004 were gathered through a study 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 2008–2013 were obtained from Statistics Canada's Industrial Chemical and Synthetic Resin 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 2005–2013, the data were reported by companies to Environment Canada on a voluntary basis in conjunction with Statistics Canada's Industrial Chemical and Synthetic Resin 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 the emission factors. The uncertainty associated with the category as a whole is evaluated at ±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 the Quality Manual of the PIRD. 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_2O abatement system with an emission monitoring system was started up in 1997. However, the plant has been indefinitely idled since the spring of 2009; hence for current years, both N_2O and CO_2 are indicated as "NO" in the CRF.

4.7.2. Methodological Issues

Emission estimates for adipic acid production were provided by the facility owner. For the 1990–1996 period, when no emission controls were in place, the reported emission estimates were calculated by multiplying the annual adipic acid production by the IPCC default generation factor of 0.3 kg N_2O/kg adipic acid.

Since 1997, the emission estimation method calculated separately emissions that occur when the abator is operating, and the second for emissions that occur when the abator is not operating because of maintenance or technical problems (equation 4-3).

Equation 4–3:

$$
\begin{aligned}
Total\ Emissions\ (t) \\
= N_2O\ Emissions\ (t)\ with\ abator \\
+ N_2O\ Emissions\ (t)\ without\ abator
\end{aligned}
$$

N_2O Emissions with Abator:

Equation 4–4:

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

where:

destruction efficiency is determined based on the difference between the amount of N_2O entering the abatement unit and that leaving the unit. It is a monthly average calculated using values recorded by analyzers, which are located at the inlet and outlet of the abator. The targeted instantaneous destruction efficiency is 97%.

abatement utilization ratio is the number of hours during which N_2O goes through the abator divided by the total operating time.

N_2O Emissions without Abator:

Equation 4–5:

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

It is important to note that the in-line continuous emission monitor has never been used to directly monitor net N_2O emissions. This is because the analyzer is limited to accurately measuring relatively low concentrations of N_2O only when the reactor is online and abating N_2O gas. The analyzer is not capable of measuring the full range of N_2O concentrations that could potentially exist in the stack. The N_2O concentration can vary from a low nominal level of 0.3% when the stream leaves the abator to a high nominal level of 35–39% N_2O in the unabated stream. When the abatement reactor is bypassed, there is no N_2O abatement occurring, and the analyzer will not record N_2O stack emissions (Cheminfo Services 2006).

The calculation technique used to estimate emissions for the 1990–1997 period is in accordance with the Tier 1 method of the IPPC Good Practice 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 4.7.2, 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 the Quality Manual of the PIRD. The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC 2006 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. Carbide, Petrochemical, Carbon Black, and Fluorochemical Production
(CRF Categories 2.B.5, 2.B.8, and 2.B.9.a)

4.8.1. Category Description

Carbide Production (CRF Category 2.B.5)

Two kinds of carbide are considered in this section: silicon carbide (SiC) and calcium carbide (CaC_2). SiC and CaC_2 are no longer produced in Canada; the last of two SiC plants closed in 2002 and the only CaC_2 plant closed in 1992.

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

There were three methanol production facilities operating in Canada during the 1990-2006 period. One was closed in 2001, one in 2005 and the other in 2006. Methanol production in Canada stopped in 2006.

Process GHG (CO_2, CH_4 and N_2O) emissions come mainly from process off-gas that is separated from methanol and combusted on-site for energy recovery. The process off-gas contains excess

CO, CO_2 and light hydrocarbons. Additional CH_4 emissions can occur in venting of process gases containing CH_4 from the methanol distillation train and methanol storage tanks and fugitive emissions from equipment leaks (Cheminfo Services 2010).

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

There have been five ethylene facilities operated by four companies in Canada since 1990; one of these, Pétromont Varennes, was shut down in 2008.

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

Three ethylene dichloride production (EDC) facilities had operated in Canada during 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.

Regarding emissions, the process off-gas that contains the chlorinated hydrocarbons is combusted within the plant prior to release, so any carbon in this off-gas is converted to CO_2. The process CO_2 emissions from EDC production come from the side reaction of feedstock oxidation. The process CH_4 emissions would most likely come from light hydrocarbons from distillation operations that are not captured by a flare gas recovery system. These emissions are vented to the atmosphere (Cheminfo Services 2010).

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

There are four facilities that have produced carbon black in Canada since 1990. Three facilities are currently operating.

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

There have been three styrene facilities that have produced styrene in Canada since 1990, but one facility 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_3) 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, however production ended in 1992. In Canada, there has been no more manufacturing or import of equipment containing HCFC-22 as of Jan. 1, 2010 (HRAI 2008).

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There has been no known production of SF_6 or perfluorocarbons (PFCs) in Canada throughout the time series.

4.8.2. Methodological Issues

Carbide Production (CRF Category 2.B.5)

A Tier 1 method (i.e. with the application of Tier 1 IPCC default emission factors) was applied to estimate CH_4 emissions from carbide production. A study was commissioned to identify and establish the production capacities of the three carbide production facilities in Canada. A time series of process CH_4 emissions was estimated for the two silicon carbide facilities from 1990 to 2001, and one calcium carbide facility from 1990 to 1991, based on assumed capacity utilization and CH_4 emission factors. Only (SiC and CaC_2) production capacity data during the time series were identified during the study. As such, the following equation was used to estimate total CH_4 emissions from carbide production:

Equation 4–6:

$$\text{Total CH}_4 \text{ emissions (t)} = \sum^{y} [(SiC\ capacity \times capacity\ utilization \times Emission\ FactorSiC) + (CaC_2\ capacity \times capacity\ Emission\ FactorCaC_2)]$$

where:

y	=	companies
SiC or CaC_2 capacity	=	data collected from the industry, kt
Capacity utilization	=	based on Cheminfo Services' knowledge of the industry, %
Emission FactorSiC	=	11.6 kg CH_4/t SiC (IPCC 2006)
Emission FactorCaC$_2$	=	4.8 kg CH_4/t CaC_2, derived from CH_4 emission factor for silicon carbide and the ratio of IPCC default Calcium Carbide CO_2 emission factor to IPCC default Silicon Carbide CO_2 emission factor (i.e. 11.6 (kg CH_4/t SiC) * (1.09 tCO_2/$tCaC_2$ / 2.62 tCO_2/tSiC))

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

When available, CH_4 emissions data directly reported for methanol production facilities were used in this submission. In the case where there are no reported data, emissions are estimated by multiplying the assumed methanol production by a sector-average emission factor, which was developed from data collected for data years 2004-2006. The assumed methanol production of a facility is calculated by multiplying its production capacity share (%) by the difference between total national methanol production and the sum of all reported methanol production. 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).

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

A consulting study was commissioned to estimate CH_4 and N_2O emissions from ethylene production. A questionnaire was sent on behalf of Environment Canada to the four companies that have had ethylene production operations in Canada. Responses received for three of the four operating plants represented 90% of Canadian ethylene capacity in 2009. Sector-wide CH_4 and N_2O emission factors were estimated as weighted averages based on the reported process emissions and production data from the three facilities for 2007–2009. When possible, for 1990–2009, weighted average facility-level process GHG emission factors are developed and applied to the estimated facility's ethylene production since there is a significant difference between the calculated emission factors for each facility. Ethylene production data for 2008–2013 were obtained from Statistics Canada's Industrial Chemical and Synthetic Resin Survey.

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 estimated ethylene production (allocated to each non-reporting facility by share of capacity) and the corresponding emission factors. The estimated production is calculated by subtracting the sum of reported production by the total national production. National ethylene production data are taken from Camford's CPI Product Profile for 1990–1995 and company-reported production for 2007–2009. For 2008–2013, production data are obtained from Statistics Canada's Industrial Chemical and Synthetic Resin Survey. The emission factors applied are treated as confidential since they are derived from business-sensitive data.

Equation 4–7:

$$CH_4 \text{ or } N_2O \text{ emisions } (t)$$
$$= \sum^{y} \begin{array}{c} Reported\ emissions + \\ (allocated\ unreported\ production \times Emission\ Factor\ CH_4/N_2O) \end{array}$$

where:

y	=	companies
allocated unreported production	=	remaining unreported ethylene production x ethylene capacity of a specific company/total unreported ethylene capacity [kt]
remaining unreported ethylene production	=	total production – total reported sample [kt]

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

CH_4 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_4 emission estimates. The annual

EDC production data come from the Canadian C2+ Petrochemical Report. The default process CH_4 emission factor for EDC as applied comes from Table 2-10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), under the name dichloroethylene. The Canadian C2+ Petrochemical Report was prepared and published by an independent consultant who supplies market intelligence to the Canadian chemical industry. It provides balances of ethylene and its derivatives using total production, dispositions and Canadian trade statistics. For the purpose of emission estimation at the provincial level, the annual EDC production was allocated by Cheminfo Services to each plant 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_4 emissions from carbon black production were also estimated in 2010 through a consulting study. A survey was sent to the three operating carbon black facilities requesting 1990–2009 data on carbon black capacity and production, and on process GHG emissions. All three facilities reported 1990–2009 data for carbon black capacity, but not all facilities reported process CH_4 emissions. From the received responses, two facility-level Tier 3 emission factors were derived as weighted averages of the reported 2007–2009 data.

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

The sector-wide EF value is lower than the IPCC default value of 11 kg CH_4/t product. It is suspected that the IPCC default EF, which is based on only one study, has included CH_4 from the combustion of fuel as well. The Canadian EF only includes the CH_4 that originates directly from the feed.

The above EF is applied when facility-level emission factors cannot be used. When process emissions are reported directly by a facility, the reported data are used in the inventory. When reported emission data are not available, estimates are calculated 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 multiply-

ing the sector average growth rate by the total sector production of the preceding year (starting from 1995). Production data for 2010-2013 are obtained from Statistics Canada's Industrial Chemical and Synthetic Resin Survey.

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

Process CO_2 emissions can come from the combustion of the process off-gas (fuel gas) as fuel or from flaring of over-pressured process streams. Methane (CH_4) could be present along with the process reactants ethylene and benzene and would be emitted if there was any venting of these process or recycle streams. Fugitive emissions from these streams would also contain methane (Cheminfo Services 2010).

In the absence of data from operating facilities, a Tier 1 approach was taken to develop process CH_4 emissions estimates. Annual styrene production data were retrieved from the Canadian C2+ Petrochemical Report. For the purpose of emission estimation at provincial level, the annual styrene production is allocated to each plant based on capacity share. The default process CH_4 emission factor for styrene (4 kg/t) comes from Table 2-10 of the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997). As the 2006 IPCC Guidelines do not cover styrene production under its petrochemicals section, a more recent emission factor cannot be found. Due to the unavailability of 2010 and 2011 production data, these data years are assumed equal to 2009 production. However, production data that are included in Statistics Canada's Industrial Chemical and Synthetic Resin Survey for 2012 and 2013 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.[10]

4.8.3. Uncertainties and Time-Series Consistency

Carbide Production (CRF Category 2.B.5)

A Tier 1 uncertainty assessment has been performed for the category of Carbide Production (Cheminfo Services 2010) based on expert knowledge following the 2006 IPCC Guidelines.

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

Regarding the carbide capacity data, an uncertainty of ±5% is applied when survey uncertainties are not provided. The uncertainty associated with the category as a whole for the time series ranges from ±0% to ±27% (Cheminfo Services 2010).

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

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the subcategory of Methanol Production, following the 2006 IPCC Guidelines.

As no plant-specific uncertainty estimates could be collected (Cheminfo Services 2010), the following set of default uncertainties (based on expert knowledge of the industry) was used in the analysis:

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

The uncertainty associated with the category as a whole for the time series ranged from 0% (for the years with no production) to ±20% for CH_4 emissions and ranged from 0% (for the years with no production) to ±30% for N_2O emissions.

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

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the category 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: ±5%;
- reported production data: ±2%;
- capacity share fractions used for allocation of national production data: ±10%;
- reported process CH_4 emissions: ±20%; and
- reported process N_2O emissions: ±30%.

The uncertainties for the time series range from ±8% to ±12% for CH_4 emission estimates and from ±12% to ±21% for N_2O emission estimates.

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

A Tier 1 uncertainty assessment has been performed by Cheminfo Services (2010) for the category of EDC production following the 2006 IPCC Guidelines.

As no plant-specific uncertainty estimates could be collected by Cheminfo Services (2010), a set of default uncertainties (based on expert knowledge of the industry) was used in the analysis. The uncertainty associated with the category as a whole for the time series is estimated at ±21% (Cheminfo Services 2010).

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

A Tier 1 uncertainty assessment has been performed by Cheminfo Services for the category of Carbon Black Production following the 2006 IPCC Guidelines.

In the Cheminfo Services (2010) study, respondents were asked to provide their best estimate of the uncertainty of each variable reported. Very few survey respondents provided uncertainty estimates for their data. As a result, the following set of default uncertainties (based on expert knowledge of the industry) was used in the analysis:

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

The Tier 1 uncertainty associated with the CH_4 emission estimates ranges from ±9% to ±11%.

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

A Tier 1 uncertainty assessment has been 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 ±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 was believed that the production data reported by HCFC-22 producers were reasonably accurate. The

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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 2000 Guidelines state that a 50% uncertainty factor for a Tier 1 HFC production estimate may be appropriate.

4.8.4. Category-Specific QA/QC and Verification

The category of Carbide Production has undergone Tier 1 QC checks as developed in the Quality Manual of the PIRD. The checks performed are consistent with the Tier 1 General Inventory Level QC Procedure outlined in the IPCC Good Practice Guidelines (IPCC 2006).

The methanol subcategory has undergone Tier 1 QC checks as developed in the Quality Manual of the PIRD. The checks performed are consistent with the Tier 1 general inventory level QC procedures outlined in the IPCC Good Practice Guidelines (IPCC 2006). Methanol production stopped in 2006 and restarted in 2011. However, the emissions inventory does not currently account for the new production between 2011 and 2013. The inventory will be updated to include new production data for the 2016 submission, as described in the planned improvements for this category (section 4.8.6).

The subcategories covering the production of ethylene, EDC, carbon black, and styrene have all undergone Tier 1 QC checks as developed in the Quality Manual of the PIRD. The checks performed are consistent with the Tier 1 General Inventory Level QC Procedure outlined in the IPCC Good Practice Guidelines (IPCC 2006).

Informal checks (such as data transcription checks, calculation checks, and unit conversion checks) were done on the category of HCFC-22 Production.

4.8.5. Category-Specific Recalculations

There have been no recalculations for this category.

4.8.6. Category-Specific Planned Improvements

Methanol production in Canada stopped in 2006 and restarted in 2011 (Methanex 2013).

The emissions estimate for the next reporting cycle will be updated to reflect new production. No other improvements are planned for this category.

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

4.9.1. Category Description

The Iron and Steel Production Category contributed 7 530 kt (1.01%) of Canada's emission in 2013, 26% more than it did in 1990.

There are four integrated iron and steel mills in Canada, all located in Ontario. However, one Canadian integrated plant also uses the EAF process to produce a portion of its steel. Annex 3.3 provides additional details on the technologies employed in Canada to produce iron and steel and on their emission profiles.

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. CO_2 emissions from carbon oxidation, which occurs when iron ore is reduced to pig iron, are included in this category. Also accounted for in this category are emissions during steel production, which occur to a much lesser extent. These come from the oxidation of carbon in crude iron and electrode consumption. Additional CO_2 given off by limestone flux in the blast furnace is covered under the Limestone and Dolomite Use subcategory (4.4).

4.9.2. 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 (EFmet_coke), and carbon content of pig iron.

Equation 4–8:

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

where:

E_{CO2_PI}	=	process emissions from pig iron production, kt
EF_{met_coke}	=	year-specific emission factors (t CO_2/ t metallurgical coke used) obtained from the Cheminfo Services (2010) study
M_i	=	mass of i used or produced, kt; where i is metallurgical coke, ore
CC_i	=	carbon content of i, % where i is metallurgical coke, ore, pig iron; in the case of ore, this value is zero according to IPCC (2000)
P_{PI}	=	production of pig iron, kt
44/12	=	ratio of the molecular weight of CO_2 to the molecular weight of carbon

For the purposes of this category's emission estimates, it was assumed that the reductant used in the Canadian industry is 100% metallurgical coke (Cheminfo Services 2010). The carbon

content in ore is almost zero (IPCC 2000). The GHG emissions associated with the use of reductants other than metallurgical coke are estimated under the appropriate industrial category in the Energy Sector.

The data source for the use of metallurgical coke was the *Report on Energy Supply and Demand in Canada* (RESD – Statistics Canada 57-003-X). 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. The emission factors for coke use (EF_{met_coke}) are year-specific; they come from the Cheminfo Services (2010) study. During the study, Cheminfo Services surveyed four integrated steel mills in Canada for their coke consumption and their emission estimates for the years 1990–2009. The emission factors were calculated as ratios of CO_2 emissions to coke consumption. No Canada-specific coke carbon content is available for 2010-2013; as a result, the 2009 coke carbon content is assumed for 2010-2013 (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 in pig iron, the CSPA[11] provided an industry-average content value, which is kept confidential.

Emissions from steel production were estimated using the following equation:

Equation 4–9:

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

where:

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

According to Equation 4–9, part of the CO_2 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 (BOFs) and electric arc furnaces (EAFs). It should be noted that the amount of pig iron fed to steel furnaces (used

in Equation 4–9) is not equal to the amount of total pig iron production (used in Equation 4–8). As part of the steel production process, there are also emissions coming from 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 for 2004–2012 (Cat. No. 41-001 and 41-019, respectively) and from the Canadian Steel Producers Association for 2013. The values of the carbon contents and emission factors mentioned in Equation 4–9 were all provided by the CSPA.[12]

The total emission from the category of Iron and Steel Production is the sum of Equation 4–8 and Equation 4–9.

Data on metallurgical coke use at provincial/territorial levels from the RESD (Statistics Canada 57-003-X) were used to derive the percentage of total reductant consumption attributed to each province and territory. CO_2 emissions at provincial/territorial levels were then estimated by multiplying the percentage derived by the national emission estimate.

It should be noted that RESD data (Statistics Canada 57-003-X) published for any given year are preliminary and subject to revision in subsequent publications.

The method described above does not account for additional CO_2 given off by the use of limestone as flux in blast furnaces, since the limestone consumption-related emissions are included in the subsector of Limestone and Dolomite Use.

The use of petroleum coke in EAF electrodes is reported by Statistics Canada with all other non-energy uses of petroleum coke. To avoid double counting, the CO_2 emissions from the consumption of electrodes in the steel production process in EAFs are therefore subtracted from the total non-energy emissions. It is assumed that there are no imported electrodes used for steel production in EAFs in Canada. If electrodes are imported, the portion of CO_2 generated by the imported electrodes needs to be subtracted from the emissions from electrode consumption before being subtracted from the total non-energy emissions.

4.9.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Iron and Steel Production. It took into account the uncertainties associated with all the parameters used in the equations stated above, such as data on metallurgical coke use, emission factor of coke, data on pig iron and steel production

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

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

and carbon contents of pig iron and steel. 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 ±5.4%.

4.9.4. Category-Specific QA/QC and Verification

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

4.9.5. Category-Specific Recalculations

There was no recalculation of CO_2 emissions from Iron and Steel Production.

4.9.6. Category-Specific Planned Improvements

As noted earlier, a smaller part of the process CO_2 emissions associated with iron and steel production originates from the use of reductants other than metallurgical coke. 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 subsector (Section 4.12). It is planned to allocate the aforementioned emission to Iron and Steel Production. The allocation of CO_2 emissions associated with the use of other reductants (i.e. other than coke and coal) to the Energy Sector will not change. This is due to the format of the RESD data, which portray fuel use in an aggregated manner.

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

4.10.1. Category Description

The Aluminium Production category accounted for 6 720 kt (0.93%) of Canada's emissions in 2013, representing an overall decrease in emissions of 35% since 1990.

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

In addition to CO_2 emissions, primary aluminium smelting is a

source of carbon tetrafluoride (CF_4) and carbon hexafluoride (C_2F_6), both of which are included in this submission. This submission also includes a small amount of SF_6 that is emitted from its use as cover gas at some aluminium plants that produce high magnesium-aluminium alloys.[13]

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

4.10.2. 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.[14] 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 estimates of CO_2, PFCs and SF_6 are Tier 3 plant-level estimates using plant-specific parameters.[15]

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_2, PFC and SF_6 emissions and plant-specific production data for the time series were obtained from the AAC. The estimation techniques applied may be Tier 3, Tier 2 or Tier 1 type, as described in Annex 3.3, depending on data availability; a Tier 3 type technique has mostly been applied for estimating emissions for recent years. For example, the largest Canadian producer of aluminium reported that its 2008 emissions were developed using plant-specific parameters (Alcan 2010). 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, for details see Annex 3.3 (Alcan 2010). The methodology used for both PFC and CO_2 emissions is based on the Framework Agreement on voluntary greenhouse gas reductions in Quebec entered into between the Government of Quebec and the AAC (AAC 2002a). According to the methodology documents supplied by the AAC, SF_6 emissions are equal to consumption in the aluminium industry.

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

14 http://www.westernclimateinitiative.org/

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

4.10.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Aluminium Production (i.e. for the CO_2, PFC and SF_6 emission estimates). It takes into account the uncertainties associated with all the parameters used in the equations. The *Aluminium Sector Greenhouse Gas Protocol* published by the IAI (IAI 2006) was the main source of the parameters' uncertainty values. The uncertainties for the CO_2, PFC and SF_6 estimates were ±7%, ±9% and ±3%, respectively. For the CO_2 and PFC estimates, it should be noted that the uncertainty assessment is done for only one year of the time series (2006 for CO_2 and 2007 for PFC). It is expected that emission estimates of more recent years would have similar uncertainties, while older estimates would have higher uncertainties. For the SF_6 estimate, it is assumed that the uncertainty is the same as that of the Magnesium Casting category, since the method used to develop SF_6 emission estimates is the same for both Aluminium Production and Magnesium Casting.

The methodology applied by smelters may be of the Tier 3, Tier 2, or Tier 1 type, depending on data availability, for details see Annex 3.3. However, for recent years, a Tier 3 type technique has been applied by all smelters for estimating emissions.

4.10.4. Category-Specific QA/QC and Verification

CO_2 and PFC emissions from Aluminium Production are key categories that have undergone Tier 1 QC checks as elaborated in the Quality Manual of the PIRD. The checks performed are consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidelines (IPCC 2006).

4.10.5. Category-Specific Recalculations

There have been no recalculations for this category.

4.10.6. Category-Specific Planned Improvements

There are currently no improvements planned for this category.

4.11. Magnesium Production (CRF Category 2.C.4)

4.11.1. Category Description

SF_6 is emitted during magnesium production and casting, where it is used as a cover gas to prevent oxidation of the molten metals. SF_6 is not manufactured in Canada and is solely imported.

During the 1990–2006 period, there were two major magnesium producers in Canada: Norsk Hydro and Timminco Metals. Norsk Hydro was shut down in the first quarter of 2007. Another magnesium producer, Métallurgie Magnola, existed between 2000 and 2003, but was shut down in April 2003. Between 1990 and 2004, Norsk Hydro had invested in research and development projects having as objectives finding a substitute for SF_6 and eventually eliminating the use of SF_6 as cover gas at its plant.[16] This research, as well as the use of substitute gas mixtures, produced significant reductions in SF_6 emissions in the mid-1990s to late 1990s. For the years 2005–2007, Norsk Hydro's SF_6 emissions were significantly reduced as a result of gradual production reduction and the plant's closure in 2007. Timminco was also closed in August 2008.

There were 11 magnesium casting facilities in operation during the 1990–2004 period (Cheminfo Services 2005b). Only a few of them had used SF_6 every year during the entire period. Some casters started using SF_6 towards the mid- or late 1990s, whereas others replaced it with an alternative gas, such as SO_2. Two facilities have ceased their casting operations over the last few years. During the 2005–2008 period, only seven facilities were in operation and had used SF_6. Two companies shut down their magnesium casting operations in different times of 2009 (one in June and one in December). In 2010, another facility moved its operations to the United States.

4.11.2. Methodological Issues

SF_6 emissions from magnesium production for 1999–2007 were directly reported by the companies (Norsk Hydro, Timminco Metals and Métallurgie Magnola Inc.) to Canada's National Pollutant Release Inventory (NPRI). Emission estimates used in this report are obtained from the NPRI's online database (http://www.ec.gc.ca/pdb/querysite/query_e.cfm). For previous years (i.e. 1990–1998), the data were provided voluntarily by the producers to Environment Canada through personal communication. Since there were no reported 2008 data for Timminco, its 2008 SF_6 value was estimated based on its 2007 data and number of months of operation in 2008 (i.e. 7 months). For 2009 onwards, since there have been no magnesium production plants operating in Canada, there has been no need to perform any data collection.

Norsk Hydro and Timminco were contacted in 2006 regarding the methodology they had applied to estimate SF_6 emissions. Both companies reported that they used the IPCC default method (Emissions of SF_6 = Consumption of SF_6), as recommended in the IPCC Good Practice Guidance (IPCC 2000). However, they have used different ways for estimating their SF_6 consumption. Norsk Hydro confirmed the use of the weight difference method,[17]

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

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

based on measuring the weight of gas cylinders used at the facility at the time when these were purchased and when these were returned to suppliers at the end of the usage. The accounting method was reported as being used by Timminco for estimating its SF_6 use.[18] In this method, accounting of delivered purchases and inventory changes of SF_6 used are recorded. The purchases must be the actual volumes received in the calendar period; therefore, beginning-of-year and end-of-year inventories are taken into account.

The technique applied to estimate emissions from magnesium production is considered to be a Tier 3 type method, as it is based on the reporting of facility-specific emission data.

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

For 2005–2007, consumption data were provided by all seven operating casting facilities through a voluntary data submission process. They were used for the calculation of emissions. For 2008, data were made available by six out of the seven casting facilities through the voluntary data submission process. For the remaining facility, it was assumed that its 2008 SF_6 use stayed at the 2007 level. For 2009, communication was established with all seven companies. Two of the companies, for which magnesium casting operations were shut down in 2009, were not able to report their 2009 SF_6 use data, but provided reasonable assumptions that could be used to estimate the 2009 SF_6 use. SF_6 use data for 2009 were provided by the other five facilities. Due to unavailability of data for a few facilities, the SF_6 emission and production values for these facilities for data years 2010-2013 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.

4.11.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of Magnesium Casting. It took into account the uncertainty associated with the SF_6 data reported by each facility. The uncertainty for the category as a whole was estimated at ±4.0%. It should be noted that the uncertainty assessment was done for only one year of the time series (2007). As such, it is expected that emission estimates of more recent years (2005 onwards) would have a similar uncertainty value, while older estimates would have a slightly higher uncertainty.

As the last magnesium production facility was closed in August 2008, it became difficult to gather the data needed for the Tier 1 uncertainty assessment of the Magnesium Production category. Hence, based on the fact that the same emission estimation method (i.e. emissions = consumption of SF_6) was applied to both categories of Magnesium Casting and Magnesium Production, it was assumed that the Magnesium Production category would have the same uncertainty (±4.0%) as the Magnesium Casting category.

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

4.11.4. Category-Specific QA/ QC and Verification

Magnesium Production and Magnesium Casting have both undergone Tier 1 QC checks as elaborated in the Quality Manual of the PIRD. The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidelines (IPCC 2006).

4.11.5. Category-Specific Recalculations

Recalculations were made in the subcategory of Magnesium Casting to reflect the new information received on 2012 for two facilities. The gross output forecast values of 2012 are updated.

4.11.6. Category-Specific Planned Improvements

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

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

4.12. Non-energy Products from Fuels and Solvent Use (CRF Category 2.D)

4.12.1. Category Description

The Non-energy Products from Fuels and Solvent Use category includes emissions from the non-energy use of fossil fuels that are not accounted for under any of the other categories of the IPPU Sector. The following are examples of fuels in non-energy applications: the use of natural gas liquids (NGLs) and refinery output as feedstocks in the chemical industry, and the use of lubricants such as engine oil and grease in transportation and industrial applications, with "use" defined as "close-to-production" consumption of fuel, e.g., burning of motor oil in the engine's combustion chamber (excludes waste oil incineration, which is allocated to the Waste Sector). All of these activities result in varying degrees of oxidation of the fuel, producing CO_2 emissions. Also included in this category are emissions from the use of hydrocarbons (such as coal) as reductants for base metal smelting, and 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 (57-003-X) under "Non-Energy Use" for each individual fuel. In the event that CO_2 emissions resulting from non-energy fuel use are allocated to another category of the IPPU Sector (as is the case for ammonia production, iron and steel production, and aluminium production), those emissions are subtracted from the total emissions from this category to avoid double counting.

4.12.2. Methodological Issues

Emission factors for non-energy use of fuels were developed based on the total potential CO_2 emission rates and the IPCC 1996 Energy Sector's default percentages of carbon stored in products (IPCC/OECD/IEA 1997). The total potential CO_2 emission factors were derived from the carbon emission factors shown in Jaques (1992), McCann (2000) and CIEEDAC (2006), which are EFs based on natural units of fuel; the IPCC provides for energy 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 below.

Fuel quantity data for non-energy fuel usage were reported by the RESD (Statistics Canada 57-003-X). It should be noted that the RESD data for any given year are preliminary and subject to revisions in subsequent publications. These data were multiplied by the emission rates shown in Annex 3.3 to estimate CO_2 emissions for this subsector.

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

This technique is considered to be a Tier 1 type method, as it is based on the use of national consumption data and average national emission factors. Methodological issues for calculating CO_2 emissions from the non-energy use of fossil fuels are not addressed specifically in the IPCC Good Practice Guidance (IPCC 2000). However, and as noted previously, the IPCC Guidelines 1996 provide a method of estimating non-energy use of fuels, based on the amount of carbon stored in the products resulting from the process. The CO_2 emissions are derived from the amount of residual carbon that is released during the production process (residual carbon = total carbon minus amounts stored in product).

4.12.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been 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 ±21%. It should be noted that the uncertainty assessment was done for only one year of the time series (2007).

The non-energy fuel data, for the time series 1996 to 2003, have been revised in this NIR. This has removed the inconsistency that existed in the time series (1996–2003 and 2004–2011) in the last NIR.

4.12.4. Category-Specific QA/QC and Verification

Non-energy Products from Fuels and Solvent Use was a key category that has undergone Tier 1 QC checks as developed in the Quality Manual of the PIRD. The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidelines (IPCC 2006).

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4.12.5. Category-Specific Recalculations

New values from RESD resulted in the recalculation of emissions for the entire time series. For most years, the impact is in the order of 10 kt, however, the impact for 2012 is in the order of 1 000 kt because the 2012 data used for the 2014 submissions were preliminary.

4.12.6. Category-Specific Planned Improvements

There are no improvements planned for the Non-energy Products from Fuels and Solvent Use category.

4.13. Electronics Industry (CRF Categories 2.E.1 & 2.E.5)

4.13.1. Category Description

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

4.13.2. 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 below, was used to estimate PFC emissions from the semiconductor manufacturing industry:

Equation 4–10:

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

where:

E_{SC}	=	total PFC emissions from semiconductor
E_{FC}	=	emissions resulting from the use of PFCs (see IPCC 2006 Volume 3, Equation 6.2)
E_{CF4}	=	CF_4 emitted as a by-product during the use of PFCs (see IPCC 2006 Volume 3, Equation 6.3)

Default Tier 2 emission factors were used from Table 3.15 of the IPCC 2000 Guidelines.

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

NF3 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

In 2013, Environment Canada commissioned a study to determine the extent of usage of NF_3 in Canada, including a survey of all potential NF_3 gas suppliers as well as seven identified potential users (Cheminfo 2014). In this survey, only one user indicated usage of NF_3 in 2013, whereas a gas distributor identified an additional purchaser in 2010. The results of the study are considered to be complete, as both Canadian fabrication plants in the SEMI World Fab Watch database responded to the survey (Cheminfo 2014). Additionally, previous research conducted by Environment Canada using the Domestic Substances List (DSL), indicated that between 33 and 199 kg of NF_3 were used in 1986. All NF_3 usage in Canada is believed to occur in the semiconductor manufacturing industry.

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

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

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

SF6 Emissions from Semiconductor Manufacturing (CRF Category 2.E.1)

The method applied to estimate SF_6 emissions from semiconductor manufacturing was similar to that used to calculate PFC and NF_3 emissions. However, there is no by-product CF_4 created during the use of SF_6 in the process. A Tier 2A estimate was conducted using IPCC 2006 Volume 3, Equation 6.2.

The heel value (h) provided and confirmed by two major SF_6 gas distributors, Air Liquide and Praxair, was 12%.[19] 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 from only 1995–2003 were obtained from major Canadian gas suppliers, it was assumed that the quantity sold per year during 1990–1994 was at the 1995 level. The SF_6 sales to semiconductor manufacturers in 2004–2009 were estimated by multiplying the total SF_6 import data (from Statistics Canada) by the sales distribution data (in %) received from SF_6 distributors (Cheminfo 2005a). No SF_6 sales data were collected for the 2010-2013 data years. The average proportion of SF_6 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 and 2013 data years, the Gross Output (GO) economic data for NAICS 334 was used to extrapolate the estimated amount of SF_6 sold to the semiconductor industry based on the 2011 GO data.

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

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

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

4.13.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has also been performed for the category of PFC Consumption as a whole. Uncertainties related to activity data (IPCC 2006) and emission factors (Japan's Ministry of the Environment 2009) were taken into account in the assessment for PFC Consumption. The uncertainty associated with the category as a whole for the time series ranges from ±10% to ±23%.

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19   Rahal H and Tardif A. 2006. Personal communications (emails from Rahal H and Tardif A to Au A, Environment Canada, dated November 22, 2006, and November 13, 2006, respectively). Praxair and Air Liquide, respectively.

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

A Tier 1 uncertainty assessment has been performed for the category of SF_6 emissions from semiconductor manufacturing.

4.13.4. Category-Specific QA/QC and Verification

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

4.13.5. Category-Specific Recalculations

For SF_6 Emissions from Semiconductor Manufacturing, the previous assumption that 2010 and later proportion of SF_6 for the semiconductor industry was the same as 2009 was removed and replaced with the assumption that the new proportion is the average of proportions from 2004-2009. For 2012 and later data years, the Gross Output (GO) for NAICS 334 was used to scale the estimated value from 2011. The emission factor (1-U) value was updated from the IPCC 1996 default value of 0.5 to the IPCC 2006 default value of 0.2.

4.13.6. Category-Specific Planned Improvements

It is planned to update the PFC model as per the IPCC 2006 Guidelines for Canada's next National Inventory submission.

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

4.14.1. 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 (4.14 and 4.15, 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 that 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).

4.14.2. 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 the imports and exports of manufactured items for the 1995 data year and the assumptions used for the derivation of this portion of the activity data could not be verified for this submission so the manufactured items were not included.

Voluntary surveys for the 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 were met with varying response rates and aggregation levels of sub-categories.

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. In 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 was reported to the 2014 survey but this information has not been quality checked nor analysed for comprehensiveness so it has not been included.

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 which 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). As the same regulatory environment existed from 2006 to current, these country specific emission factors were used from 2010 onwards. 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 sub-categories default emission factors from the IPCC 2006 guidelines (IPCC 2006) were used for 1995 onwards.

Estimation Methodology

The actual numbers of the various types of equipment are not available for Canada so the IPCC Tier 2a approach (IPCC 2006) has been modified to work with the annual quantities of HFC consumed by category and subcategory, as discussed in the Approaches for Emissions Estimates in section 7.1.2.1 of the IPCC 2006 Guidelines (IPCC 2006). For the calculation of the net consumption of a chemical in a specific subcategory a modified

Table 4–7   HFCs Used in Canada and Their Timeframe

HFC Type	Timeframe	HFC Type	Timeframe
HFC-125	continual 1995 - 2013	HFC-236fa	continual 1996 - 2013
HFC-134a	continual 1995 - 2013	HFC-245FA	2008 onwards
HFC-143a	continual 1995 - 2013	HFC-32	continual 1995 - 2013
HFC-152a	continual 1995 - 2013	HFC-365mfc	2008 onwards
HFC-227ea	continual 1995 - 2013	HFC-41	1999 & 2000
HFC-23	continual 1995 - 2013	HFC-4310mee	1998 onwards

version of the IPCC equation 7.1 (IPCC 2006, Volume 3) is used to suit the Canadian data as show in equation Equation 4–11.

Equation 4–11:

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

where:

$C_{net,i}$	=	Net consumption 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 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).

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 emissions estimate takes into consideration the quantity of HFC that has already been emitted during the assembly stage. Likewise, the emissions 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 that time of decommissioning.

For solvents, this same approach is applied using only the emission factors for operational emissions and the term related to the amount of solvent destroyed (IPCC 2006, Volume 3, Equation 7.5).

The annual total emissions are calculated using IPCC 2006, Volume 3, Equation 7.4.

4.14.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of 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 2005c) and emission factors (Japan's Ministry of the Environment 2009) were used. It should be noted that the category uncertainty can vary throughout the time series because it is dependent on the magnitude of each of the subcategory emission estimates, which changes from year to year. The uncertainty associated with the category as a whole for the time series ranged from ±34% to ±50%.

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

4.14.4. Category-Specific QA/QC and Verification

Consumption of halocarbons resulting in HFC emissions was a key category that has undergone Tier 1 QC checks as developed in the Quality Manual of the PIRD. The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidelines (IPCC 2006). Two items of note were found:

- In the case of manufactured items, data on 1995 exports have not been included in this submission; this may have increased emissions estimates for the entire time series (1995-2013).
- For unspecified refrigeration equipment, the emissions estimate has not been performed for all reporting years; this caused a small decrease in estimated emissions.

4.14.5. Category-Specific Recalculations

The emissions from all of the sub-categories have been recalculated. New data for HFC bulk imports for 2008 to 2012 and some new country specific emission factors for refrigeration and air conditioning were used. For the remaining categories default emission factors for the remaining application areas were chosen from the IPCC 2006 guidelines.

The continuous improvement revision to the activity data resulted in a change ranging from a 0.4 Mt (78%) in 1995 to a 1.0 Mt (11%) decrease in 2011. The ERT recommendations, continuous improvement, and changes to the 2006 Guidelines (IPCC 2006) resulted in updated country -specific emission factors. The resulting changes in estimates range from 0 Mt (0%) in 1995 to a decrease of 1.9 Mt (24%) in 2012 emissions.

4.14.6. Category-Specific Planned Improvements

The assumptions for HFC contained in the 1995 imported and exported manufactured items from the previous submission will be reviewed and incorporated and any emissions omissions will be included.

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

4.15.1. Category Description

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

4.15.2. Methodological Issues

The IPCC Tier 2 methodology was used to estimate emissions from the consumption of PFCs for the years 1995–2013. 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 since 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 2013 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 2011-2013 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)

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, the amount of PFCs 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

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

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 1995and 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, 100% of the quantities remaining in systems built in 1995 would be emitted in 2008. This is likely an over estimation because various regulatory requirements currently existing in Canada would prohibit the release of PFCs.

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

During the production of closed cell foam, approximately 10% of the PFCs used are emitted (IPCC/OECD/IEA 1997). The remaining quantity of PFCs is trapped in the foam and are emitted slowly 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 emissions 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:

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

4.15.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment has been performed for the category of PFC Consumption. Similar to HFC Consumption, the uncertainties related to activity data (IPCC 2006) and emission factors (Japan's 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%.

4.15.4. 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 the Quality Manual of the PIRD. The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

4.15.5. Category-Specific Recalculations

There have been no recalculations for this category.

4.15.6. Category-Specific Planned Improvements

It is planned to update the PFC model as per the IPCC 2006 Guidelines for Canada's next National Inventory Report.

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

4.16.1. Category Description

The Other Product Manufacture and Use category includes emissions from the use of SF_6 in electrical equipment (CRF Category 2.G.1), emissions of N_2O from medical applications (CRF Category 2.G.3.a), emissions of N_2O from use as a propellant (CRF Category 2.G.3.b), PFC emissions from other contained product uses which are not ODS substitute or electronics industry related (CRF Category 2.G.4), and CO_2 emissions from the use of urea in selective catalytic reduction (SCR) vehicles (CRF Category 2.G.4).

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. Process CO_2 emissions associated with the production of solvents are included in the Industrial Processes Sector.

Nitrous Oxide of Canada (NOC) in Maitland, Ontario, is the only known producer of compressed N_2O for commercial sales in Canada. It supplies N_2O to two of the three primary N_2O gas distributors that essentially account for the total commercial market in Canada. These companies sell cylinders of N_2O to a relatively large number of sub-distributors. It is estimated that there may be 9000 to 12 000 final end-use customers for N_2O in Canada, including dental offices, clinics, hospitals and laboratories (Cheminfo Services 2006).

N_2O is used in a limited number of applications, with anaesthetic use representing the vast majority of consumption in Canada. Use as a propellant in food products is the second largest type of end use in Canada. Other areas where N_2O can be used include production of sodium azide (a chemical that is used to inflate automobile airbags), atomic absorption spectrometry and semiconductor manufacturing. According to the distributors that were surveyed during the recent study, approximately 82% of their N_2O sales volume is used in dentistry/medical applications, 15% in food processing propellants and only 3% for the other uses (Cheminfo Services 2006).

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

4.16.2. Methodological Issues

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

In electric utilities, SF_6 is used as an insulating and arc-quenching medium in high-tension electrical equipment, such as electrical switchgear, stand-alone circuit breakers and gas-insulated substations. In Canada, SF_6 is primarily used in high voltage circuit breakers and related equipment.

A modified Tier 3 method was used to estimate SF_6 emissions from electrical equipment in utilities for certain years (i.e. 2006–2013) of the time series, in place of the previous top-down approach (which assumed that all SF_6 purchased from gas distributors replaces SF_6 lost through leakage). The SF_6 emission estimates by province for 2006–2013 were provided by the Canadian Electricity Association (CEA) and Hydro Quebec, which collectively represent electricity companies across Canada. The emission data submitted by the CEA and Hydro Quebec were prepared following the *SF_6 Emission Estimation and Reporting Protocol for Electric Utilities* ("the Protocol") (Environment Canada and Canadian Electricity Association and Hydro Quebec 2008). The national SF_6 estimate for each year of 2006–2013 was the sum of all provincial estimates. The Protocol is the result of a collaborative effort between Environment Canada, the CEA, and Hydro Quebec.

In summary, the *Protocol* explains how the (country-specific) modified Tier 3 method was derived from the IPCC Tier 3 life cycle methodology. It also explains the different options available for estimating the equipment life cycle emissions. These are equal to the sum of SF_6 used to top up the equipment and the equipment disposal and failure emissions (which are equal to nameplate capacity less recovered quantity for disposal emissions or to simply nameplate capacity for failure emissions). A more detailed description of the methodology is also 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_6 from these organizations only started in the 2006 data year. Hence, the application of the Protocol was not possible. Surveys of SF_6 distributors were used to obtain usage data prior to the application of the *Protocol*. Section 7.3.2.2 of the 2000 IPCC Good Practice Guidance suggests four approaches for such a situation: 1) overlap, 2) surrogate method, 3) interpolation, and 4) trend extrapolation. Each of these techniques has been evaluated for its applicability in this particular situation. The surrogate and trend extrapolation methods could not be used because, according to the 2000 IPCC Good Practice Guidance, it is not good practice to use these approaches for a long period. The interpolation approach could not be used because data for intermittent years were needed. The overlap approach was determined to be the most appropriate option in this case for the following reasons:

- The overlap between two or more sets of annual emission estimates could be assessed. (In this case, the overlap was assessed between four sets of annual estimates derived from the distributor surveys and obtained under the *Protocol* for 2006, 2007, 2008 and 2009.)
- There was a consistent and proportional relationship between the estimates developed using the "old" (i.e. used in the previous submission) and the modified Tier 3 methods. (In this case, the national estimates developed using the modi-

fied Tier 3 method were consistently around 10–20% of those developed using the old method.)

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_2O Emissions from Medical Applications (CRF Category 2.G.3.a) and Propellant Usage (CRF Category 2.G.3.b)

N_2O emissions 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_2O sales pattern by application (Cheminfo Services 2006). The sales patterns for 2006–2013 are assumed to be the same as the one for 2005. The amounts of N_2O sold for anaesthetic and propellant purposes are calculated from the total domestic sales volume was and their respective share of sales.

N_2O import data for 2012 and 2013 are no longer available from Statistics Canada. As such, the 2012 and 2013 N_2O import data were therefore estimated based on a trend line built upon the N_2O imports of 2008 to 2011.

The national emission estimates were divided by the national total population to yield an emissions per capita factor. This factor was then multiplied by the population in each province and territory to estimate emissions at provincial/territorial levels. The 1990–2013 annual population statistics were obtained from Statistics Canada (2014, Cat. No. 91-215-X).

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

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

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

The 2006 IPCC Guidelines recommended equation (Volume 2, Equation 3.2.2) was used for the estimation of emissions from the use of urea-based additives in catalytic converters.

Catalytic converters which employ urea to help reduce NO_x emissions are referred to as Selective Catalytic Reduction catalysts (SCR). To determine the activity for these emission estimate calculations, road transportation activity data must be considered. More specifically, the vehicle populations, fuel consumption ratios and kilometre accumulation rates are employed 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 A3.1.

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 while 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[20].

4.16.3. Uncertainties and Time-Series Consistency

A Tier 1 uncertainty assessment was conducted for the category of SF_6 from Electrical Equipment. It should be noted, though, that the uncertainty assessment was done using 2007 data. It is expected that emission estimates of this submission would have much lower uncertainty values. The uncertainty for the category as a whole was estimated at ±30.0%. Depending on the years, the data source and methodology used for SF_6 from electrical equipment could vary, as explained in the Methodological Issues section above.

A Tier 1 uncertainty assessment has been performed for the categories of N_2O Emissions from Medical Applications and Propellant Usage. It took into account the uncertainties associated with domestic sales, import, sales patterns and emission factors. The uncertainty for these combined categories was evaluated at ±19%. It should be noted, though, that the uncertainty assessment was done e expected that the uncertainty for this Sector would not vary considerably from year to year as the data sources and methodology applied were the same.

A Tier 1 uncertainty assessment has been performed for the category of PFC Consumption as a whole. The uncertainties related

to activity data (IPCC 2006) and emission factors (Japan's 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%.

A Tier 1 uncertainty assessment has been performed for the category of CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles. The overall uncertainty was found to be ±50%.

4.16.4. Category-specific QA/QC and Verification

SF_6 Consumption in Electrical Equipment has undergone Tier 1 QC checks as developed in the Quality Manual of PIRD. The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

The categories of N_2O Emissions from Medical Applications and Propellant Usage have undergone Tier 1 quality control checks as developed in the Quality Manual of the PIRD. The checks performed were consistent with the Tier 1 general inventory level quality control procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

PFC Emissions from Other Contained Product Uses has undergone Tier 1 QC checks as developed in the Quality Manual of the PIRD. The checks performed were consistent with the Tier 1 General Inventory Level QC Procedures outlined in the IPCC Good Practice Guidance (IPCC 2000).

The category of CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles has undergone informal quality control checks throughout the modelling process.

4.16.5. Category-specific Recalculations

For SF_6 Consumption in Electrical Equipment, the 2015 activity data for Quebec is updated in this submission.

N_2O Emissions from Medical Applications and Propellant Usage have not been recalculated.

CO_2 Emissions from the Use of Urea in Selective Catalytic Reduction (SCR) Vehicles was added as a new source of greenhouse gas emissions.

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20   Rideout G. 2014. Personal communications (email sent to McKibbon S. November 4, 2014). Pollution Inventories and Reporting Division.

4.16.6. Category-specific Planned Improvements

There are no planned improvements for the categories of SF_6 from Electrical Equipment, N_2O Emissions from Medical Applications and Propellant Usage, and for CO_2 Emissions from the Use of Urea in SCR Vehicles.

The PFC estimation methodology will be updated as per the IPCC 2006 Guidelines for Canada's next National Inventory submission.

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Chapter 5

Agriculture (CRF Sector 3)

5.1.   Overview

Emission sources from the Agriculture Sector include the enteric fermentation (CH4) and manure management (N_2O and CH_4) categories from animal production and the agricultural soils (N_2O) and field burning of crop residues (CH_4 and N_2O) categories for emissions that occur during crop production. Carbon dioxide emissions from lime and urea application are now reported in the Agriculture Sector; however carbon dioxide 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, as well as 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,[1] llamas, alpacas, horses, goats, elk, deer, wild boars, foxes, mink and rabbits, 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 2013.

Since 1990, cropping practices have changed in Canada, with canola production increasing from 3 Mt to 18 Mt, corn production from 7 Mt to 15 Mt, soybean production from 1.3 Mt to 5.4 Mt, and wheat production from 32 Mt to 38 Mt. Synthetic nitrogen consumption has increased from 1.2 Mt N in 1990 to 2.5 Mt N in 2013, the area under summerfallow has decreased by 5.9 million hectares (Mha) and the regions using conservation tillage have increased by 13 Mha.

As a result of those changes, total greenhouse gas (GHG) emissions from the Canadian Agriculture Sector have increased from 49 Mt CO_2 eq in 1990, to 60 Mt CO_2 eq in 2013 (Table 5–1). This difference represents an increase of 23% from 1990, mainly due to higher populations of beef cattle and swine (14% and 26% increases, respectively), as well as an increase in the use of synthetic nitrogen fertilizers (110%).

Emissions of CH_4 from livestock accounted for 27 Mt CO_2 eq in 1990 and 29 Mt CO_2 eq in 2013, and mean estimates lie within an uncertainty range of -16 to +20%. Over the time series of 1990 to 2013, mean CH_4 emissions are estimated to have increased by 2.5 Mt CO_2 eq, a 9% increase. The observed increase in emissions falls within an uncertainty range of 4% to 12%. Emissions of N_2O from agricultural soils and livestock accounted for 21 Mt CO_2 eq in 1990 and 29 Mt CO_2 eq in 2013; mean estimates lie within an uncertainty range of -27 to +29%. Over the time series, mean N_2O emissions increased by 7.5 Mt CO_2 eq, an increase of 35%.

Emissions from the Agriculture Sector peaked in 2005,and decreased to 56 Mt CO_2 eq in 2011, with reductions in emissions from animal production as major livestock populations decreased (Enteric Fermentation and Manwure Management, Table 5–1). Since 2011 livestock populations have stabilized while fertilizer emissions have continued to increase and, combined with high crop production in 2013 (and therefore high emissions from residue decomposition), emissions have increased from their low point in 2011. Total agricultural emissions in 2013 were once again close to their peak level in 2005.

In this submission, compared to previous submissions, emissions were calculated as being 2.3 Mt CO_2 eq higher in 1990, 3.3 Mt CO_2 eq in 2005 and 2.5 Mt CO_2 eq in 2012, recalculations of 4.6%, 5.4% and 4.3% respectively (Table 5–2). Recalculations are mainly a result of the implementation of 2006 IPCC Guidelines, but also include continuous inventory improvements and some small changes due to the Expert Review Team's (ERT) recommendations. The types of changes affect all source categories and vary from the implementation of new animals, to modifications of emission factors based on new science or changes to parameters used in emission factor equations due to updating methodologies to the 2006 IPCC Guidelines (Table 5–3). Over 95% of agricultural emissions are methane and nitrous oxide, and as a consequence the changes to global warming potential (GWPs) have a very large

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1   In common reporting format (CRF) tables, bison emissions are reported under the Intergovernmental Panel on Climate Change (IPCC) category "buffalo" though the species referred to is the North American bison *(Bison bison)* that is raised for meat production using methods similar to beef cattle. In the text of the NIR, this animal category will be discussed as bison.

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

GHG Source Category			GHG Emissions (kt CO_2 eq)							
			1990	2000	2005	2009	2010	2011	2012	2013
Agriculture TOTAL[1]			49 000	59 000	62 000	58 000	57 000	56 000	58 000	60 000
Enteric Fermentation (CH_4)										
			23 000	28 000	31 000	27 000	26 000	25 000	25 000	25 000
	Dairy Cattle		4 400	3 900	3 700	3 600	3 600	3 600	3 600	3 700
	Beef Cattle[2]		18 000	23 000	26 000	22 000	21 000	20 000	21 000	20 000
	Others[3]		730	1 100	1 300	1 100	1 100	1 100	1 100	1 100
Manure Management			7 600	9 200	9 900	8 700	8 500	8 400	8 400	8 400
	Dairy Cattle	CH_4	980	880	850	810	820	820	810	840
		N_2O	560	450	420	390	390	390	380	380
	Beef Cattle[2]	CH_4	960	1 120	1 240	1 070	1 030	1 000	1 000	990
		N_2O	1 900	2 700	3 000	2 600	2 400	2 400	2 400	2 400
	Swine	CH_4	1 300	1 700	2 000	1 600	1 600	1 600	1 600	1 600
		N_2O	90	110	130	110	110	110	110	110
	Poultry	CH_4	160	190	190	190	190	190	190	190
		N_2O	430	530	540	550	560	560	560	560
	Others[4]	CH_4	50	50	50	50	50	50	50	50
		N_2O	150	210	250	210	190	170	170	170
	Indirect Source of N_2O		1 000	1 200	1 300	1 200	1 100	1 100	1 100	1 100
Agricultural Soils (N_2O)			17 000	19 000	19 000	20 000	21 000	20 000	22 000	24 000
Direct Sources			14 000	16 000	15 000	16 000	17 000	17 000	18 000	19 540
	Synthetic Nitrogen Fertilizers		5 700	7 400	6 800	8 200	8 400	8 800	9 900	10 700
	Manure Applied as Fertilizers		1 800	2 000	2 200	1 900	1 800	1 800	1 800	1 800
	Crop Residue Decomposition		4 500	4 600	5 000	5 400	5 600	5 100	5 300	6 400
	Cultivation of Organic Soils		60	60	60	60	60	60	60	60
	Mineralization of Soil Organic Carbon		660	650	610	690	730	780	830	890
	Conservation Tillage[5]		-360	-810	-920	-1 000	-1 000	-1 100	-1 200	-1 400
	Summerfallow		1 400	1 100	800	600	500	500	500	500
	Irrigation		340	400	410	380	390	400	410	450
	Manure on Pasture, Range and Paddock		220	240	250	220	220	210	210	210
Indirect Sources			3 000	3 700	3 700	3 900	3 900	3 900	4 300	4 600
Crop Residue Burning (CH_4 & N_2O)			230	130	50	50	30	30	40	50
Lime and Urea Application (CO_2)			1 200	1 600	1 400	1 800	1 800	2 000	2 300	2 600

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

impact on agricultural emission recalculations. A discussion of the impact of GWPs on reported emissions in this year's inventory can be found in Section 2.1 of Chapter 2, Greenhouse Gas Emission Trends.

Rice is not produced in Canada and is not a source of CH_4 emissions. Prescribed burning of savannas is not practised in Canada. Finally, GHG emissions from on-farm fuel combustion are included in the Energy Sector (Chapter 3).

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 2015 NIR

		Recalculations (kt CO$_2$ eq)						
		1990	**2000**	**2005**	**2009**	**2010**	**2011**	**2012**
Previous submission (2014 NIR), kt CO$_2$ eq		47 000	56 000	58 000	56 000	55 000	53 000	56 000
Current submission (2015 NIR), kt CO$_2$ eq		49 000	59 000	62 000	58 000	57 000	56 000	58 000
Total change considering GWPs:								
	kt CO$_2$ eq	2 300	2 800	3 300	2 200	1 800	3 000	2 500
	%	5	5	5	4	3	5	4
Change due to new GWPs:								
	kt CO$_2$ eq	2 500	3 100	3 500	2 800	2 700	2 600	2 500
	%	5	6	6	5	5	5	5
Summary of changes based on current GWPs								
Change due to 2006 IPCC Guidelines:		1 600	2 500	2 000	2 000	1 600	2 200	2 000
Enteric Fermentation and Manure Management:	kt CO$_2$ eq	4 300	5 500	4 600	5 100	4 800	4 900	4 800
	%	9	10	8	9	9	9	9
Agricultural Soils:	kt CO$_2$ eq	-3 900	-4 600	-3 800	-5 000	-5 000	-4 700	-5 100
	%	-8	-8	-7	-9	-9	-9	-9
Urea, Lime and Urea-containing Fertilizers:	kt CO$_2$ eq	1 200	1 600	1 200	1 800	1 800	2 000	2 300
	%	3	3	2	3	3	4	4
Change due to ERT recommendation(s):		1	7	1	8	7	7	7
Enteric Fermentation and Manure Management:	kt CO$_2$ eq	1	7	1	8	7	7	7
	%	0	0	0	0	0	0	0
Change due to continuous improvement or refinement:		-1 900	-2 700	-2 100	-2 600	-2 500	-1 800	-2 000
Enteric Fermentation and Manure Management:	kt CO$_2$ eq	60	46	59	38	12	175	92
	%	0	0	0	0	0	0	0
Agricultural Soils:	kt CO$_2$ eq	-1 900	-2 800	-2 100	-2 600	-2 500	-2 000	-2 100
	%	-4	-5	-3	-5	-4	-4	-4

5.2.   Enteric Fermentation
(CRF Category 3.A)

5.2.1.   Source Category Description

In Canada, animal production varies from region to region. In western Canada, beef 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 also has traditionally produced swine in high-density, intensive production facilities. Over the past 20 years, some swine production has shifted to western Canada. Other animals that produce CH$_4$ by enteric fermentation are raised as livestock, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boar and sheep; however, populations of these animals have traditionally been low. Over 95% of enteric fermentation emissions come from cattle in Canada.

Methane (CH$_4$) is produced during the normal digestive process of enteric fermentation by herbivores. Microorganisms break down carbohydrates and proteins into simple molecules for absorption through the gastro-intestinal tract and CH$_4$ is produced as a by-product. This process results in an accumulation of CH$_4$ in the rumen that is emitted by eructation and exhalation. Some CH$_4$ is released later in the digestive process by flatulence, but this accounts for less than 5% of total emissions. Large ruminant animals, such as cattle, generate the most CH$_4$.

5.2.2.   Methodological Issues

The diversity of animal production systems and regional differences in production facilities complicate emission estimation. For each animal category/subcategory, CH$_4$ emissions are calculated, by province, by multiplying the animal population of a given category/subcategory by its corresponding regionally derived emission factor.

For cattle, CH$_4$ emission factors are estimated using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodology, based on the equations provided by IPCC Good Practice Guidance (IPCC 2000). A national study by Boadi et al. (2004) broke down cattle subcategories, by province, into subannual production stages and defined their physiological status, diet, age class, sex, weight, growth rate, activity level and production environment. These data were integrated into IPCC Tier 2 equations to

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Table 5–3   Qualitative Summary of the Revisions to Methodologies, Corrections and Improvements Carried out for Canada's 2015 Submission

Correction or Improvement	Recalculation Category	Years Affected
1. Recalculation of swine populations due to changes in Statistics Canada's reporting structures (changing of weight categories)	CH_4 emissions from enteric fermentation and manure management, and direct and indirect N_2O emissions from manure management	2006–2011
2. Modification of historic non-dairy animal weights due to corrections carried out in online weight reporting tool for consistency with data publlished on AAFC website	CH_4 emissions from enteric fermentation and manure management, and direct and indirect N_2O emissions from manure management and agricultural soils	1990-2013
3. Implementation of enteric fermentation equations from 2006 IPCC Guidelines: Including changes to: i) 10.2/10.3-net energy of maintanence, ii) 10.6 - net energy of growth, iii) summation of gross energy (10.16) with the removal of NE gain from weight loss, and iv) change of Ym from 6% to 6.5%	CH_4 emissions from enteric fermentation and manure management	1990-2013
4. Implementation of 2006 IPCC Guidelines, manure management Equation 10.24 volatile solid excretion rates	CH_4 emissions from manure management	1990-2013
5. Recalculation of all regional CH_4 manure management emission factors for animal categories other than cattle, based on new volatile solid excretion rates, where previously all non-cattle emission factors were calculated based on the regional population distribution in 2001	CH_4 emissions from manure management	1990-2013
6. Integration of new animal categories, specifically: mink, fox, rabbits, deer/elk, and wild boars	CH_4 emissions from enteric fermentation and manure management, and direct and indirect N_2O emissions from manure management and agricultural soils	1990-2013
7. Integrated consistent bison weights for N_2O and CH_4 manure management models, based on ERT recommendations from 2014 review	CH_4 emissions from manure management, and direct and indirect N_2O emissions from manure management and agricultural soils	1990-2013
8. Implementation of 2006 IPCC Guidelines, indirect emissions from leaching of nitrogen from manure storage	Indirect N_2O emissions from manure managemeent	1990-2013
9. Improvement of crop area estimates using a combination of earth observations data and the Census of Agriculture resulted in changes in number of agricultural ecodistricts, and refinement of ecodistrict-based N_2O emission factors	Direct and indirect N_2O emissions from agricultural soils	1990-2013
10. Use of EFLEACH of 0.75%, instead of 2.5% from the Good Practice Guidance (IPCC 2000)	Indirect N_2O emissions from leaching and runoff of N in agricultural soils	1990-2013
11. Adoption of country-specific N_2O emission factors for animal manure deposited on pasture, range and paddock based, on a scientific publication (Rochette et al. 2014) and research results (Lemke et al. 2012) collected from Canada	Animal manure deposited on pasture, range and paddock	1990-2013
12. Implementation of the 2006 IPCC Guidelines by including a new source category of soil N_2O emissions resulting from losses of soil organic matter due to management changes in Cropland Remaining Cropland	Mineralization of soil organic matter	1990-2013
13. Implementation of the 2006 IPCC Guidelines including a new source category of soil CO_2 emissions from agricultural use of lime previously reported in LULUCF and the use of a new activity data source: Natural Resources Canada – Canadian Minerals Yearbook	CO_2 emissions from agricultural use of lime	1990-2013
14. A new source of soil CO_2 emissions from agricultural use of urea and urea-containing nitrogen fertilizers has been included based on the 2006 IPCC Guidelines	CO_2 emissions from urea and urea-containing N fertilizers	1990-2013

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produce annual emission factors for each individual animal sub-category 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 1990–2013 time period are reflected in a 20% increase in CH_4 emission factors from this animal category. As milk production increases, the requirement of energy for lactation (NE_l) becomes greater and requires increased food consumption. In beef cattle, changes in mature body weight influence maintenance and growth energy (NE_m and NE_g) requirements and as a consequence feed consumption. From 1990 to 2003, larger breeds became popular and emission factors increased from 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 sub-category 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 18% to 22%. Since finishing animals have a lower emission factor, the overall emission factor of Non-Dairy cattle has decreased from its peak in 2005.

For non-cattle animal categories, CH_4 emissions from enteric fermentation continue to be estimated using the IPCC Tier 1 meth-

odology. Poultry, Rabbits and Fur-bearing animal categories are excluded from enteric fermentation estimates, since no emission factors are 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 2013, uncertainty ranges from the 2012 analysis are applied to new emission estimates.

The uncertainty range for CH_4 emissions from enteric fermentation was similar in 1990 and 2013, and mean estimates lie within a range of -17 to +22% (Table 5–4). Over the time series of 1990 to 2013, mean emissions are estimated to have increased by 2.4 Mt CO_2 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 (43%). Calculations of uncertainty in emissions and emission factors were the most sensitive to the use of IPCC default parameters in the Tier 2 calculation methodology, in particular the methane conversion rate (Y_m) and the factor associated with the estimation of the net energy of maintenance (Cf_i) (Karimi-Zindashty et al. 2012). The uncertainty in the estimates of average national livestock populations for all livestock categories were low (under 6%), including uncertainty in minor livestock populations due to the fact that population estimates were based on the recent (2011) census.

The methodology and parameter data used in the calculation of emission factors are consistent throughout the entire time series (1990–2013) 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 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 elaborated 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 forms. The IPCC Tier 2 emission factors for cattle, derived from Boadi et al. (2004), have been reviewed by independent experts (McAllister and Basarab 2004).

Table 5–4   Uncertainty in Estimates of Emissions of CH_4 from Enteric Fermentation

Animal Category	Uncertainty Source		Mean Value[1]	2.5% Prob[2]	97.5% Prob
Dairy Cattle	Population (1000 head)		956	907 (-5.2%)	1 006 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		155	130 (-16%)	188 (+21%)
	Emissions (Mt CO_2 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)		68	55 (-19%)	83 (+22%)
	Emissions (Mt CO_2 eq)		20	17 (-19%)	26 (+25%)
Other Animals	Emissions (Mt CO_2 eq)		1.1	0.9 (-18%)	1.3 (+17%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	23	19 (-17%)	28 (+22%)
		2013	25	21 (-17%)	31 (+22%)
	Trend	1990–2013	2.4 (11%)	1.4 (+6%)	3.2 (+16%)

Notes:
1. Mean value reported from database, with the exception of Trend, which is the difference between 1990 and 2013.
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 2013.

Table 5–5   Recalculations of Estimates of Emissions and Their Impact on Emission Trend and Total Agricultural Emissions from Enteric Fermentation, Manure Management CH$_4$ and Manure Management N$_2$O

Emission Source	Year	Submission Year	Category Emissions (kt)	Change in Emissions (kt)	Relative Change Category Emissions (%)	Relative Change New GWP[1] (kt CO$_2$ eq)	Observed Change with GWP Change[2] (kt CO$_2$ eq)	Old Trend (%)	New Trend (%)
Enteric Fermentation	1990	2014	767	146	19	3 658	6 727	Long term (1990 - 2012)	
		2015	914						
	2005	2014	1 045	210	20	5 261	9 440	9.0	10
		2015	1 255						
	2012	2014	837	171	20	4 271	7 620	Short term (2005 - 2012)	
		2015	1 007					-20	-20
Manure Management CH$_4$	1990	2014	122	18	15	456	944	Long term (1990 - 2012)	
		2015	140						
	2005	2014	153	20	13	491	1 103	7.6	5.5
		2015	172						
	2012	2014	131	15	11	365	890	Short term (2005 - 2012)	
		2015	146					-14	-15
Manure Management N$_2$O	1990	2014	10	0.3	3	96	-27	Long term (1990 - 2012)	
		2015	11						
	2005	2014	14	0.4	3	133	-34	15	16
		2015	14						
	2012	2014	12	0.4	4	126	-15	Short term (2005 - 2012)	
		2015	12					16	-16

Notes:
1. Value is equaivalent to the kt change in gas, multiplied by the GWP of 25
2. Total difference between reported value in 2014 NIR and reported value in 2015 NIR

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 associated with the implementation of the 2006 IPCC Guidelines resulted in a 20% increase in emission estimates from enteric fermentation (Table 5–5) without considering the increase in GWPs (see the discussion of GWP changes in Chapter 2). The recalculation occurred equally across the entire time series, and there was little impact on the emissions trend during the period of 1990 to 2012, which increased from 9% to 10%. This small readjustment to the trend is a result of the change in the proportion of emissions from Non-Dairy cattle relative to Dairy cattle.

The 20% increase in emissions is due to changes in equations and parameters used in the calculation of gross energy (GE) intake with the implementation of the 2006 IPCC Guidelines. Changes to net energy of growth (NEg) and the removal of the net energy gain associated with weight loss (NEmobilised) accounted for 5% to 8% of the total recalculation (Table 5–6). The largest proportional impact of recalculation was associated with an increase in the methane conversion rate (Ym) from 6% to 6.5% of the GE. The modifications to net energy of maintenance (NEm) associated with the introduction of new Cfi coefficients for lactating animals and the introduction of temperature dependency on the calculation of Cfi for Non-Dairy cattle accounted for roughly 35% and 60% of the increase in emissions from this source category. More detailed explanations of the changes to the Tier 2 equations can be found in Annex 3.4. Section A3.4.2.1.1.

The time series of carcass weight data was reviewed and some changes were made to Non-Dairy cattle weights in certain years. Furthermore, Swine populations were revised by Statistics Canada from 2006 to 2012 and new animal categories were included, specifically Deer and Elk, and Wild Boar. Overall, these changes account for less than 3% of the total recalculation of emissions in any given year.

Table 5–6   Changes in Tier 2 Equations and Parameters Related to the 2006 IPCC Guidelines, Corrections to Activity Data and Country-specific Input Parameters: Impact on Enteric Fermentation Emissions

Modifications with 2006 IPCC Guidelines	Inventory Year	Recalculation Emissions Enteric Fermentation (kt CO$_2$ eq) GWP=25[1]	Proportion of Total Source Change (%)
Changes to net energy (NE) equations, growth and weight loss: Equations 10.6 (NEg), 10.16 (removal of NE$_{mobilised}$)[2]	1990	295	8
	2005	313	6
	2012	218	5
Methane conversion rate - Ym (6.0% to 6.5%)	1990	1 336	37
	2005	1 731	33
	2012	1 275	30
Changes to NE maintainance parameters, Equations 10.2 and 10.3 (Cfi and NE$_m$)	1990	2 013	55
	2005	3 138	60
	2012	2 692	63
Activity data (swine populations, non-dairy cattle weights) and new animals	1990	15	0.4
	2005	19	0.4
	2012	65	2

Notes:

1. Value is equivalent to the kt change in gas, multiplied by the GWP of 25

2. Equation 10.6 refers to the change from Equation 4.3a in the GPG (IPCC, 2000) and 10.16 refers to the gross energy equation, 4.11 in the GPG where the NE$_{mobilised}$ has been removed from the equation

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 diet composition fed to livestock 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. 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$_4$ and N$_2$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. Generally, poorly aerated manure management systems generate high CH$_4$ emissions but relatively low N$_2$O emissions, whereas well-aerated systems generate high N$_2$O emissions but relatively low CH$_4$ emissions.

Manure management practices vary regionally and also by animal category. Dairy, poultry and swine production occur in modern high-density production facilities. Dairy and swine produce large volumes of liquid manure while poultry produces solid manure, both of which are spread on a limited landbase. Feedlot beef production results in large volumes of drylot and solid manure, whereas low-density pasturing systems for beef result in widely dispersed manure in pastures and paddocks. Production systems for other animals, such as bison, goats, horses, llamas/alpacas, deer and elk, wild boar and sheep are generally in pastured or medium-density production facilities producing mainly solid manure. Fur-bearing animals also produce solid manure.

5.3.1.   CH$_4$ Emissions from Manure Management (CRF Category 3.B (a))

5.3.1.1.   Source Category Description

Shortly after manure is excreted, the decomposition process begins. In well-aerated conditions, decomposition is an oxidation process producing CO$_2$; however, if little oxygen is present, carbon is reduced, resulting in the production of CH$_4$. The quantity

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of CH_4 produced depends on manure characteristics and on the type of manure management system. Manure characteristics are in turn linked to animal category and animal nutrition.

5.3.1.2.   Methodological Issues

Methane emissions from manure management are calculated for each animal category/subcategory by multiplying its population by the corresponding emission factor (see Annex 3.4 for detailed methodology). The animal population data are the same as those used for the enteric fermentation emission estimates (Section 5.2.2). Methane emission factors for manure management are estimated using the IPCC Tier 2 methodology (IPCC 2006).

All Tier 2 parameters were taken from expert consultations described in Boadi et al. (2004) and Marinier et al. (2004, 2005) or from the 2006 IPCC Guidelines. For dairy and beef cattle, the Boadi et al. (2004) Tier 2 animal production model was used to derive gross energy of consumption (GE) from which volatile solids (VS) were estimated using Equation 10.23 of the 2006 IPCC Guidelines and manure ash contents from Marinier et al. (2004). All other livestock used parameters taken from Marinier et al. (2004) 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 Swine, Sheep and Poultry, different parameters were used for animal subcategories based on size class for swine and sheep as well as for turkeys, broilers and layers in the poultry category.

Emission factors were derived using the CH_4 producing potential (B_0) and CH_4 conversion factors (MCF) taken from the 2006

IPCC Guidelines. AWMS for each animal category were taken from Marinier et al. (2005) for each province, taking into account regional differences in production practices and manure storage systems. A more complete description of the derivation of the distribution factor for manure management systems is contained in Annex 3.4, Section A3.4.3.

An increase in emission factors over the period of 1990 to 2013 (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 of swine production from eastern to western Canada.

5.3.1.3.   Uncertainties and Time-Series Consistency

The uncertainty analysis of emissions of methane from agricultural sources using the Monte Carlo technique included methane emissions from manure management. The analysis used parameter estimates and uncertainty distributions from Marinier et al. (2004) supplemented with information from Karimi-Zindashty et al. (2012) and additional and updated parameters specific to this analysis. Details of this analysis can be found in Annex 3.4, Section A3.4.3.8.

The estimate of 3.7 Mt CO_2 eq from manure management CH_4 emissions from Canadian livestock in 2013 lies within an uncertainty range of -32% to +27% (Table 5–7). The emission estimate from manure management in 1990, 3.5 Mt CO_2 eq, has a slightly larger uncertainty range, -33% to +38%, due to greater uncertainty associated with the type of manure management systems in

Table 5–7   Uncertainty in Estimates of Emissions of CH_4 from Manure Management

Animal Category	Uncertainty Source		Mean Value[1]	2.5% Prob.[2]	97.5% Prob
Dairy Cattle	Population (1000 head)		956	907 (-5.2%)	1 006 (+5.2%)
	Tier 2 Emission Factor (kg/head/year)		33.6	13 (-60%)	50 (+50%)
	Emissions (Mt CO_2 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_2 eq)		0.99	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_2 eq)		1.6	0.80 (-51%)	2.3 (+44%)
Other Animals	Emissions (Mt CO_2 eq)		0.24	0.16 (-35%)	0.28 (+15%)
Total Emissions	Emissions (Mt CO_2 eq)	1990	3.5	2.3 (-33%)	4.8 (+38%)
		2013	3.7	2.5 (-32%)	4.7 (+27%)
	Trend	1990–2013	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 2013.

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 2013.

1990. The estimate of a 5.5% increase in mean emissions between 1990 and 2012 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_0) (Karimi-Zindashty et al. 2012).

The methodology and parameter data used in the calculation of emission factors are consistent for the entire time series (1990–2013) 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-level QC checks as elaborated 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 forms. The IPCC Tier 2 CH_4 emission factors for manure management practices by all animal categories derived from Marinier et al. (2004) have been reviewed by independent experts (Patni and Desjardins 2004). These documents have been archived in both paper and electronic form.

Internal Tier 2-level 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 to evaluate if 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 resulting from the implementation of the 2006 IPCC Guidelines resulted in an 11% to 15% increase in emission estimates from manure management (Table 5–5) disregarding the changes due to new GWPs. The largest portion

(80-95%) of the recalculation is associated with the changes to the cattle VS, resulting from changes in enteric fermentation equations and the calculation of gross energy (Table 5–8), outlined in Section 5.2.5, including changes to include urinary energy in the calculation of VS according to Equation 10.23 of the new guidelines. The recalculation was larger in 1990 (15% increase) (Table 5–5). This skewed recalculation is mainly due to the importance of Dairy cattle in the calculation of total manure management emissions, and the decline in Dairy cattle populations from 1990 to present. The inclusion of urinary energy in the VS Equation 10.23 of the 2006 IPCC Guidelines also increased emissions by roughly 11% to 16% for animals other than cattle, but the recalculation was smaller in 1990 compared to 2012, likely due to the relative importance of the swine category in total manure management emissions (Table 5–1).

Furthermore, with the recalculation of VS due to the implementation of the 2006 IPCC Guidelines, provincial (regional) emission factors were recalculated in the emission model (Table 5–8). Each province in Canada has a different emission factor, depending on the manure management distributions and the parameters used in the calculation of VS. Previously, a single national emission factor for each animal category was calculated based on 2001 interprovincial population distributions. In this submission, emission factors are weighted annually on the basis of the regional population distributions. Because the national emission factors were sensitive to variations in the relative distribution of swine in different provinces, emissions increased in 1990 by 6% but decreased in 2012 by -9%, mainly due to recalculations in the swine emission factor and the shift of swine populations between eastern and western Canada.

The introduction of new animal categories, i.e., Deer and Elk, Wild Boar, Rabbits and Fur-Bearing Animals (Mink and Fox), added 10 to 30 kt CO_2 eq, accounting for roughly 4% to 6.5% of the recalculation. Corrections to Swine populations decreased emissions in 2012. Finally, a correction was made to the Bison emission factor, which decreased emissions by 0.3 to 0.4 kt CO_2 eq based on the ERT's preliminary recommendations from the 2014 review, which noted an inconsistency between the bison weight used for CH_4 emissions and N_2O emissions,. Recalculations had little effect on the emission trends.

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.

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Table 5–8   Changes Related to the Implementation of 2006 IPCC Guidelines and Continuous Improvements: Impacts to Manure Management

Modifications with 2006 IPCC Guidelines	Inventory Year	Change Emissions Manure Management (kt CO$_2$ eq) GWP=25[3]	Proportion of Total Source Change (%)
Gross energy cattle[1]	1990	357	78
	2005	395	80
	2012	345	94
Equations 10.23 (volatile solids)[2]	1990	48	11
	2005	69	14
	2012	59	16
Regionally weighted emission factors	1990	29	6
	2005	-4	-1
	2012	-32	-9
Bison emission factor[1]	1990	-0.30	-0.1
	2005	-0.40	-0.1
	2012	-0.30	-0.1
Changes in swine populations	1990	0	0
	2005	0	0
	2012	-21	-5.7
Introduction of new animals	1990	22	4.9
	2005	32	6.5
	2011	14	3.9

Notes:
1. These values also include modifications to Equation 10.23 for cattle.
2. Equation 10.23 refers to the change from Equation 4.16 in the GPG (IPCC, 2000) in the calculation of volatile solids with the inclusion of urinary energy (UE).
3. Value is equivalent to the kt change in gas, multiplied by the GWP of 25.

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$_2$O Emissions from Manure Management (CRF Category 3.B (b))

5.3.2.1.   Source Category Description

The production of N$_2$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$_4^+$) to nitrate (NO$_3^-$), and denitrification is the reduction of NO$_3^-$ to N$_2$O or N$_2$. Manure from Non Dairy cattle, Sheep and Lamb, Goat and Horses, Deer and Elk, Wild Boar and Fur-bearing animals are mainly handled with a solid and dry lot system, which is the manure management system that emits the most N$_2$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$_2$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 the Enteric Fermentation category estimates (Section 5.2) and CH$_4$ Emissions from Manure Management (Section 5.3.1). The average annual nitrogen excretion rates for domestic animals are taken from the 2006 IPCC Guidelines. The amount of manure nitrogen subject to losses because of leaching and volatilization of NH$_3$ and NO$_x$ during storage is adjusted by animal type and manure management system according to the default values provided in the 2006 IPCC Guidelines.

The fraction of nitrogen available for conversion into N$_2$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$_2$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_2O from agricultural sources (Karimi-Zindashty et al. 2014). For N_2O emissions from manure management, the uncertainty in the parameters defined in the Tier 1 methodology of the 2006 IPCC Guidelines and all uncertainty in AWMS systems, animal populations and characterizations were identical to those used in the analysis of enteric fermentation and manure management CH_4 defined in Sections 5.2.3 and 5.3.1.3. Details of this analysis can be found in Annex 3.4, Section A3.4.6.

The estimate of direct N_2O emissions in 2013 of 3.6 Mt CO_2 eq from manure management lies within an uncertainty range of 2.1 Mt CO_2 eq (-43%) to 5.4 Mt CO_2 eq (+51%) (Table 5–9). Most uncertainty is associated with the IPCC Tier 1 emission factor (+/-100% uncertainty). Due to the size of the N_2O model, the initial uncertainty analysis was limited to providing sound estimates of uncertainty for emission source categories and a basic sensitivity analysis. A complete analysis of the trend uncertainty has not yet been completed, due to limitations in software capabilities.

The same methodology, emission factors and data sources are used for the entire time series (1990–2013), with the exception that bull weights were maintained constant as noted in Section 5.2.3.

5.3.2.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated 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 rebuilding of the agricultural N_2O emission database.

There have been very few published data on N_2O emissions from manure management storage in Canada or in regions with practices and climatic conditions comparable to those of Canada. More standardized and detailed research is required in Canada to improve upon the current methodology.

5.3.2.5. Recalculations

Recalculations associated with the implementation of the 2006 IPCC Guidelines resulted in a 3-4% increase in emission estimates of N_2O from manure management (Table 5–5). Recalculations in this source category are due to the introduction of new animals, the correction to the nitrogen excretion rate for bison, which increased from 55 to 68 kg N/head/year, as well as minor modifications to Non-Dairy cattle weights and swine populations as outlined in Section 5.2.5. Final reported values in CO_2 eq are also modified due to the change in the GWP of N_2O.

5.3.2.6. Planned Improvements

Data from direct measurements of N_2O emissions from manure management in Canada are scarce. Recent scientific advances in analytical techniques allow direct measurements of N_2O emissions from point sources. However, it will likely take several years before N_2O emissions can be reliably measured and verified for various manure management systems in Canada.

As noted in Section 5.3.1.6, plans are in place to analyze whether improvements could be made to the values used for the

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Table 5–9   Uncertainty Estimates for Emissions of N_2O from Manure Management and Agricultural Soils

Emission Source		Mean Value[1]	2.5% Prob.[2]	97.5% Prob
			Mt CO_2 eq	
Manure Management	Direct Emissions	3.6	2.1 (-43%)	5.4 (+51%)
	Indirect Emissions	1.1	0.5(-60%)	1.9 (+70%)
Agricultural Soils (N_2O)		24	15 (-36%)	37 (+52%)
Direct Sources		20	14 (-28%)	26 (+34%)
	Synthetic Nitrogen Fertilizers	11	7.0 (-35%)	15 (+43%)
	Manure Applied as Fertilizers	1.8	1.2 (-33%)	2.6 (+41%)
	Crop Residue Decomposition	6.4	4.2 (-35%)	9.3 (+45%)
	Cultivation of Organic Soils	0.06	0.01 (-79%)	0.12 (+96%)
	Mineralization of Soil Organic Carbon	0.89	0.6 (-35%)	1.3 (+41%)
	Manure on Pasture, Range and Paddock	0.21	0.1 (-60%)	0.4 (+75%)
	Soil N Mineralization/Immobilization	-0.54	-0.3 (-44%)	-0.8 (+55%)
Indirect Sources		4.6	1.8 (-60%)	7.9 (+70%)
	Atmospheric Deposition	1.8	0.4 (-75%)	3.7 (110%)
	Leaching and Runoff	2.9	0.6 (-80%)	5.7 (100%)

Notes:
1. Mean value reported from database.
2. Values in parentheses represent the uncertain percentage of the mean.

distribution of AWMS based on Statistics Canada 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 short term.

Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.3.3. Indirect N₂O Emissions from Manure Management (CRF Category 3.B (c))

5.3.3.1. Source Category Description

The production of N_2O from manure management can also occur indirectly through NH_3 volatilization and leaching of N during storage and handling of animal manure. A fraction of the nitrogen in manure that is stored is transported off-site through volatilization in the form of NH_3 and NO_x and subsequent redeposition. Furthermore, solid manure exposed to rainfall will be prone to loss of N through leaching, 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_2O.

5.3.3.2. Methodological Issues

Indirect emissions of N_2O from manure management are estimated separately for NH_3 volatilization and N leaching using the IPCC Tier 1 methodology. The fractions of manure nitrogen subject to losses because of leaching and volatilization of NH_3 and NO_x during storage are adjusted by animal type and manure management system according to the default values provided in the 2006 IPCC Guidelines. Emission factors of N_2O for NH_3 volatilization and leaching of N during manure storage and handling are taken from the 2006 IPCC Guidelines.

5.3.3.3. Uncertainties and Time-Series Consistency

A full uncertainty analysis using the Monte Carlo technique has not been carried out to estimate indirect emissions of N_2O from manure management. Most uncertain quantities associated with livestock populations, manure N excretion rates, AWMS, fractions of N leaching and NH_3 volatilization along with indirect N_2O emission factors are available, but cannot be implemented for this submission. Uncertainty is assumed to be equivalent to the uncertainty associated with indirect emissions from agricultural soils.

The same methodology, emission factors and data sources are used for the entire time series (1990–2013).

5.3.3.4. QA/QC and Verification

These categories have undergone Tier 1 QC checks as elaborated 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

There are no recalculations for the indirect N_2O emissions from the Manure Management source category as these are new reporting categories outlined in the 2006 IPCC Guidelines. Volatilization from manure storage was previously reported under indirect emissions from agricultural soils and has increased by approximately 3% to 4% due to the addition of new animals and changes to the bison N excretion value. Final reported values in CO_2 eq are also modified due to the change in the GWP of N_2O.

5.3.3.6. Planned Improvements

As noted in Section 5.3.1.6, plans are in place to analyze whether improvements could be made to the values used for the distribution of AWMS based on Statistics Canada farm environmental management surveys. Efforts have also been made to develop country-specific fractions of NH_3 volatilization and N leaching by livestock categories and AWMS for dairy, beef cattle, and swine, for implementation over the medium term

5.4. N₂O Emissions from Agricultural Soils (CRF Category 3.D)

Emissions of N_2O from agricultural soils consist of direct and indirect emissions. The emissions of N_2O from anthropogenic nitrogen inputs occur directly from the soils to which the nitrogen is added, and also indirectly through two pathways: i) volatilization of nitrogen from synthetic fertilizer and manure as NH_3 and 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 N_2O emissions by altering mineralization of organic nitrogen, nitrification and denitrification.

5.4.1. Direct N₂O Emissions from Soils (CRF Category 3.D.1)

Direct sources of N_2O 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 driven by soil organic matter decay from 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 N_2O. Emission factors associated with fertilizer application depend on many factors, such as soil types, climate, topography, farming practices and environmental conditions (Gregorich et al. 2005; Rochette et al. 2008b).

5.4.1.1.2. Methodological Issues

Canada has developed a country-specific, Tier 2 methodology to estimate N_2O emissions from synthetic nitrogen fertilizer application on agricultural soils, which takes into account moisture regimes and topographic conditions. Emissions of N_2O are estimated by ecodistrict and are scaled up at provincial and national levels. The amount of nitrogen applied is obtained from yearly fertilizer sales. All 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 N_2O from agricultural sources noted in Section 5.3.2.3, included all direct and indirect emissions from soils (Table 5–9). For N_2O emissions from fertilizer, the analysis considered the uncertainty in the parameters defined in the country-specific methodology (Rochette et al. 2008b) used to develop N_2O emission factors, the uncertainty in provincial fertilizer sales, and the uncertainty in crop areas and production at the ecodistrict level.

The estimate of N_2O emissions of 11 Mt CO_2 eq from application of fertilizers on agricultural soils in 2013 lies within an uncertainty range of 7.0 Mt CO_2 eq (-35%) to 15 Mt CO_2 eq (+43%) (Table 5–9). 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 precipitation over potential evapotranspiration ratio (P/PE).

The same methodology and emission factors are used for the entire time series (1990–2013).

5.4.1.1.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated 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 Canada carries out its own Tier 2 QC checks through historical records and consultations with regional and provincial agricultural industries.

Emissions of N_2O associated with 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

In this submission, a major improvement was made through the incorporation of cropland activity data based on land-use mapping for agricultural regions derived from Earth Observation (EO) data. A series of land-use maps were generated for 1990, 2000 and 2010 using several spatial datasets, which were integrated using rule sets. The resulting maps grouped 30-metre pixels into seven primary land-use categories: cropland, grassland, forest, settlement, wetland, water and other land. The map-based product data were then aggregated to cropland SLC polygons. The Census of Agriculture provided apportioning ratios for cropland area attributes that could be applied to the map-based cropland area estimates on an SLC basis. As a result of this improvement, cropland area, along with its attributes (major field crops, tillage practices, summerfallow, and perennial and annual crop conversion), was affected, resulting in an increase of the total cropland area by 0.14 Mha in 1990, 2.9 Mha in 2005, and 3.4 Mha in 2012. These crop area recalculations modified the distribution of fertilizer N among ecodistricts, shifting more crop production area onto the dryland prairies, which tend to have lower emission factors.

Total recalculations resulted in a decrease of 260 kt CO_2 eq in 1990, 320 kt CO_2 eq in 2005, and 440 kt CO_2 eq in 2012, including the change in the GWP of N_2O (Table 5–10).

5.4.1.1.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source; in the mid term, research efforts will be made to differentiate between N_2O emission factors from organic and inorganic N sources. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

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Table 5–10   Recalculations of Estimates of N₂O 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 N₂O)	Change in Emissions (kt N₂O)	Relative Change Category Emissions (%)	Relative Change New GWP[1] (kt CO₂ eq)	Observed Change with GWP Change (kt CO₂ eq)	Old Trend (%)	New Trend (%)
Synthetic Nitrogen Fertilizers	1990	2014	19.1	-0.10	-0.5	-30	-259	Long term (1990 - 2012)	
		2015	19.0					76	76
	2005	2014	25.8	-3.08	-11.9	-917	-321		
		2015	22.7					Short term (2005 - 2012)	
	2012	2014	33.5	-0.11	-0.3	-33	-435	47	47
		2015	33.4						
Manure Applied as Fertilizers	1990	2014	5.7	0.15	2.5	43	-26	Long term (1990 - 2012)	
		2015	5.9					3.6	3.6
	2005	2014	7.1	0.17	2.3	49	-35		
		2015	7.2					Short term (2005 - 2012)	
	2012	2014	5.9	0.15	2.5	45	-27	-16	-16
		2015	6.1						
Crop Residue Decomposition	1990	2014	15.4	-0.20	-1.3	-59	-243	Long term (1990 - 2012)	
		2015	15.2					11	17
	2005	2014	16.8	-0.07	-0.4	-20	-221		
		2015	16.7					Short term (2005 - 2012)	
	2012	2014	17.0	0.69	4.1	207	3	1.5	6.0
		2015	17.7						
Animal Manure on Pasture, Range and Paddock	1990	2014	7.1	-6.4	-89.8	-1907	-1993	Long term (1990 - 2012)	
		2015	0.7					22	-2.8
	2005	2014	11.1	-10.2	-92.4	-3053	-3186		
		2015	0.8					Short term (2005 - 2012)	
	2012	2014	8.7	-8.0	-91.9	-2379	-2483	-22	-16
		2015	0.7						

Notes:

1. Numbers are calculated using the change in emissions between 2014 NIR and 2015 NIR multiplied by the new GWP of N₂O (298).

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 N₂O emissions. Emissions from this category include all the manure managed by drylot, liquid and other animal waste management systems.

5.4.1.2.2. Methodological Issues

Similar to the methodology used to estimate emissions from synthetic nitrogen fertilizers, the method used to estimate N₂O 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, and 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 N₂O 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 N₂O emission factors, as noted in Section 5.4.1.1.3.

The estimate of N₂O emissions of 1.8 Mt CO₂ eq from manure spreading in 2013 lies within an uncertainty range of 1.2 Mt CO₂ eq (-33%) to 2.6 Mt CO₂ eq (+41%) (Table 5–9). The main source of uncertainty in the calculation of emissions from manure includes the slope of the P/PE regression equation for estimating N₂O emission factors,

animal N excretion rates, and emission factor modifiers for texture ($RF_{TEXTURE}$) and tillage (RF_{TILL}).

The same methodology and emission factors are used for the entire time series (1990–2013).

5.4.1.2.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated 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

In this year's submission, changes to calculations of the direct emissions of N_2O from spreading of manure on agricultural soils included the redistribution of N among ecodistricts that are related to agricultural activities due to improvements in crop area estimates based on EO measurements as described in Section 5.4.1.1.5 and the inclusion of more livestock categories as detailed in Section 5.3.1.5. As a consequence, the total N from manure applied to agricultural fields increased. Final reported values in CO_2 eq are also modified due to the change in the GWP of N_2O.

Total recalculations resulted in a decrease of 26 kt CO_2 eq in 1990, 35 kt CO_2 eq in 2005, and 27 kt CO_2 eq in 2012 (Table 5–10).

5.4.1.2.6. 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 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 on the field to decompose. The remaining plant matter is a nitrogen source for nitrification and denitrification and thus can contribute to N_2O production.

5.4.1.3.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of nitrogen contained in crop residue multiplied by the emission factor at the ecodistrict level and scaled up to the provincial and national levels. The amount of nitrogen contained in crop residues is estimated using country-specific crop char-

acteristics (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_2O emissions from crop residue decomposition, the uncertainty analysis considered the uncertainty in crop production, as well as the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N_2O emission factors as noted in Section 5.4.1.1.3.

The estimate of N_2O emissions of 6.4 Mt CO_2 eq from crop residue decomposition in 2013 lies within an uncertainty range of 4.2 Mt CO_2 eq (-35%) to 9.3 Mt CO_2 eq (+45%) (Table 5–9). The main sources of uncertainty in the calculation of emissions from crop residue decomposition include the slope of the P/PE regression equation for estimating N_2O emission factors and emission factor modifiers for texture ($RF_{TEXTURE}$) and tillage (RF_{TILL}).

The same methodology and emission factors are used for the entire time series (1990–2013).

5.4.1.3.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated 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 the direct emissions of N_2O from decomposition of crop residues were mainly due to the recalculation of the areas of crops and, as a consequence, crop residual N among ecodistricts due to improvements from EO based crop area estimates as described in Section 5.4.1.1.5.

Total recalculations consisted of a decrease of 240 kt CO_2 eq in 1990, 220 kt CO_2 eq in 2005, and an increase of 3 kt CO_2 eq in 2012, including the change in the GWP of N_2O (Table 5–10). The small increase in emissions for 2011 and 2012 was due to a correction or a transcription error in the agricultural database. Residue decomposition from tame hay and alfalfa production was excluded in the last submission. The correction of this error resulted in an average increase in the emissions from crop residue decomposition of 350 kt CO_2 eq for these two years exclusively. As a result, the trend was also modified, demonstrating an increase of 17% from 1990-2012, compared to the previous published trend of 11%, and an increase of 6.1% from 2005-2012, compared to the previous estimate of 1.5%.

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5.4.1.3.6. 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 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_2O can be emitted.

5.4.1.4.2. Methodological Issues

The emissions from manure excreted by grazing animals are calculated using a country-specific IPCC Tier 2 method that was derived from field flux measurements (Rochette et al. 2014; Lemke et al. 2012). Details of these new emission factors can be found in Annex 3.4, Section A3.4.5. Emissions are calculated for each animal category by multiplying the number of grazing animals for that category by the appropriate nitrogen excretion rate and by the fraction of manure nitrogen available for conversion to N_2O.

5.4.1.4.3. Uncertainties and Time-Series Consistency

The uncertainty of the new estimates of N_2O emissions associated with 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 and not for the new emission factors. Animal populations, and their characterizations were identical to those used in the analysis of CH_4 from enteric fermentation and manure management defined in Sections 5.2.3 and 5.3.1.3.

Under these assumptions, the estimate of N_2O emissions of 0.2 Mt CO_2 eq from pasturing Canadian livestock in 2013 lies within an uncertainty range of 0.1 Mt CO_2 eq (-60%) to 0.4 Mt CO_2 eq (+75%) (Table 5–1).

The same methodology and emission factors are used for the entire time series (1990–2013).

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 adoption of country-specific emission factors and the inclusion of several new livestock categories resulted in significant recalculations and decreased emissions by 2.0 Mt CO_2 eq in 1990, 3.2 Mt CO_2 eq in 2005, and 2.5 Mt CO_2 eq in 2012 (Table 5–1). In comparison with the IPCC default EF for major (2%) and minor livestock (1%), emission factors were 3.2 and 1.6 times lower in eastern Canada and 46.5 and 23.3 times lower in western Canada for major and minor livestock, respectively. Lower emission factors observed on the Canadian Prairies compared with the more humid climate in eastern Canada are consistent with the findings of Rochette et al. (2008), who reported that moisture deficit defined as ratio of precipitation over potential evapotranspiration during the growing season is a major contributing factor for N_2O emissions on arable cropland in Canada. The population of cattle (dairy and non-dairy) from 1990 to 2012 increased by 28% for western Canada, but decreased by 20% for eastern Canada. Because of the difference in the N_2O EFs and the relative size of cattle population between eastern and western Canada the recalculations resulted in a change of the long-term trend from an increase of 22% in the previous submission to a decrease of 3% in this submission (Table 5–11).

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 Section of the LULUCF (Chapter 6). Nonetheless, N mineralization associated with the loss of soil organic carbon contributes to the overall N balance of agricultural lands. This nitrogen, once in an inorganic form, is prone to loss in the form of N_2O during either nitrification or denitrification. As a result, this N must be taken into account for its contribution to soil N_2O emissions.

5.4.1.5.2. Methodological Issues

Emissions are estimated using an IPCC Tier 2 approach based on the amount of nitrogen contained in soil organic matter that is

Table 5–11   Recalculations of Estimates of N$_2$O Emissions and Their Impact on Emission Trend from Conservation Tillage Practices, Summerfallow and Irrigation

Emission Source	Year	Submission Year	Category Emissions (kt N$_2$O)	Change in Emissions (kt N$_2$O)	Relative Change Category Emissions (%)	Relative Change New GWP[1] (kt CO$_2$ eq)	Observed Change with GWP Change (kt CO$_2$ eq)	Old Trend (%)	New Trend (%)
Conservation Tillage Practices	1990	2014	-0.98	-0.22	22	-65	-53	Long term (1990 - 2012)	
		2015	-1.19					324	239
	2005	2014	-2.83	-0.27	10	-81	-47		
		2015	-3.10					Short term (2005 - 2012)	
	2012	2014	-4.14	0.09	-2	28	77	46	31
		2015	-4.05						
Summerfallow	1990	2014	4.46	0.11	3	34	-19	Long term (1990 - 2012)	
		2015	4.57					-64	-66
	2005	2014	2.64	0.02	1	6	-26		
		2015	2.66					Short term (2005 - 2012)	
	2012	2014	1.59	-0.02	-1	-5	-24	-40	-41
		2015	1.57						
Irrigation	1990	2014	0.91	0.23	25	69	58	Long term (1990 - 2012)	
		2015	1.14					41	22
	2005	2014	1.06	0.31	29	91	78		
		2015	1.36					Short term (2005 - 2012)	
	2012	2014	1.28	0.11	9	33	18	21	2
		2015	1.39						

Notes:

1. Numbers are calculated using the change in emissions between 2014 NIR and 2015 NIR multiplied by the new GWP of N$_2$O (298).

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 2013 is taken from carbon reported for Cropland Remaining Cropland of LULUCF excluding the effect of forestland conversion to cropland within 20 years (i.e. N$_2$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$_2$O emission factors (EF$_{BASE}$) 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 new 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-level QC checks as elaborated 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 no recalculations in this source of emission estimates as this is a new source category.

5.4.1.5.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. The uncertainty for this category will be calculated in the next round of uncertainty analysis.

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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 higher N_2O production (Mosier et al. 1998).

5.4.1.6.2. Methodological Issues

The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils. Emissions of N_2O are calculated by multiplying the area of cultivated histosols by the IPCC default emission factor.

Areas of cultivated histosols at a provincial level are not surveyed in the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada have resulted in an estimated area of 16 kha of cultivated organic soils in Canada, a constant level for the period 1990–2013 (Liang et al. 2004a).

5.4.1.6.3. Uncertainties and Time Series Consistency

For N_2O emissions from organic soils, the uncertainty analysis considered the uncertainty in organic soil areas and the uncertainty in the default emission factor.

The estimate of N_2O emissions of 0.06 Mt CO_2 eq from organic soils in 2013 lies within an uncertainty range of 0.01 Mt CO_2 eq (-79%) to 0.12 Mt CO_2 eq (+96%) (Table 5–9). 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 (1990–2013).

5.4.1.6.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated 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 except for the change in the GWP of N_2O.

5.4.1.6.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.7. Changes in N_2O Emissions from Adoption of No-Till and Reduced Tillage

5.4.1.7.1. Source Category Description

This category is not derived from additional nitrogen inputs (i.e. fertilizer, manure or crop residue); rather, it is implemented as modifications to N_2O emission factors due to the change from conventional to conservation tillage practices—namely, reduced tillage (RT) and no-tillage (NT).

5.4.1.7.2. Methodological Issues

Compared with conventional or intensive tillage (IT), direct seeding or NT as well as RT change several factors that influence N_2O production, including decomposition of soil organic matter, soil carbon and nitrogen availability, soil bulk density, and water content (McConkey et al. 1996, 2003; Liang et al. 2004b). As a result, compared with conventional tillage, conservation tillage (i.e. RT and NT) generally reduces N_2O emissions for the Prairies (Malhi and Lemke 2007), but increases N_2O emissions for the non-Prairie regions of Canada (Rochette et al. 2008a). The net result across the country amounts to a small reduction in emissions. This reduction is reported separately, as a negative estimate (Table 5–1).

Changes in N_2O 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_2O fluxes on NT or RT to mean N_2O fluxes on IT (N_2O_{NT}/N_2O_{IT}), represents the effect of NT or RT on N_2O emissions (see Annex 3.4).

5.4.1.7.3. Uncertainties and Time-Series Consistency

For N_2O emissions from 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 5.4.1.2.4, and the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N_2O emission factors as noted in Section 5.4.1.1.3.

The estimate of N_2O emission reductions of -1.4 Mt CO_2 eq from conservation tillage practices in 2013 lies within an uncertainty range of -44% to +55% based on the uncertainty range of combined emissions of tillage, irrigation and summerfallow practices (Table 5–9). Tillage practice calculations are dependent on all soil emission calculations, and uncertainty is therefore influenced by all factors denoted 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 (1990–2013).

5.4.1.7.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated 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 denoted in previous sections, including the recalculation of EO-based crop areas, as detailed in Section 5.4.1.1.5. When total cropped areas in ecodistricts are changed, this can have a large impact on the distribution of the different types of tillage used in that area and, as a consequence, can result in proportionally large changes in emission reductions associated with conservation tillage, ranging from 10% to 22%. These changes resulted in a recalculation of -53 kt CO_2 eq in 1990, -47 kt CO_2 eq in 2005, and 77 kt CO_2 eq in 2012. Final reported values in CO_2 eq are also modified due to the change in the GWP of N_2O. The largest change in this category is observed in the long-term trend, which has decreased from a 320% decline in emissions as published in the previous submission, to a 240% decline in emissions based on the new tillage area estimates (Table 5–11). Similarly, these recalculations reduced the short-term trend from 46% to 31% (Table 5–11).

5.4.1.7.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. However, work is ongoing to develop level and trend uncertainty estimates using the IPCC Tier 2 method.

5.4.1.8. N_2O 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_2O emissions. Summerfallow (SF) is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, several soil factors may stimulate N_2O emissions relative to a cropped situation, such as higher soil water content, higher soil temperature, and greater availability of soil carbon and nitrogen (Campbell et al. 1990, 2005).

5.4.1.8.2. Methodological Issues

Experimental studies have shown that N_2O emissions in fallow fields are not statistically different from emissions on continuously cropped fields (Rochette et al. 2008b). Omitting areas under SF in calculations of N_2O emissions because no crops are grown or fertilizer applied could lead to underestimating total N_2O emissions. The emissions from SF land are therefore calculated through a country-specific method by summing emissions from fertilizer nitrogen, manure nitrogen application to annual crops and crop residue nitrogen for a given ecodistrict and multiplying the sum by the proportion of that ecodistrict area under SF (Rochette et al. 2008b). A more detailed description of the approach is provided in Annex 3.4.

5.4.1.8.3. Uncertainties and Time-Series Consistency

For N_2O emissions from summerfallow, the uncertainty analysis considered the uncertainty in summerfallow areas, manure management factors defined in Sections 5.3.2.3 and 5.4.1.2.4, crop residue decomposition defined in Section 5.4.1.3.3, and the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N_2O emission factors as noted in Section 5.4.1.1.3.

The estimate of N_2O emissions of 0.50 Mt CO_2 eq from summerfallow land in 2013 lies within an uncertainty range of -44% to +55%, based on the uncertainty range of combined emissions of tillage, irrigation and summerfallow practices (Table 5–9). Summerfallow emission calculations overlie all soil emission calculations, and uncertainty is therefore influenced by all factors denoted 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 (1990–2013).

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5.4.1.8.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated 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 denoted in previous sections, in particular the recalculation of crop areas based on Earth Observations as outlined in Section 5.4.1.1.5. These changes resulted in a very small recalculation of -19 kt CO_2 eq in 1990, -26 kt CO_2 eq in 2005, and -24 kt CO_2 eq in 2012, including the change in the GWP of N_2O. These recalculations did not change the long- or short-term trend for this emission source category (Table 5–12).

5.4.1.8.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source. Further uncertainty work will be carried out to establish trend uncertainty over the medium term.

5.4.1.9. N_2O Emissions from Irrigation

5.4.1.9.1. Source Category Description

Similar to tillage practices and summerfallow, the effect of irrigation on N_2O emissions is not derived from additional nitrogen input but reflects changes in soil conditions that affect N_2O emissions. Higher soil water content under irrigation increases the potential for N_2O emissions through increased biological activity, reducing soil aeration (Jambert et al. 1997) and thus enhancing denitrification.

5.4.1.9.2. Methodological Issues

The methodology is country specific and is based on the assumptions that 1) irrigation water stimulates N_2O production in a way similar to rainfall water and 2) irrigation is applied at rates such that amounts of precipitation plus those of irrigation water are equal to the potential evapotranspiration at the local conditions. Consequently, the effect of irrigation on N_2O emissions from agricultural soils was estimated using an EF_{BASE} estimated at a P/PE = 1 (precipitation/potential evapotranspiration, EF_{BASE} = 0.017 N_2O-N/kg N) for the irrigated areas of a given ecodistrict. To improve the transparency, the effect of irrigation on soil N_2O emissions is also reported separately from other source categories.

5.4.1.9.3. Uncertainties and Time-Series Consistency

For N_2O emissions from irrigation, the uncertainty analysis considered the uncertainty in irrigation areas, manure management factors defined in Sections 5.3.2.3 and 5.4.1.2.4, and the uncertainty defined in the country-specific methodology (Rochette et al. 2008b) used to develop N_2O emission factors as noted in Section 5.4.1.1.3.

The estimate of N_2O emissions of 0.45 Mt CO_2 eq from irrigated land in 2013 lies within an uncertainty range of -44% to +55% based on the uncertainty range of combined emissions of

Table 5–12   Recalculations of Estimates of N_2O 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 N_2O)	Change in Emissions (kt N_2O)	Relative Change Category Emissions (%)	Relative Change New GWP[1] (kt CO_2 eq)	Observed Change with GWP Change (kt CO_2 eq)	Old Trend (%)	New Trend (%)
Indirect Emissions, Volatilization and Redeposition	1990	2014	6.48	-2.88	-44.4	-858	-941	Long term (1990 - 2012)	
		2015	3.60					37	57
	2005	2014	8.67	-3.87	-44.6	-1152	-1245		
		2015	4.80					Short term (2005 - 2012)	
	2012	2014	8.89	-3.29	-37.0	-981	1081	2.6	16
		2015	5.60						
Indirect Emissions, Leaching, Erosion and Runoff	1990	2014	21.60	-14.8	-68.4	-4403	-4662	Long term (1990 - 2012)	
		2015	6.82					33	34
	2005	2014	25.02	-17.0	-68.0	-5069	-5369		
		2015	8.01					Short term (2005 - 2012)	
	2012	2014	28.73	-19.6	-68.2	-5835	-6180	15	14
		2015	9.15						

Notes:

1. Numbers are calculated using the change in emissions between 2014 NIR and 2015 NIR multiplied by the new GWP of N_2O (298).

tillage, irrigation and summerfallow practices (Table 5–9). 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 denoted 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 (1990–2013).

5.4.1.9.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated 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 denoted in previous sections, in particular, the recalculation of crop areas based on Earth observations as outlined in Section 5.4.1.1.5. The incorporation of Earth observations resulted in an increase of irrigated areas by 130 kha in 1990, 150 kha in 2005, and 70 kha in 2012. These changes resulted in an increase in emissions of 58 kt CO_2 eq in 1990, 78 kt CO_2 eq in 2005, and 18 kt CO_2 eq in 2012, including the change in the GWP of N_2O. Recalculations were relatively small in 2012 (an increase of 9%), but large in previous years (as high as 34% in 1996) and, as a result, reduced the long-term and short-term emission trend for this source (Table 5–12).

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_2O 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_3 and NO_x 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_2O.

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_3 or NO_x, which can be redeposited elsewhere and undergo further transformation, resulting in N_2O emissions off-site. The quantity of this volatilized nitrogen depends on a number of factors, such as rates of fertilizer and manure nitrogen application, fertilizer types, methods and time of nitrogen application, soil texture, rainfall, temperature, and soil pH.

5.4.2.1.2. Methodological Issues

There are few published scientific data that actually determine N_2O emissions from volatilization and redeposition of NH_3 and NO_x. Leached or volatilized N may not be available for the process of nitrification and denitrification for many years, particularly in the case of N leaching into groundwater. Even though Indirect Soil N_2O Emissions from Agricultural Soils are a key source category for level and trend assessments for Canada, there are difficulties in defining the duration and boundaries for this source of emissions because no standardized method for deriving the IPCC Tier 2 emission factors is provided by the IPCC Guidelines.

The IPCC Tier 1 methodology is used to estimate indirect N_2O 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_3-N and NO_x-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, 20% of the applied manure nitrogen to cropland, and from 12% to 48% of excreted manure nitrogen during handling and storage (IPCC 2006). The default IPCC emission factor, 0.01 kg N_2O-N/kg N, is used to derive the N_2O emission estimate (IPCC 2006).

5.4.2.1.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N_2O emissions from volatilization and redeposition 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_2O emissions of 1.8 Mt CO_2 eq from volatilization and redeposition in 2013 lies within an uncertainty range of 0.5 Mt CO_2 eq (-74%) to 3.7 Mt CO_2 eq (+110%) (Table 5–9). Most

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uncertainty is associated with the IPCC Tier 1 emission factor of 1% (uncertain range, 0.2% to 5%).

The same methodology and emission factors are used for the entire time series (1990–2013).

5.4.2.1.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated 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

In previous submissions, approximately half of volatilized N was from manure storage. Emissions decreased in this sector by 941 kt CO_2 eq, 1245 kt CO_2 eq and 1081 kt CO_2 eq in 1990, 2005 and 2012 respectively, including the change in the GWP of N_2O. The inclusion of several minor livestock categories resulted in a small increase of less than 1% in overall emissions from total N volatilized from all categories, but this change is hidden within large recalculations based on the division of indirect N loss between manure storage and field application. These recalculations resulted in little difference in the long- or short-term trend based on total volatilization, but with the separation of volatilization between manure storage and soil application, the new trend for this category is now an increase of 57%, which is more consistent with the large increase over time in the application of N fertilizers.

5.4.2.1.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source.

5.4.2.2. 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_2O emissions off-site.

5.4.2.2.2. Methodological Issues

There are few published scientific data that determine N_2O emissions from leaching, erosion and runoff in Canada. Similar to N_2O emissions from volatilization and redeposition of NH_3 and NO_x,

this source is poorly defined because no standardized method for deriving the IPCC Tier 2 emission factors is provided by the IPCC Guidelines.

A modified IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from leaching, runoff and erosion of fertilizers, manure and crop residue nitrogen from agricultural soils. Indirect N_2O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using $FRAC_{LEACH}$ 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_2O-N/kg N (IPCC 2006).

The default value for the fraction of nitrogen that is lost through leaching and runoff ($FRAC_{LEACH}$) in the Revised 1996 Guidelines is 0.3; however, $FRAC_{LEACH}$ can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC 2006), such as in the Prairie region of Canada. Accordingly, it is assumed that $FRAC_{LEACH}$ would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with no moisture deficit during the growing season (May through October), the maximum $FRAC_{LEACH}$ value of 0.3 recommended by the IPCC (2006) Guidelines is assigned. The minimum $FRAC_{LEACH}$ value of 0.05 is assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts, $FRAC_{LEACH}$ is estimated by the linear extrapolation of the two end-points described above.

5.4.2.2.3. Uncertainties and Time-Series Consistency

The Monte Carlo uncertainty analysis of indirect N_2O emissions from leaching, erosion and runoff of N considered the uncertainty in the parameters defined in the Tier 1 methodology of the Revised 1996 IPCC Guidelines, and the uncertainty in the estimate of total N.

The estimate of N_2O emissions of 2.9 Mt CO_2 eq from leaching, erosion and runoff of N in 2013 lies within an uncertainty range of 0.6 Mt CO_2 eq (-80%) to 6.3 Mt CO_2 eq (+120%) (Table 5–9). 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 (1990–2013).

5.4.2.2.4. QA/QC and Verification

This category has undergone Tier 1-level QC checks as elaborated 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 the implementation of the 2006 IPCC Guidelines to reduce EF_{LEACH} from 2.5% to 0.75%.

Total recalculations consisted of a decrease of 4.7 Mt CO_2 eq in 1990, 5.4 Mt CO_2 eq in 2005, and 6.2 Mt CO_2 eq in 2012 (Table 5–12). Final reported values in CO_2 eq are also modified due to the change in the GWP of N_2O. These recalculations had little impact on the long- or short-term 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. CH₄ and N₂O 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 disease control through residue removals, even though this practice has declined in recent years because of concerns over soil quality and environmental issues. Crop residue burning is a net source of CH_4, CO, NO_x and N_2O (IPCC 2006).

5.5.2. Methodological Issues

There are no published data on emissions of N_2O and CH_4 from field burning of agricultural residues in Canada. Thus, the IPCC default emission factors and parameters from the 2006 IPCC Guidelines were used for estimating emissions.

A complete time series of activity data on the type and the percent of each crop residue subject to field burning was developed based on Statistics Canada's *Farm Environmental Management Survey* (FEMS)[2] and on expert consultations (Coote et al. 2008).

Crop-specific parameters, such as moisture content of the crop product and ratio of above-ground crop residue to crop product, required for estimating the amount of crop residue burned, were obtained from Janzen et al. (2003), and are consistent with the values used to estimate emissions from crop residue decomposition.

5.5.3. Uncertainties and Time-Series Consistency

The uncertainties associated with CH_4 and N_2O emissions from field burning of agricultural residues were determined using an IPCC Tier 1 method (IPCC 2006).

The uncertain quantities associated with CH_4 and N_2O emissions from field burning of agricultural residues are the amount of field crop residues burned and emission factors. The uncertainty in the amount of crop residues burned is estimated, based on the area of specific seeded crop, to be ±50% (Coote et al. 2008). The uncertainties associated with the emission factors are not reported in the 2006 IPCC Guidelines but are assumed to be similar to those associated with burning of Savanna and grassland: ±40% for CH_4 and ±48% for N_2O (IPCC 2006). The level and trend uncertainties for CH_4 emission estimates from 1990 to 2013 were estimated to be ±29% and ±23%, respectively. The level and trend uncertainties for N_2O emission estimates were estimated to be ±29% and ±23%, respectively.

5.5.4. QA/QC and Verification

CH_4 and N_2O emissions from field burning of agricultural residues have undergone Tier 1-level QC checks as elaborated 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 except for changes in GWPs for N_2O and CH_4.

5.5.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates from this source.

5.6. CO₂ Emissions from Lime Application (CRF Category 3.G)

5.6.1. Source Category Description

In Canada, limestone is often used for certain crops, such as alfalfa, to neutralize acidic soils, increase the availability of soil nutrients, particularly phosphorus, reduce the toxicity of heavy metals, such as aluminium, and improve the crop growth environment. During this neutralization process, CO_2 is

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2   http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5044&lang=en&db=imdb&adm=8&dis=2#a4

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_2 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 ±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 0.3 ± 0.19 Mt CO_2 eq for the level uncertainty.

The same methodology is used for the entire time series of emission estimates (1990–2013).

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

CO_2 emissions from agricultural use of lime were formerly reported in Cropland Remaining Cropland of LULUCF. Recalculations were carried out because of the change in data source for the entire time series, and the impact of these recalculations was an increase in emissions of 0.17 Mt CO_2 eq for 1990 and 0.04 Mt CO_2 eq for 2012. Natural Resources Canada collected and published data on agricultural use of lime in 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). Data for lime was formerly based on informal consultation with the Canadian Fertilizer Institute; they were not published and were only available until 2004.

5.6.6. Planned Improvements

There is no immediate plan in place aimed at improving emission estimates for this source.

5.7. CO₂ Emissions from Urea Fertilization
(CRF Category 3.H)

5.7.1. Source Category Description

When urea or urea-based nitrogen fertilizers are applied to a soil to augment crop production, CO_2 is released upon the hydrolysis of the urea. According to the 2006 IPCC Guidelines the quantity of CO_2 released to the atmosphere should be accounted for as an emission. In addition to urea, Canadian farmers also use significant amounts of urea ammonium nitrate (28-0-0) with a mixture of 30% $CO(NH_2)^2$.

5.7.2. Methodological Issues

Emissions associated with urea application were calculated from the amount and composition of the urea or urea-based fertilizers applied annually—specifically, the respective stoichiometric relationships that describe the breakdown of urea into CO_2. 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 EF specified in the 2006 IPCC Guidelines. The overall mean and uncertainties were estimated to be 2.3 ± 1.2 Mt CO_2 eq for the level uncertainty.

The same methodology and data sources are used for the entire time series of emission estimates (1990–2013).

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_2, additional emissions of CH_4, N_2O and CO due to wildfires and controlled burning, and N_2O released following Land conversion to Cropland. All emissions from and removals by the LULUCF Sector are excluded from the national totals.

In 2013, the estimated net GHG flux in the LULUCF Sector, calculated as the sum of CO_2[1] emissions and removals and non-CO_2 emissions, amounted to removals of 15 Mt. If these were included in the national totals, they would decrease the total Canadian GHG emissions by 2.1%. Table 6–1 provides the net flux estimates for 1990 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, with net category totals fluctuating between -274 Mt (1992) and 9 Mt (1995) (see Figure 6–2). This variability is mainly due to differences in areas of managed forests burned by wildfire. These fluctuations are

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1   Unless otherwise indicated, all emissions and removals are in CO_2 equivalents.

Table 6–1   LULUCF Sector Net GHG Flux Estimates, Selected Years

Sectoral Category	Net GHG Flux (kt CO_2 eq)[2]							
	1990	2000	2005	2009	2010	2011	2012	2013
Land Use, Land-Use Change and Forestry TOTAL[1]	**-87 000**	**-77 000**	**16 000**	**-7 900**	**81 000**	**82 000**	**60 000**	**-15 000**
a. Forest Land	**-250 000**	**-250 000**	**-140 000**	**-140 000**	**-65 000**	**-69 000**	**-94 000**	**-160 000**
Forest Land remaining Forest Land	-250 000	-250 000	-140 000	-140 000	-64 000	-68 000	-94 000	-160 000
Land converted to Forest Land	-1 000	- 980	- 920	- 790	- 740	- 700	- 650	- 590
b. Cropland	**10 000**	**-2 100**	**-8 400**	**-8 700**	**-8 400**	**-8 000**	**-7 700**	**-7 400**
Cropland remaining Cropland	480	-7 300	-13 000	-13 000	-12 000	-12 000	-11 000	-11 000
Land converted to Cropland	9 900	5 200	4 300	3 900	3 800	3 700	3 600	3 700
c. Grassland	**640**	**1 000**	**850**	**420**	**320**	**630**	**1 600**	**680**
Grassland remaining Grassland	640	1 000	850	420	320	630	1 600	680
Land converted to Grassland	NO	NO	NO	NO	NO	NO	NO	NO
d. Wetlands	**5 900**	**4 300**	**4 300**	**3 900**	**3 900**	**3 700**	**3 700**	**3 600**
Wetlands remaining Wetlands	1 300	2 400	2 200	2 300	2 300	2 300	2 300	2 300
Land converted to Wetlands	4 700	1 900	2 100	1 700	1 600	1 500	1 400	1 300
e. Settlements	**4 200**	**3 600**	**4 200**	**4 400**	**4 400**	**4 500**	**4 400**	**4 400**
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	6 700	6 900	6 900	7 000	7 000	7 000
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**	**170 000**	**160 000**	**130 000**	**150 000**	**150 000**	**150 000**	**150 000**

Notes:
1. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.
2. Negative sign indicates net removals of CO_2 from the atmosphere.
NE = Not estimated, NO=Not Occuring

Table 6–2   Summary of Recalculations in the LULUCF Sector

2014 NIR and 2015 NIR Estimates and List of Changes[1]		1990	2000	2005	2009	2010	2011	2012
By CO_2 eq[2]								
Previous submission (2014 NIR), old GWPs	kt	-71 000	-52 000	53 000	-27 000	76 000	77 000	41 000
Previous submission (2014 NIR), new GWPs	kt	-70 000	-51 000	54 000	-27 000	78 000	79 000	43 000
Current submission (2015 NIR), new GWPs	kt	-87 000	-77 000	16 000	-7 900	81 000	82 000	60 000
Total change	kt	**-16 000**	**-25 000**	**-37 000**	**20 000**	**5 600**	**5 400**	**19 000**
	%	**23%**	**49%**	**-69%**	**-71%**	**7%**	**7%**	**47%**
Change due to new GWPs[3]	kt	620	370	1 000	970	1 800	1 800	1 700
	%	-0.9%	-0.7%	2%	-4%	2%	2%	4%
Change due to 2006 IPCC Guidelines	kt	-20 000	-27 000	-38 000	19 000	7 400	4 300	3 800
	%	28%	53%	-69%	-72%	10%	5%	9%
Change due to Expert Review Team (ERT) recommendation(s)		C	C	C	C	C	C	C
Change due to continuous improvement or refinement	kt	2 700	1 800	- 200	- 540	-3 500	- 690	14 000
	%	-3.8%	-3.5%	0%	2%	-5%	-1%	32%
Memo item: changes in transfers to HWP[4]	kt	59	90	-12	-740	-140	1 400	16 000
By Gas: CO_2								
Previous submission (2014 NIR)	kt	-77 000	-55 000	44 000	-37 000	58 000	59 000	24 000
Current submission (2015 NIR)	kt	-94 000	-80 000	5 300	-18 000	63 000	63 000	42 000
Total change	kt	**-17 000**	**-25 000**	**-38 000**	**18 000**	**4 100**	**3 700**	**18 000**
	%	**22%**	**46%**	**-88%**	**-50%**	**7%**	**6%**	**74%**
Change due to 2006 IPCC Guidelines	kt	-20 000	-27 000	-38 000	19 000	7 400	4 300	3 800
	%	26%	50%	-87%	-52%	13%	7%	16%
Change due to continuous improvement or refinement	kt	2 600	1 800	-360	-730	-3 300	-550	14 000
	%	-3.4%	-3%	-1%	2%	-6%	-1%	58%
By Gas: CH_4								
Previous submission (2014 NIR)	kt	180	100	290	280	510	520	490
Current submission (2015 NIR)	kt	180	100	300	280	500	510	480
Total change	kt	1.0	0.7	4	5	-7	-4	-13
	%	0.5%	0.7%	1%	2%	-1%	-0.7%	-3%
Change due to continuous improvement or refinement	kt	1.0	0.7	4.4	5.2	-7.1	-3.9	-13
	%	0.5%	0.7%	1%	2%	-1%	-0.7%	-3%
By Gas: N_2O								
Previous submission (2014 NIR)	kt	7.1	3.8	12	11	21	22	20
Current submission (2015 NIR)	kt	7.2	3.9	12	12	21	21	19
Total change	kt	**0.1**	**0.0**	**0.2**	**0.2**	**-0.3**	**-0.2**	**-0.6**
	%	**1%**	**1%**	**2%**	**2%**	**-1%**	**-0.8%**	**-3%**
Change due to continuous improvement or refinement	kt	0.1	0.04	0.2	0.2	-0.3	-0.2	-0.6
	%	1%	1%	2%	2%	-1%	-0.8%	-3%

Notes:

1. Totals may not add up due to rounding. Annex 9 describes the rounding protocol.

2. Recalculations other than total change and those due to new GWPs are calculated using new GWP values.

3. Change due to new GWPs is calculated using estimates from 2014 NIR converted to both old and new GWP values.

4. Change due to updated inputs to HWP from forest harvest and deforestion is displayed as a memo item in CO_2 units due to its indirect impact on Forest and Forest Conversion estimates.

 C = Confidential.

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carried over to the LULUCF Sector totals, which vary between net emissions and net removals, depending on the net flux from managed forests.

The Cropland category displays a steady trend towards decreasing emissions in the period 1990–2006, from emissions of 10 Mt in 1990 to net removals of 9.6 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 7.4 Mt in 2013, 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 1990–2013, net fluxes in the Wetlands category (peat extraction and flooded lands) fluctuate between 3.6 Mt and 6.2 Mt. Emissions from flooded lands 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 1.3 Mt.

Net emissions reported in the Settlements category fluctuate between 3.5 Mt (1996 and 1997) and 4.6 Mt (2007), mainly driven by trends in emissions from conversion from forested land, resulting in emissions of 6.8 Mt in 2013. Steady removals of an average of 2.5 Mt from the growth of urban trees offset these emissions by an average of 40% throughout the reporting period.

Emissions from the Harvested Wood Products category, reported for the first time in this submission, vary over the 1990–2013 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 harvests prior to 1990 are disposed of during the reporting period. As a result, emissions fluctuate between 134 Mt in 2009 (lowest harvest year) and 168 Mt in 2000 (one of the peak harvest years).

Expert Review Teams (ERTs) that examined Canada's previous inventory submissions have made various recommendations for the LULUCF Sector. Table 6–2 and Table 6–3 refer to recommendations that have been addressed in this submission. Some changes have been incorporated into this submission in response to the recommendations of the ERTs that reviewed Canada's 2014 submission, though the review report was not yet available at the time this submission was prepared.

This year's submission includes important recalculations (Table 6–2) due to the use of new GWPs and to several changes to forest-related estimates, including updated slash burning and harvest activity data and, most notably,

a change in the estimation approach and the allocation of emissions from HWP from forest harvest and forest conversion. Emissions from HWP are reported in this submission as a new category (4.G) in accordance with the new United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines on annual inventories. Recalculations in other categories include the integration of new Cropland area estimates based on Earth Observation (EO) methodologies, inclusion of a new source of emissions from the decay of off-site peat, and implementation of a new approach to estimate carbon sequestration by urban trees (Table 6–3). The cumulative impact of these recalculations resulted in an increase in the calculated sink for 1990 of 16 Mt, a decrease in the calculated source in 2005 of 37 Mt and an increase in the calculated source in 2012 of 19 Mt.

The LULUCF Sector uses a decentralized system for Forest Land and Cropland estimates coordinated within Canada's national multidisciplinary framework for monitoring, accounting and reporting emissions and removals in managed lands. A framework has been established for coordinating, planning and integrating the activities of many groups of scientists and experts across several government levels and research institutions.

Planned improvements include continued work on the HWP model structure, in particular including the fate of HWP in solid waste disposal sites and improving the integration of residential firewood consumption, completion of uncertainty estimates in all LULUCF categories, and quantification of missing land use and land-use change categories.

The remainder of this chapter provides detail on each LULUCF Sector category. Section 6.2 gives an overview of the representation of managed lands; each subsequent section provides a short description of a land category (Sections 6.3–6.7). Section 6.8 is devoted to the cross-category estimates of forest conversion to other lands, and Section 6.9 describes the new Harvested Wood Products category.

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 Convention.

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

Table 6–3   Summary of Changes in the LULUCF Sector

List of Changes	Change Category	Years Affected
Forest Land		
Ontario wildfire area revisions	Continuous improvement	Complete time series
Revisions to slash burning activity data	Continuous improvement	Complete time series
Revisions to official harvest activity data	Continuous improvement	2008–2012
Removal of emissions from harvested wood products[1]	2006 IPCC Guidelines	Complete time series
Cropland		
Integration of Earth Observation data	Continuous Improvement	Complete time series
Removal of emissions from liming[2]	2006 IPCC Guidelines	Complete time series
Reporting of carbon stock changes in areas previously reported as confidential	Expert Review Team Recommendation[3]	Complete time series
Removal of emissions from harvested wood products[1]	2006 IPCC Guidelines	Complete time series
Wetlands		
Inclusion of emissions from decay of off-site peat	2006 IPCC Guidelines	Complete time series
Removal of emissions from harvested wood products[1]	2006 IPCC Guidelines	Complete time series
Settlements		
Implementation of new Tier 2 approach for urban trees based on Earth Observation data	2006 IPCC Guidelines	Complete time series
Removal of emissions from harvested wood products[1]	2006 IPCC Guidelines	Complete time series
Harvested Wood Products		
New harvested wood products in-use pool	2006 IPCC Guidelines	Complete time series

Notes:

1. Emissions from wood products obtained from harvesting and forest conversion are now reported under the LULUCF category Harvested Wood Products.

2. Emissions from liming are now reported in the Agriculture Sector.

3. Recommendation in the 2013 Annual Inventory Review Report to provide information on carbon stock changes associated with Forest Land and Grassland conversion to Cropland in areas reported as confidential.

Canadian forests are under the direct influence of human activities, prompting the non-trivial question of what areas properly embody the "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: 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 un-managed 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 in Forest Land, Cropland or agricultural Grasslands categories. Currently, managed lands included in the Wetlands category are those where human interventions have directly altered the water table—which include peatlands drained for peat extraction and flooded lands (hydroelectric reservoirs) (IPCC 2006).

The Settlements category includes all built-up land: urban, rural residential, land devoted to industrial and recreational use; roads, rights-of-way and other transportation infrastructure; and resource exploration, extraction and distribution (mining, oil and gas). The diversity of this category has so far precluded a complete assessment of its extent in the Canadian landscape. However, the conversion of Forest Land and un-managed 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

Table 6–4 Land Use and Land-use Change Matrix for the 2013 Inventory Year (Areas in kha)[1]

		Final Land Use					
		Forest Land	**Cropland**	**Grassland**	**Wetlands**	**Settlements**	**Other**
Initial Land Use	**Forest Land**	231 645	405	NO	49	514	NO
	Cropland	63	49 803	NO	NE	NE	NO
	Grassland	NO	27	7166[2]	NE	1	NO
	Wetlands	NO	NE	NO	417[3]	NE	NE
	Settlements	NO	NE	NO	NO	442[3]	NO
	Other	NO	NO	NO	53	NE	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.

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.

Table 6–4 illustrates the land-use areas (diagonal cells) and cumulative land-use change areas (non-diagonal cells) in 2013. 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 un-managed tundra to Settlements in northern Canada. Column totals equal the total land area as reported in the CRF for each category. The full time series of the land use and land-use change matrix is available in Table 4.1 of the CRF series.

The LULUCF land monitoring system includes the conversion of un-managed forests and grassland to other land categories. Un-managed land converted to any use always becomes "managed"; once land has become managed, it does not revert to "un-managed" status, even if management practices are discontinued. Parks and protected areas are included in managed lands.

The LULUCF estimates as reported in the CRF tables are spatially attached to "reporting zones" (Figure 6–1). These reporting zones are essentially the same as Canada's terrestrial ecozones (Marshall and Shut 1999), with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairies ecozone is divided into a semi-arid and a subhumid component. Estimates are reported for 17 of the 18 reporting zones, leaving out the northernmost ecozone of Canada: the Arctic Cordillera, where no direct human-induced GHG emissions and removals are detected for this sector. More details on the spatial estimation and reporting framework can be found in Annex 3.5.

The areas reported in the CRF tables represent those used for annual estimate development, but not always the total land area under a land category or subcategory in a specific inventory year. Hence areas of land converted to flooded land (reservoirs) represent a fraction of total reservoir areas (those flooded for 10 years or less), not the total area of reservoirs in Canada.

Similarly, the areas of land conversion reported in the CRF tables refer to the cumulative total land area converted over the last 20 years (10 years for reservoirs) and 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

Forest and other wooded lands cover 388 million hectares (Mha) of Canadian territory; forest lands alone occupy 348 Mha (NRCan 2013). Managed forests, those under direct human influence, extend to 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 (Table 6–5).

In 2013, the net GHG balance of managed Forest Land amounted to removals of 162 Mt (Table 6–1 and CRF Table 4). This estimate includes net emissions and removals of CO_2, as well as N_2O, CO and CH_4 emissions from slash burning and wildfires. For the purpose of UNFCCC reporting, managed forest lands are divided into the subcategories Forest Land remaining Forest Land (232 Mha, net removals of 161 Mt) and Land converted to Forest Land (0.06 Mha, net removals of 0.59 Mt) in 2013.

Figure 6–1   Reporting Zones for LULUCF Estimates

Reporting Zones

1	Arctic Cordillera	10	Boreal Plain
2	Northern Arctic	11	Subhumid Prairies
3	Southern Arctic	12	Semiarid Prairies
4	Taiga Shield East	13	Taiga Plain
5	Boreal Shield East	14	Montane Cordillera
6	Atlantic Maritime	15	Pacific Maritime
7	Mixedwood Plain	16	Boreal Cordillera
8	Hudson Plain	17	Taiga Cordillera
9	Boreal Shield West	18	Taiga Shield West

6.3.1. Forest Land Remaining Forest Land

6.3.1.1. Methodological Issues

Vegetation absorbs CO_2 from the atmosphere through photosynthesis, and some of this carbon is sequestered in standing vegetation (biomass), dead organic matter and soils. Carbon dioxide is returned to the atmosphere by vegetation respiration and the decay, through heterotrophic respiration, of organic matter. The natural CO_2 exchanges between the atmosphere and biota are large fluxes, globally recycling on the order of one seventh of the total atmospheric CO_2 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 immediate 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 complex scientific inquiries.

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 (NFCMARS – Kurz and Apps 2006) includes a model-based approach (Carbon Budget Model of the Canadian Forest Sector, CBM-CFS3 – Kull et al. 2011; 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_2 emissions

and removals. The model uses regional ecological and climate parameters to simulate carbon transfers among pools, to the forest product sector and to the atmosphere. The conceptual approach remains that recommended by the IPCC (IPCC 2006), in which net removals or emissions are calculated as the difference between CO_2 uptake by growing trees and emissions from forest management activities (harvesting), heterotrophic respiration and natural disturbances. The interested reader will find additional information on estimation methodology 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 7 to 10 Mt, corresponding largely to differences in the total areas subject to this forestry management practice (from 70 kha in 1990 to 80 kha in 1991). 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 the forest products sector and the associated CO_2 emissions from the manufacturing, use and disposal of wood products are reported in the Harvested Wood Products category (Section 6.9).

Much of the interannual variability of the GHG budget of managed forests hinges on the occurrence, location and severity of fires. During the 1990–2013 period, immediate emissions from wildfire fluctuated between 11 and 280 Mt. The consumption of dead organic matter (DOM) by fires accounts for 77% 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 dead wood and litter on the forest floor. On average, 8% of immediate fire

Figure 6–2   Areas Disturbed and Emissions/Removals in Forest Land Remaining Forest Land
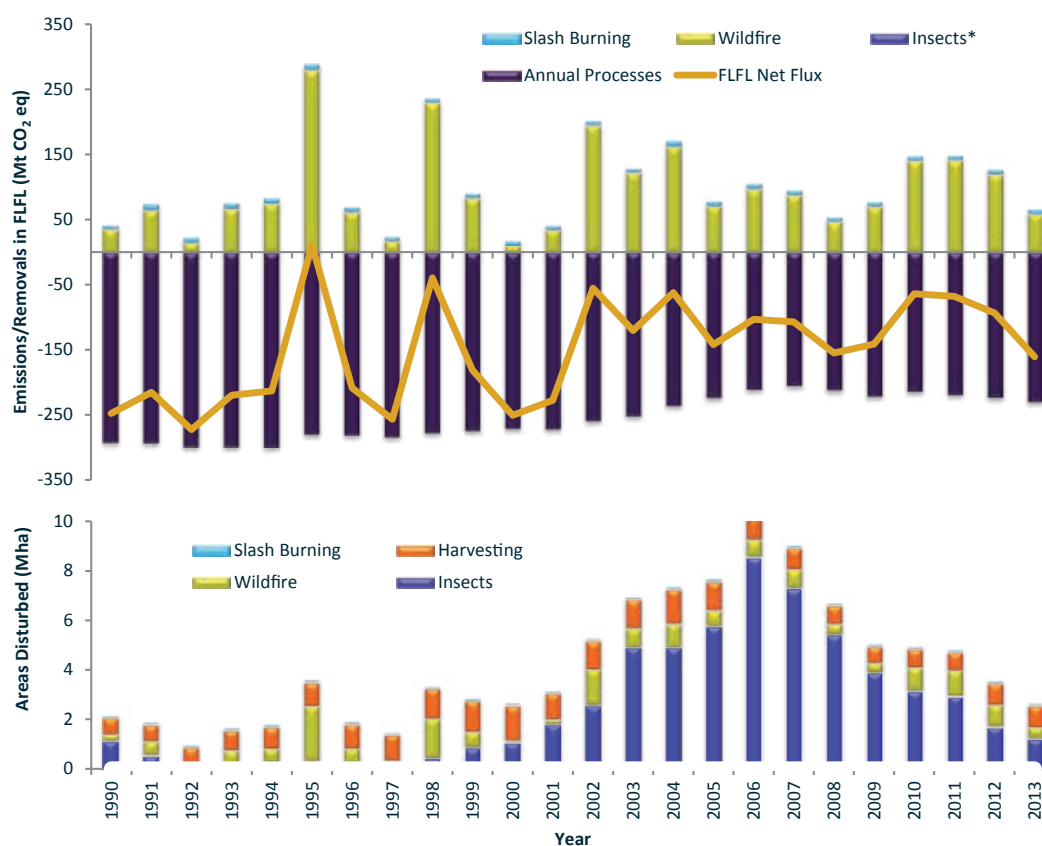
* Insect epidemics cause minimal immediate emissions; however, their influence on the net flux of managed forests, due to tree mortality and DOM decay, can be seen in the Annual Processes component.

emissions in CO_2 equivalents are in the form of CO, 8% in the form of CH_4, and 4% in the form of N_2O.

Over the last decade, insect epidemics have affected a total of over 45 Mha[2] of managed forests, with 82% being located in the Montane Cordillera reporting zone and corresponding to the epidemics of Mountain Pine Beetle. 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 its release due to the decay of organic matter through heterotrophic respiration (-3000 and 2700 Mt, respectively, in 2013). 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.

2   May include areas repeatedly infested, e.g., a hectare infested in three successive years is counted as three hectares towards the 45 Mha.

The managed forest GHG balance is not spatially homogeneous. In 2013, managed forests were net sources in the Taiga Shield East and Montane Cordillera 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 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 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. In order to avoid double counting, estimates of C stock changes in CRF Table 4.A exclude carbon emissions emitted as CO_2, CH_4 and CO due to biomass burning, which are reported in Table 4(V). Emissions and removals are automatically tallied in CRF Table 4.

Harvesting wood from managed forests results in a transfer of carbon from 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

Table 6–5   GHG Balance of Managed Forests by Reporting Zone, 2013[1]

Reporting Zone Number	Reporting Zone Name	Managed Forest Area (kha)	Net GHG Balance (kt CO_2 eq)	C Transfers to HWP (kt C)[2]
1	Arctic Cordillera	–	NA	NA
2	Northern Arctic	–	NA	NA
3	Southern Arctic	–	NA	NA
4	Taiga Shield East	1 100	2 100	1
5	Boreal Shield East	56 000	-55 000	7 900
6	Atlantic Maritime	15 000	-23 000	5 300
7	Mixedwood Plains	2 700	-8 200	160
8	Hudson Plains	300	- 560	NA
9	Boreal Shield West	29 000	-13 000	1 800
10	Boreal Plains	38 000	-32 000	5 500
11	Subhumid Prairies	1 800	-1 300	230
12	Semiarid Prairies	40	- 22	0
13	Taiga Plains	21 000	-22 000	990
14	Montane Cordillera	36 000	23 000	11 000
15	Pacific Maritime	13 000	-14 000	5 800
16	Boreal Cordillera	17 000	-14 000	280
17	Taiga Cordillera	410	- 140	0
18	Taiga Shield West	1 800	-1 400	56
Canada Total		**230 000**	**-160 000**	**39 000**

Notes

1. Negative sign indicates removal of CO_2 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.

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-CFS3 (Metsaranta et al. 2014). 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.

Throughout the entire time series, the uncertainties about annual estimates are expressed as a 95% confidence interval, bound by 2.5th and 97.5th percentiles of the Monte Carlo run outputs. The uncertain range of the CO_2 estimates is 96 Mt in 1990, 108 Mt in 2005 and 101 Mt in 2013 (Table 6–6). On average, uncertainty was ±55 Mt of the median result from the Monte Carlo runs throughout the entire times. Non-CO_2 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_2 balance approaches neutrality. This does not represent varying uncertainty levels; it is an artefact of the combination of large fluxes cancelling each other while their respective uncertainties do not.

Probability distributions are asymmetrical around the net flux estimate. 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 uncertain 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),[3] which comprises information from provincial resource management agencies, compiled and updated by the Canadian Forest Service. Estimates of area burned for the period 2004–2013 were obtained from the National Burned Area Composite (NBAC).[4] 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 (2004–2013) 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

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[3] http://www.nrcan.gc.ca/node/13159

[4] http://www.nrcan.gc.ca/node/13159

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Table 6–6   Estimates of the Net Annual CO_2, CH_4 and N_2O Fluxes for Forest Land Remaining Forest land, with 2.5th and 97.5th Percentiles, for Selected Years

Gas	Inventory Year	Net Flux (Mt)	2.5th Percentile (Mt)	% Uncertainty (2.5th Percentile)	97.5th Percentile (Mt)	% Uncertainty (97.5th Percentile)
CO_2	1990	- 253	- 335	32	- 239	6
	2005	- 152	- 230	51	- 122	19
	2013	- 169	- 238	41	- 137	19
CH_4	1990	3.5	3.2	-9	5.2	48
	2005	6.5	5.5	-16	8.5	30
	2013	5.5	4.9	-12	7.2	31
N_2O	1990	1.7	1.6	-7	2.6	47
	2005	3.3	2.8	-14	4.3	32
	2013	2.8	2.5	-10	3.6	29

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 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 bias in total ecosystem stocks between model predictions and ground plot measurements was 1%. The contribution of aboveground biomass and deadwood to the error in ecosystem subtotal pools was small. However, the contribution from soils was large. Results from this research indicate that there are important pool-, region- and species-specific variations that require further study.

6.3.1.4.   Recalculations

In previous submissions, in accordance with the default IPCC methodology (IPCC 2003), carbon in harvested wood was deemed as an immediate emission from managed forests, irrespective of use. With the implementation of the 2006 IPCC Guidelines in this submission, the transfer of carbon in harvested wood out of managed forests to wood products are now considered, and emissions from the use and eventual disposal of these products are reported under the new Harvested Wood Products category (Section 6.9, Harvested Wood Products). As a result of the removal of immediate emissions from harvested wood, the net GHG flux from managed forests was recalculated downwards across the time series, ranging from 107 Mt in 2007 to 187 Mt in 2005 (Figure 6–3). This resulted in a switch from net emissions to net removals in several years, except 1995, an extremely bad fire year.

Updates in harvest statistics from 2008–2012 also resulted in recalculations in which the amount of carbon harvested increased by as much as 13% in 2012 (4.5 Mt C) (Figure 6–3). The largest recalculation occurred in 2012 as harvest rates in Quebec were revised upwards for that year.

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Figure 6–3   Recalculations in Forest Land Remaining Forest Land (FLFL)
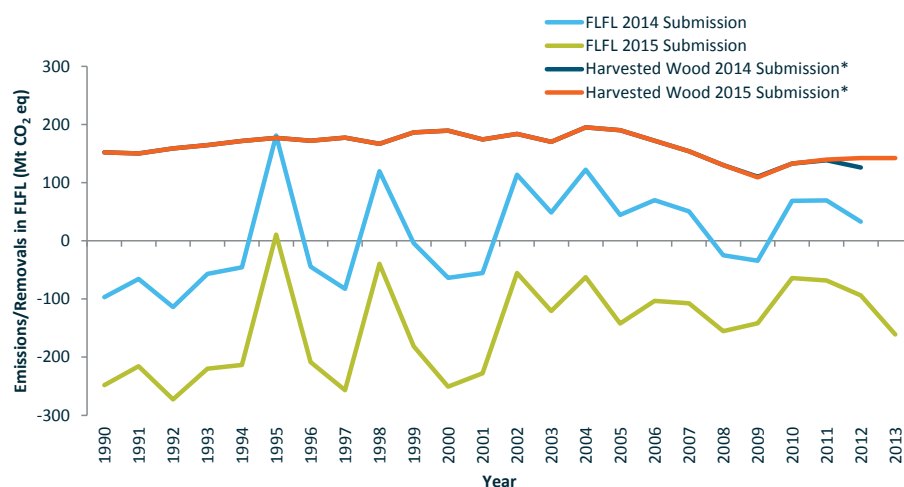
* Harvested Wood lines represent C harvested from managed forests that was reported as instant oxidation in the 2014 submission and is now transferred to HWP category for the 2015 submission

Recalculations also occurred in immediate emissions from wildfire, which ranged from -5 Mt in 2007 to 14 Mt in 2002 (representing an 8% change for 2002, a large fire year). This was due to the random selection of forest stands chosen to burn by the CBM within each spatial unit, and to a lesser extent, to revisions to areas burned in Ontario as a result of activity data updates. Wildfire recalculations did not significantly affect the overall trend in managed forests.

Finally, burning of post-harvest residues or "slash burning"the most recent. Recalculations in emissions associated with these corrections were less than 1 Mt (10%) for all years.

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. The methodology used in the production of uncertainty estimates for forest fluxes will be re-examined before the next NIR submission.

6.3.2.   Land Converted to Forest Land

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 63 kha in 2013. 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. Eightythree 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) and only 10% in the Prairie provinces (Boreal Shield West, Boreal Plains and Subhumid Prairies reporting zones).

Net removals declined throughout the period, from 1.0 Mt in 1990 to 0.6 Mt in 2013. Net carbon accumulation largely occurs in biomass (140 Gg C in 2013 – 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 this 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 2009–2013 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 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.

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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. Cropland

Cropland covers approximately 50 Mha of the Canadian territory. In 2013, the net GHG balance in the Cropland category amounted to removals of 7.4 Mt CO_2 eq (Table 6–1 and CRF Table 4). For the purpose of reporting under the UNFCCC, Cropland is divided into Cropland remaining Cropland (net removals of 11 Mt CO_2 eq in 2013) and Land (either forest or grassland) converted to Cropland (net emissions of 3.7 Mt CO_2 eq and 0.021 Mt CO_2 eq, respectively, in 2013). The estimates in Land converted to Cropland include net emissions and removals of CO_2, as well as N_2O and CH_4 emissions.

6.4.1. Cropland Remaining Cropland

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_2 emissions/removals in mineral soils, CO_2 emissions from cultivation of organic soils, and CO_2 emissions/removals resulting from changes in woody biomass from specialty crops. An enhanced Tier 2 approach is used for estimating CO_2 emissions from and removals by mineral soils triggered by changes in land management practices.

6.4.1.1. CO_2 Emissions and Removals in Mineral Soils

Mineral soils constitute the majority of Cropland areas (> 99%). The amount of organic carbon retained in these soils is a function of 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_2 emission to or removal from the atmosphere.

In 1990, changes in mineral soil management amounted to a net CO_2 emission of about 0.15 Mt CO_2 eq (Table 6–7). This small source steadily increased to a removal of 14 Mt CO_2 eq in 2006, and subsequently gradually decreased to 11 Mt CO_2 eq in 2013. 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

Table 6–7 **Base and Recent Year Emissions and Removals Associated with Various Land Management Changes on Cropland Remaining Cropland**

Categories	Land Management Change (LMC)	Emissions/Removals (Gg CO_2)[1]							
		1990	2000	2005	2009	2010	2011	2012	2013
Total Cropland remaining Cropland		480	-7 300	-13 000	-13 000	-12 000	-12 000	-11 000	-11 000
Cultivation of Histosols		300	300	300	300	300	300	300	300
Perennial woody crops		31	60	2	- 15	- 26	- 20	- 43	- 58
Total mineral soils		150	-7 700	-13 000	-13 000	-12 000	-12 000	-12 000	-11 000
Change in crop mixture	Increase in perennial	-3 600	-8 000	-12 000	-13 000	-13 000	-13 000	-13 000	-13 000
	Increase in annual	7 000	7 900	8 200	9 900	10 000	11 000	12 000	12 000
Change in tillage	Conventional to reduced	- 910	-1 100	-1 000	- 930	- 900	- 860	- 830	- 800
	Conventional to no-till	- 440	-2 600	-3 400	-3 600	-3 600	-3 600	-3 600	-3 800
	Other	0	- 290	- 830	- 960	- 960	- 960	- 960	- 950
Change in summerfallow (SF)	Increase in SF	2 300	2 100	1 900	1 700	1 700	1 700	1 600	1 600
	Decrease in SF	-4 400	-7 100	-7 700	-8 200	-8 400	-8 500	-8 700	-8 800
Land conversion—Residual emissions[2]		170	1 400	1 800	1 900	1 900	1 900	1 900	1 900

Notes:

1. Negative sign indicates removal of CO_2 from the atmosphere.

2. Net residual CO_2 emissions from the conversion of Forest Land and Grassland to Cropland that occurred more than 20 years prior to the inventory year, including emissions from the decay of woody biomass and DOM.

NO = Not occurring.

have tended to stabilize as the adoption of conservation tillage and the decrease in summerfallow have levelled off and the soil sink has approached a steady-state. Higher emissions due to an increasing proportion of annual crops in the crop mixture also contribute to the stabilization of the net soil sink by partially offsetting soil carbon gains. The area of summerfallow declined by 79% from 1990 to 2013, resulting in a net sink that increased from 2.0 Mt CO_2 eq in 1990 to 7.2 Mt CO_2 eq in 2013. The increase in net sink due to the adoption of conservation tillage practices (from 1.4 Mt CO_2 eq in 1990 to 5.5 Mt CO_2 eq in 2013) is substantiated by a net increase of 13 Mha in areas under no-till and reduced tillage over the 1990–2013 period. The net change in crop mixture resulted in a change from a source of 3.4 Mt CO_2 eq in 1990 to a sink of 0.5 Mt CO_2 eq in 2013.

The net increase since 1990 in the sink arising from changes in management practices was partially offset by an increase in net residual CO_2 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 reestablishment of perennial vegetation (Janzen et al. 1997; Bruce et al. 1999). Other land management changes, such as changes in irrigation, manure application and fertilization, are also known to have positive impacts on SOC. Lack of activity data for these land management changes (LMCs) associated with specific crops prevented their

inclusion in the inventory at this time. Estimates of CO_2 changes in mineral soils were derived from the following LMCs:

- change in the proportion of annual and perennial crops;
- change in tillage practices; and
- change in area of summerfallow.

Carbon emissions and removals were estimated by applying country-specific carbon emission and removal factors multiplied by the relevant area of land that underwent a management change. Calculations were performed at 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_2 emissions/removals by mineral soils undergoing a specific LMC are expressed as:

Equation 6–1:

$$\Delta C = F \times A$$

where:

ΔC	=	change in soil carbon stock, Mg C
F	=	average change in SOC subject to LMC, Mg C/ha
A	=	area of LMC, ha

In reality, 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 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 3393 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, 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_2 emissions or removals involve estimates of uncertainties for area and carbon factors of management changes for fallow, tillage and annual/perennial crops (McConkey et al. 2007).

The uncertainty about the area in a management practice for an ecodistrict varied inversely with the relative proportion it occupied 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.[5]

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. More details about estimating process and situational uncertainties are presented in Annex 3.5. Uncertainty estimates associated with emissions/removals of CO_2 from mineral soils were developed by McConkey et al. (2007), who reported uncertainty values at ±19% for the level and ±27% for the trend. These uncertainty estimates have not been updated since the 2011 annual submission. With the major changes in agricultural activity data from the incorporation of EO data, uncertainty estimates for Cropland remaining Cropland need to be updated.

Consistency in the CO_2 estimates is ensured through the use of the same methodology for the entire time series of estimates (1990–2013).

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 Canada, while maintaining its own QA/QC procedures for estimates developed internally (see Section 1.3, Chapter 1), has implemented additional QC checks for estimates obtained from partners, as well as for all estimates and activity data contained in its LULUCF data warehouse and entered into the CRF reporter. In addition, the activity data, methodologies and changes are documented and archived in both paper and electronic form.

Carbon change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). The comparison showed that empirical data on changes in SOC in response to no tillage were highly variable, particularly for eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. For the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, and this compared favourably with the range of 0.46–0.56 Mg C/ha per year in the modelled factors in western Canadian soil zones. For eastern Canada, only two empirical change factors were available, but they fell within the range of the modelled values (0.60–1.07 Mg C/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled). For conversion of crop fallow to continuous cropping, the modelled rate of carbon storage obtained (0.33 Mg C/ha per year) was more than twice the average rate of 0.15 ± 0.06 Mg C/ha per year derived from two independent assessments of the literature. This difference led to the decision to use empirically based factors for changes in 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, a major improvement was made through the incorporation of Cropland activity data based on land-use mapping for agricultural regions derived from EO information. A series of land-use maps were generated for 1990, 2000 and 2010 using several spatial data sets which were integrated using rule sets. The resulting maps grouped 30-metre pixels into seven primary land use categories: cropland, grassland, forest, settlement, wetland,

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5   T. Huffman, Agriculture and Agri-Food Canada, personal communication to Brian McConkey, 2007.

water and other land. The map-based data were then aggregated to cropland SLC polygons. The Census of Agriculture provided apportioning ratios for cropland area attributes which could be applied to the map-based cropland area estimates at the scale of SLC polygons. As a result of this improvement, estimates of Cropland areas and the distribution of these areas on the landscape, along with their attributes, changed (tillage practices, summerfallow, and perennial and annual crop conversion). Overall, an increase in the total Cropland area of 0.14 Mha in 1990, 2.9 Mha in 2005, and 3.4 Mha in 2012 was observed. The change in cropland attributes resulted in significant recalculations, with an increase in emissions of 2.2 Mt CO_2 eq in 1990, and an increase in removals of 2.6 Mt CO_2 eq in 2005 and 0.6 Mt CO_2 eq in 2012.

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.

6.4.1.2. CO_2 Emissions from Cultivation of Organic Soils

Category Description

In Canada, cultivated organic soils are defined as the conversion of organic soils to agriculture for annual crop production, normally accompanied by artificial drainage, cultivation and liming. Organic soils used for agricultural production in Canada include the Peaty Phase of Gleysolic soils, 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 1990–2013) was estimated to be 16 kha, or 0.03% of the Cropland area. Close to 90% of the area of cultivated histosols is located in the Boreal Shield East, Mixedwood Plains and Boreal Plains reporting zones.

Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties from the area estimates for the cultivated histosols and the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols are assessed to be ±50% (Hutchinson et al. 2007). The 95%

confidence limits of the default emission factor are ±90% (IPCC 2006). The overall mean and uncertainties associated with this source of emissions were estimated to be 0.3 ± 0.09 Mt CO_2 eq for the level uncertainty and 0 ± 0.13 Mt CO_2 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 (1990–2013).

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 aimed at improving emission estimates for this source.

6.4.1.3. CO_2 Emissions and Removals in Woody Biomass

Category Description

Perennial woody biomass currently includes vineyards, fruit orchards and Christmas tree farms. It also accumulates on abandoned cropland allowed to revert to natural vegetation. In the definitional framework adopted in Canada for LULUCF reporting, abandoned cropland is still considered Cropland until there is evidence of a new land use; however, there is little information on the dynamics of cropland abandonment or recultivation. Owing to these data limitations, only vineyards, fruit orchards and Christmas trees are considered; for the time being changes in woody biomass from "abandoned cropland" on Cropland remaining Cropland are excluded.

Methodological Issues

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yields. Vineyards and fruit trees are pruned annually, and old plants are replaced on a rotating basis for disease prevention, stock improvement or introduction of new varieties. For all three crops, it is assumed that, because of rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass carbon within existing farms, as carbon lost from harvest or replacement would be balanced by gains due to new plant growth. The approach therefore was limited to detecting changes in areas under vineyards, fruit orchards and

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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 about mass of woody biomass carbon. The default uncertainty of ±75% (i.e. 95% confidence limits) for woody biomass on Cropland from the 2006 IPCC Guidelines was used.

If the loss in area of fruit trees, vineyards or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial to annual crop conversion with associated uncertainty that contributes to carbon change uncertainty. For area of gain in fruit trees, vineyards or Christmas trees, the uncertainty in annual carbon change was also assumed to be the default uncertainty of ±75% (i.e. 95% confidence limits) (IPCC 2006).

The overall mean and uncertainties associated with emissions or removals of CO_2 from woody specialty crops were estimated to be -58 ± 6 kt CO_2 eq for the level uncertainty and -89 ± 130 kt CO_2 eq for the trend uncertainty (McConkey et al. 2007).

The same methodology was used for the entire time series of emission estimates (1990–2013).

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

Because of the incorporation of EO data, the total area of Christmas tree farms, vineyards and fruit orchards increased by 14 kha in 1990, 14 kha in 2005, and 18 kha in 2012. As a result of this recalculation, there was a small increase in removals of 25 kt CO_2 eq in 1990, 38 kt CO_2 eq in 2005, and 31 kt CO_2 eq in 2012.

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.

6.4.2. Land Converted to Cropland

This subcategory includes the conversion of Forest Land and Grassland to Cropland. Emissions from the conversion of Forest Land to Cropland account for nearly 100% of the total emissions in this category, which have decreased from 9.6 Mt CO_2 eq in

1990 to 3.7 Mt CO_2 eq in 2013. Emissions from the conversion of Grassland are relatively insignificant.

6.4.2.1. Forest Land Converted to Cropland

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 41% of forest area conversion in 2013). 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 405 kha over the 20 years prior to 2013. 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 6.8, Forest Conversion. In 2013, immediate emissions from this year's forest conversion accounted for 1.5 Mt CO_2 eq, or 27% of all emissions from Forest Land converted to Cropland, while residual emissions from events that occurred in the last 20 years accounted for the remaining 4 Mt CO_2 eq. Nearly 95% 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 was 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_2 source from change in management practices in the 20 years following conversion, and the N_2O emissions from the decay of soil organic matter. The soil emissions from Forest Land converted to Cropland were calculated by multiplying the total area of conversion by the empirically derived emission factor along with modelling-based SOC dynamics (see Annex 3.5). As explained below, patterns of change in SOC after the conversion of Forest Land to Cropland clearly differ between eastern and western Canada.

Eastern Canada

All agricultural land in the eastern part of the country was forested before its conversion to agriculture. Many observations, either in the scientific literature or the Canadian Soil Information System, of forest SOC comparisons with adjacent agricultural land in eastern Canada show a mean loss of carbon of 20% at depths to approximately 20–40 cm (see Annex 3.5). Average

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nitrogen change was −5.2%, equivalent to a loss of approximately 0.4 Mg N/ha. For those comparisons where both nitrogen and carbon losses were determined, the corresponding carbon loss was 19.9 Mg C/ha. Therefore, it was assumed that nitrogen loss was a constant 2% of carbon 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 carbon loss and its rate constant associated with the conversion of Forest Land can be found in Annex 3.5.

Following a Tier 2–type methodology, as was done for direct N_2O emissions from agricultural soils (see Agriculture Sector, Chapter 5), emissions of N_2O from Forest Land conversion to Cropland were estimated by multiplying the amount of carbon loss by the fraction of nitrogen loss per unit of carbon and by an emission factor (EF_{BASE}). EF_{BASE} was determined for each ecodistrict based on topographic and climate conditions (see Annex 3.4).

Western Canada

Much of the current agricultural land in western Canada (Prairies and British Columbia) was grassland in the native condition. Hence, Forest Land converted to Cropland has been primarily of forest that lies on the fringe of former grassland areas.

The Canadian Soil Information System (CanSIS) represents the best available data source for SOC under forest and agriculture. On average, these data suggest that there is no loss of SOC from forest conversion and that, in the long term, the balance between carbon 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 carbon 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 nitrogen change in western Canada for sites at least 50 years from breaking was +52% (see Annex 3.5), reflecting substantial added nitrogen in agricultural systems compared with forest management practices. However, recognizing the uncertainty about actual carbon-nitrogen dynamics for forest conversion, loss of Forest Land to Cropland in western Canada was assumed not to be a source of N_2O.

Uncertainties and Time-Series Consistency

Greenhouse gas fluxes from Forest Land converted to Cropland result from the combination of (i) logging and burning—

Table 6–8   Uncertainty about CO_2 Emission Components and Non-CO_2 Emissions from Forest Land Converted to Cropland for the 2013 Inventory Year

Emission Components	Emissions (kt CO_2 eq)	Uncertainty (kt CO_2 eq)
Immediate CO_2 emissions	1 322	±925
Residual CO_2 emissions from the DOM pool	1 861	±465
Residual CO_2 emissions from the soil pool	311	±190
CH_4 emissions	125	±36
N_2O emissions	73	±26

immediate emissions from biomass and dead organic matter; (ii) organic matter decay and subsequent CO_2 emissions in the DOM pool; and (iii) net carbon losses from SOC. Note that immediate CO_2 emissions always refer to area converted in the inventory year; residual emissions, while also occurring on land converted during the inventory year, mostly come from land converted over the last 20 years. Non-CO_2 emissions are produced only by burning, and occur during the conversion process.

Immediate and residual CO_2 emissions from the biomass and DOM pools represent the largest components of this category, and contribute the most to the category uncertainty (Table 6–8). 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 6.8.2 was incorporated in all analyses.

The fate of biomass and DOM upon forest conversion and the ensuing emissions are modelled in 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. The Monte Carlo analysis was carried out 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_2 flux from the soil pool was estimated analytically (McConkey et al. 2007). More information on the general approach used to conduct this analysis is provided in Annex 3.5.2.4.

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.

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The activity data, methodologies and changes to methodologies are documented and archived in both paper and electronic form.

Recalculations

There was a small increase in the area of Forest Land conversion to Cropland due to the addition of areas previously excluded in accordance with Statistics Canada confidentiality restrictions under the Statistics Act. In response to previous ERT comments, these areas and related carbon stock changes are reported in CRF Table 4.B of this submission, but added to a neighbouring reporting zone. Recalculations in the emissions were due to the removal of carbon transferred to HWP resulting from this conversion that was reported as immediate CO_2 emissions in previous submissions and is now reported as carbon input to the HWP in-use pool (see Section 6.9). These changes led to downward recalculations of 3.8 Mt CO_2 eq in 1990, 1.8 Mt CO_2 eq in 2005, and 1.9 Mt CO_2 eq in 2012.

Planned Improvements

Planned improvements described under Section 6.8, Forest Conversion, will also affect this category.

6.4.2.2.   Grassland Converted to Cropland

Conversion of native grassland to Cropland occurs in the Prairie region of the country and generally results in losses of SOC and soil organic nitrogen and emissions of CO_2 and N_2O to the atmosphere. Carbon losses from the above-ground or below-ground biomass or DOM upon conversion are insignificant, based on findings from a recent work by Bailey and Liang (2013) on burning of managed grassland in Canada, who reported that the average above-ground biomass was 1100 kg ha^{-1} in the Brown Chernozem, and 1700 kg ha^{-1} in the Dark Brown Chernozem. The above-ground biomass for the managed grassland would be lower than its respective yield under crop production (Liang et al. 2005). Total emissions in 2013 from soils amounted to 21 kt CO_2 eq, including carbon losses and N_2O emissions from the conversion.

Methodological Issues

A number of studies on changes of SOC and soil organic nitrogen 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 nitrogen was 0.06 kg N lost/kg C (see Annex 3.5).

The CENTURY model (Version 4.0) is used to estimate the SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils. More details of methodologies for determining the maximal carbon loss and its rate constant associated with the breaking of grassland can be found in Annex 3.5.

Similar to N_2O emissions in Forest Land converted to Cropland, emissions of N_2O in Grassland converted to Cropland were estimated by a Tier 2 methodology, multiplying the amount of carbon loss by the fraction of nitrogen loss per unit of carbon by a base emission factor (EF_{BASE}). EF_{BASE} is determined for each ecodistrict based on climate and topographic characteristics (see Annex 3.4.3).

Uncertainty and Time-Series Consistency

The conversion from agricultural grassland to cropland occurs, but within the definitional framework for managed lands, the conversion to Grassland from Cropland cannot occur (see Section 6.2). Therefore, the uncertainty in absolute value of the area of this conversion cannot be larger than the uncertainty about the area of Cropland or Grassland. Hence, the uncertainty of the area of conversion was considered to be equivalent to the lower of the uncertainties of the area of either Cropland or Grassland in each ecodistrict. The uncertainty of SOC change was estimated as in Forest Land conversion to Cropland. The overall mean and uncertainty associated with emissions due to SOC losses from Grassland conversion to Cropland were estimated to be 21 ± 25 kt CO_2 eq for the level uncertainty, and -220 ± 150 kt CO_2 eq for the trend uncertainty.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2013).

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 incorporation of EO-based cropland and grassland areas increased the area of agriculturally managed Grassland converted to Cropland, resulting in upward adjustments in emissions of 180 kt CO_2 eq in 1990, 54 kt CO_2 eq in 2005, and 7 kt CO_2 eq in 2012.

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.

6.5.   Grassland

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: the natural shortgrass prairie in south-

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ern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. Agricultural grassland is found in three reporting zones: Semi-arid Prairies (7058 kha), Montane Cordillera (108 kha), and Pacific Maritime (64 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 either as not estimated (Wetlands converted to Grassland) or as not occurring (Table 6–4).

6.5.1. Grassland Remaining Grassland

6.5.1.1. Category Description

Managed grassland is sometimes burned in Canada naturally by lightning, by accidental ignition, as a management tool to control invasive plants and stimulate the growth of native species, or as part of military training exercises. Burning from managed grassland is a net source of CH_4, CO, NO_x and N_2O (IPCC 2006).

6.5.1.2. Methodological Issues

The emissions of CH_4 and N_2O from burning of managed agricultural grassland were estimated using the IPCC Tier 1 method by taking into consideration the area of burn, fuel load and combustion efficiency for each burning event. Emission factors of CH_4 (2.7 g CH_4 kg^{-1}dry matter burned and 0.07 g N_2O kg^{-1} dry matter burned) were taken from the 2006 IPCC Guidelines (IPCC 2006).

Activity data on area, fuel load and combustion efficiency for each burning event for managed agricultural grassland were collected through consultations (Bailey and Liang 2013).

6.5.1.3. Uncertainties and Time-Series Consistency

The uncertainty associated with emissions from this source is due to the uncertainties from the area estimate, average fuel load per hectare and combustion efficiency, along with emission factors. The 95% confidence limits associated with the amount of burned materials based on expert judgement are assessed to be ±50%. The 95% confidence limits of the default emission factors are ±40% for CH_4 and ±48% for N_2O (IPCC 2006). The overall uncertainties associated with this source of emissions using error propagation were estimated to be ±64% for CH_4, and ±69% for N_2O, respectively.

The same methodology and emission factors are used for the entire time series of emission estimates (1990–2013).

6.5.1.4. 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.

6.5.1.5. Recalculations

There was no change in activity data or in the method for emission estimates except for the update on the GWPs of CH_4 and N_2O.

6.5.1.6. Planned Improvements

There is no immediate plan in place to improve emission estimates for this source.

6.6. Wetlands

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 compliance with 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: peatlands drained for peat extraction; and 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.

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6.6.1. Peat Extraction

6.6.1.1. Source Category Description

Of the estimated 123 Mha of peatlands in Canada,[6] 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; 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 (Figure 6–4), from 2.7 Mt in 2000 to 2.3 Mt in 2013. Emissions from peat extraction are reported under

Land converted to Wetlands for the first 20 years after conversion and under Wetlands remaining Wetlands thereafter.

6.6.1.2. 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, CO_2 is the dominant GHG emitted from commercial peatlands and the only gas reported under this category. The main sources of emissions are the rapid oxidation of exposed peat, resulting in a threefold increase in CO_2 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.

6.6.1.3. 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.

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6   This area includes peatlands that would be classified as Forest, Cropland and Grassland in the IPCC land classification.

Figure 6–4   Managed for Peat Extraction and CO_2 Emissions from These Lands, 1990–2013 (LWL: Land Converted to Wetlands; WLWL: Wetlands Remaining Wetlands)
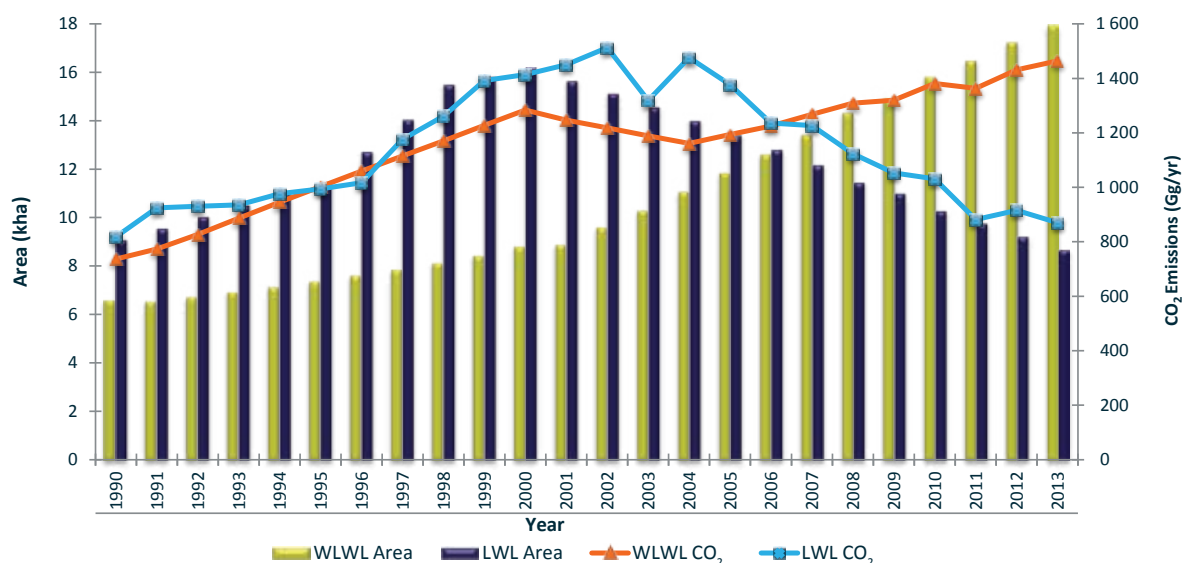
Spatially referenced information on the areas of peatlands managed for peat extraction is currently not available; these areas are therefore modelled using information provided by the industry.[7] Reliance on this data source introduces uncertainty into the activity data. In addition, the fate of abandoned 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.

6.6.1.4. QA/QC and Verification

Section 1.3 in Chapter 1 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well. Areas were derived in collaboration with the Canadian Sphagnum Peat Moss Association.

6.6.1.5. Recalculations

Updated peat production data for 2012 and new data for 2013 were incorporated into the modelled peat extraction areas. This change in activity data resulted in small recalculations across the time series, with an average annual decrease of 2 kt from 1990 to 2005 and an average annual increase of 5 kt from 2006 to 2012.

An error in the allocation of emissions from peat production fields and stockpiles to the subcategories Land converted to Wetlands and Wetlands remaining Wetlands was corrected. This resulted in recalculations for the individual Wetlands subcategories, but not for category totals.

The largest recalculation is due to the inclusion of CO_2 emissions from the decay of peat transported off-site for non-energy uses such as horticulture. A country-specific C fraction parameter (0.26 tonnes C/tonne air-dry peat) was developed from laboratory analysis of pure peat products. National peat production statistics were used to represent the annual amount of extracted peat.

Total recalculations range from an increase of 0.7 Mt (83%) in 1990 to 1.2 Mt (107%) in 2012.

6.6.1.6. 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).

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7   Gerry Hood, Canadian Sphagnum Peat Moss Association, personal communication to D. Blain, Environment Canada, 2006.

6.6.2.   Flooded Lands (Reservoirs)

This category includes in theory all lands that have been flooded regardless of purpose. Owing to methodological limitations, this submission includes only large hydroelectric reservoirs created by land flooding. Existing water bodies dammed for water control or energy generation were not considered if flooding was minimal (e.g. Manitoba's Lake Winnipeg, the Great Lakes).

Since 1970, land conversion to flooded lands occurred 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 2013. In 2013, 52% of the 90 kha of reservoirs flooded for 10 years or less were previously forested (mostly un-managed forests).

Total emissions from reservoirs declined from 4.4 Mt in 1990 to 1.3 Mt in 2013.

6.6.2.1. 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-CFS3 (refer to Section 6.8 below and Annex 3.5). Emissions from the burning and decay of all non-flooded dead organic matter are reported under Land converted to Wetlands for the first 10 years post-clearing and in Wetlands remaining Wetlands beyond this period. The construction of large reservoirs in northern Quebec (Toulnustuc, Eastmain1, Peribonka), whose impoundments were completed in 2005, 2006 and 2008, respectively, resulted in this type of forest clearing prior to flooding. Note that emissions from forest clearing in the general area surrounding future reservoirs (e.g. for infrastructure development) are reported under Forest Land converted to Settlements.

The second methodology is applied to estimate CO_2 emissions from the surface of reservoirs whose flooding has been completed. The default approach to estimate emissions from flooding assumes that all biomass carbon is emitted immediately (IPCC 2006). In the Canadian context, this approach would overestimate emissions from reservoir creation, since the largest proportion of any submerged vegetation does not decay for an extended period. A domestic approach was developed and used to estimate emissions from reservoirs based on measured CO_2 fluxes above reservoir surfaces from multiple research studies, consistent with the descriptions of IPCC Tier 2 methodology (IPCC 2006) and following the guidance in Appendix 2 of IPCC (2006). Annex 3.5 of this National Inventory Report contains more detail on this estimation methodology. The assessment includes CO_2 emissions only. Emissions from the surface of flooded lands are

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reported for a period of 10 years after flooding, in an attempt to minimize the potential double counting of dissolved organic carbon lost from the watershed and subsequently emitted from reservoirs. Therefore, only CO_2 emissions are calculated for hydro-electric reservoirs where flooding had been completed between 1981 and 2013.

For each reservoir, the proportion of pre-flooding area that was forest is used to apportion the resulting emissions to the subcategories Forest Land converted to Wetlands and Other Land converted to Wetlands.

It is important to note that fluctuations in the area of lands converted to flooded land (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but 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 the reservoir areas in Canada.

6.6.2.2. Uncertainties and Time-Series Consistency

For Forest Land converted to Wetlands, refer to the corresponding subheading in Section 6.8, 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 reporting zones 4 and 5. Much of the DOC in these zones originate from unmanaged lands, and are not a reporting requirement.

6.6.2.3. QA/QC and Verification

Section 1.3 in Chapter 1 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

For Forest Land converted to Wetlands, also refer to the corresponding subheading in Section 6.8, 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.

6.6.2.4. Recalculations

Recalculations in the flooded lands subcategory are mainly due to the removal of emissions from HWP resulting from forest conversion to flooded lands; such emissions were reported as immediate CO_2 emissions in previous submissions and are now reported as carbon input to the HWP in-use pool (see Section 6.9). These changes led to an average downward recalculation of 10 kt (less than 1% of the category total) for the 1990–2013 period.

Although activity data for flooded lands have not changed, there have been updates to activity data for slash burning and wildfire disturbances in the Forest Land category. These updates 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 (average increase of 3 kt or 0.12%).

6.6.2.5. Planned Improvements

Further refining estimates of CO_2 emissions from the surface of reservoirs will partly depend on the ability to quantify lateral transfers of dissolved carbon from watersheds to reservoir systems. The monitoring of dissolved organic carbon as it travels through the landscape to the point of emission or long-term storage is beyond current scientific capabilities, and will require long-term investments in research. Efforts to ensure activity data are updated and validated will continue on an ongoing basis.

6.7. Settlements

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 2013 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 2013, 515 kha of Lands converted to Settlements accounted for emissions of 7 Mt. Forest Land conversion to Settlements represents 98% of these emissions.

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6.7.1. Settlements Remaining Settlements

6.7.1.1. Source Category Description

This category includes estimates of carbon sequestration by urban trees in Canada. Estimates of CO_2 removals from tree growth on other Settlement subcategories outside of urban areas are not included. Total removals from urban tress were relatively stable throughout the time series at 2.5 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 (0.5 Mt) reporting zones, which together accounted for 66% of total removals.

6.7.1.2. Methodological Issues

The CO_2 removals from urban trees were estimated using a Tier 2A crown cover methodology from the 2006 IPCC Guidelines (IPCC 2006). Urban tree crown (UTC) cover estimates for 1990 and 2012 were developed for a significant portion of the total urban area using a point-based sampling approach. Sample points were interpreted manually and classed into broad categories of tree crown or non-crown, based on digital air photos or high resolution satellite imagery. The total crown cover area was then estimated using UTC and total urban area estimates, for each time period. The estimate of total crown cover area was then multiplied by a crown cover area growth rate (CRW) to yield an annual gross sequestration rate; net sequestration was estimated by applying a factor to the gross value. The net sequestration factor adjusted gross estimates to account for decomposition; the result was an estimate of the net annual carbon sequestration by urban trees. A Canadian-specific CRW value based on field data did not exist. A domestic CRW value (2.12 t C/ha) was therefore derived from data sets from the United States (Nowak et al. 2013) adjusting for Canada's shorter average growing season. The net carbon sequestration factor was estimated as 74% of the gross sequestration based on United States analysis (Nowak 2013). A more detailed description of this estimation methodology can be found in Annex 3.5.

6.7.1.3. 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 about the total urban area is estimated at 15% in 1990 and 10% in 2012. The uncertainty about the national scale gross carbon sequestration (16%) was estimated from uncertainty estimates associated with data for the United States. The total uncertainty associated with the estimates of the net CO_2 sequestration of urban trees is 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 (1990–2013).

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. They apply to this category as well.

Estimates of regional UTC values used were compared with published UTC values for Canadian cities which 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 (PNV) approach (IPCC 2006) and, when weighted on the basis of urban area, were within a few percent (2%) of those expected using the PNV approach.

6.7.1.5. Recalculations

There were important recalculations in this category due to the implementation of a new approach recommended by the 2006 IPCC Guidelines. Estimates of CO_2 removals from urban trees were increased by on average 2.4 Mt per year.

The approach used in previous submissions produced estimates of modest removals of less than 0.2 Mt. The previous approach was based on applying both a constant stocking rate (number of trees/ha) and a net biomass accumulation rate applied to an estimate of the non-built-up portion of urban areas. The stocking rate and biomass accumulation rates used in previous submissions considerably underestimated UTC (previously assumed to be 5%) compared to the UTC estimate derived with the new point-based sampling approach for this submission (27% on a national basis).

6.7.1.6. Planned Improvements

There are no immediate plans to improve estimates for this category. Continued work will focus on improving activity data estimates and the coefficients used to estimate gross and net removals.

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6.7.2. Land Converted to Settlements

6.7.2.1. Source Category Description

In 2013, emissions from Land conversion to Settlements amounted to nearly 7 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; this is the leading forest conversion type since 2000. On average, during the 1990–2013 period, 25 kha of Forest Land are converted annually to Settlements, predominantly in the Boreal Plains, Boreal Shield East, Atlantic Maritime and Mixedwood Plains reporting zones. Forest Land conversion accounts for 98% of emissions reported under this category. A consistent methodology was developed for all forest conversion, which is outlined in Section 6.8.

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 2013, the conversion of nonforest land to Settlements in the Canadian north accounted for emissions of 150 kt; this value is very similar in the entire trend from 1990. The major source of emissions in this category is associated with conversion of Grassland to Settlements in reporting zone 13, the Taiga Plains.

6.7.2.2. 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 Worldwide Reference System 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. Lack of available imagery prevented the implementation of the system beyond 2000.

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.

6.7.2.3. Uncertainties and Time-Series Consistency

For Forest Land converted to Settlements, refer to the corresponding subheading in Section 6.8, Forest Conversion.

The uncertainty about the area of non-forest land converted to Settlements in the Canadian north is estimated at 20%; the uncertainty about the preconversion standing biomass varies between 35% and 50%. Annex 3.5 provides more information.

6.7.2.4. QA/QC and Verification

Section 1.3 in Chapter 1 describes the general QA/QC procedures being implemented for Canada's GHG inventory; they apply to this category as well.

For Forest Land converted to Settlements, refer to the corresponding subheading in Section 6.8, Forest Conversion.

6.7.2.5. 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 post2000 time period.

In addition, planned improvements described under Section 6.8, Forest Conversion, will also affect this category (see Section 6.8.5, Planned Improvements).

6.8. 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 2013, Forest Land conversion to Cropland, Wetlands and Settlements amounted to total emissions of 14 Mt, down from 19 Mt in 1990. This decline includes a 4.2 Mt decrease in immediate and residual emissions due to Forest Land conversion to Cropland and a 1.6 Mt decrease in emissions from Forest Land conversion

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to Wetlands (reservoirs). There was, however, a small increase of 0.2 Mt in immediate and residual emissions due to 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 46 kha in 2013) 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 hence are 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 2013, immediate emissions (3.1 Mt) represented only 23% 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.

With a current annual conversion rate of 27 kha, Forest Land conversion to Settlements accounts for the largest share of forest losses to other land categories, i.e., 59% in 2013. Conversion to Cropland (19 kha), meanwhile, is the second most important cause of forest conversion, representing 41% of all forest area lost. 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 (flooded land); because much of the pre-conversion C stocks are flooded, these punctual events may not release commensurate quantities of greenhouse gases.

Geographically, the highest rates of forest conversion occur in the Boreal Plains (reporting zone 10), which accounts for 51% of the total forest area lost in 2013.

Forest conversion affects both managed and un-managed forests. Losses of un-managed forests occur mainly in reporting zones 4 (Taiga Shield East) and 5 (Boreal Shield East), and are caused mostly by reservoir impoundment; they occur to a smaller extent in reporting zones 8 and 9.

6.8.1. 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 great variety of circumstances across the country,

including policy and regulatory frameworks, market forces and resource endowment. The economic activities causing forest losses are very 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 and 2008. For implementation purposes, all permanent forest removal wider than 20 m from tree base to tree base and at least 1 ha in area was considered forest conversion. This convention was adopted as a guide to consistently label linear patterns on the landscape. The other main information sources consist of databases or other documentation on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs. Expert opinion was called upon when the remote sensing sample was insufficient, to resolve differences among records and remote sensing information, and to resolve apparent discrepancies across the 1975–1990, 1990–2000 and 2000–2008 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 Land conversion to Settlements where CBM-CFS3 decay rates were used. Hence, methods are in general consistent with those used in the Forest Land remaining Forest Land subcategory. Annex 3.5 summarizes the estimation procedures.

6.8.2. Uncertainties and Time-Series Consistency

An overall uncertainty estimate of ±30% bounds the estimate of the total forest area converted annually in Canada (Leckie 2011), placing with 95% confidence the true value of this area for 2013 between 32 kha and 60 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 about area estimates derived from remote sensing.

6.8.3. 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.

6.8.4. Recalculations

Recalculations were mainly due to the removal of emissions from HWP resulting from forest conversion to other land uses; such emissions were reported as immediate CO_2 emissions in previous submissions and are now reported as carbon input to the HWP in-use pool (see Section 6.9). This change led to an average downward recalculation of 4.8 Mt (24%) for the 1990–2013 period.

For the 1990–2012 period, the recalculations on area rates show a very small increase (less than 1%) due to the addition of forest areas converted to Cropland that were excluded in previous submissions due to confidentiality issues (see Section 6.4.2.1).

6.8.5. Planned Improvements

Integration of updated data for forest conversion based on ongoing mapping activity is planned for the next inventory submission.

6.9. Harvested Wood Products

The Harvested Wood Products category is reported for the first time in this submission in accordance with the new UNFCCC reporting guidelines on annual inventories and 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 in which carbon begins to be stored in a pool of HWP that are in use. As a result, emissions fluctuate between 134 Mt in 2009 (lowest harvest year) and 168 Mt in 2000 (one of the peak harvest years). In 2013, HWP amounted to total emissions of 145 Mt, slightly higher than the 140 Mt emitted in 1990 (Table 6–9).

6.9.1. 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. This model is an upgrade of the Carbon Budget Model Framework for Harvest Wood Products (CBM-FHWP) that was used to prepare preliminary estimates for HWP reported in the NIR of the previous submission. The model tracks HWP sub-pools and carbon flows between sub-pools through the action of events (e.g. manufacturing, use, trade and disposal).

Inputs to the model (see Table 6–9) include the annual mass of carbon from harvest in Forest Lans 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 and covering the period 1941-1989.

Residential firewood data are derived from Statistics Canada and the National Forestry Database Program (NDFP). These data are input separately into the model to ensure consistency with estimates reported by the Energy Sector, albeit at the cost of some methodological inconsistencies. In this submission, some of the carbon reported as emitted as residential firewood that comes from the forest ecosystem is currently still also reported as emitted through the decay of dead biomass. Furthermore, some of the residential firewood might come

from woody biomass in areas outside the managed forest and as result represent carbon that is currently not accounted for in the ecosystem model.

The model takes the annual carbon input from harvested wood, exports a portion as roundwood, converts all harvested wood into commodities, exports some of the commodities produced, and keeps track of the additions to and retirement from HWP in-use and bioenergy.

More information on the estimation methodology, the data sources and the proportions used in the model for exports and for domestic use and storage into the different commodities is available in Annex 3.5.

The temporal pattern of emissions results from historical commodity production combined with the duration of the economic lives of various commodities (Table 6–9). The impact of any significant changes in harvest levels, or in the mix of products, is therefore spread out 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.

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Table 6–9   Carbon Stocks in HWP Pool and Emissions Resulting from Their Use and Disposal

| Inventory Year | C Stocks (Mt C)[1] | | | | | Emissions (Mt CO$_2$)[1] | | |
| | Inputs | | | Exports | Net Stocks[4] | Domestic Harvest | Worldwide from Canadian Harvest | TOTAL |
	Forest Harvest[2]	Forest Conversion[2]	Incremental Firewood[3]					
1990	41	1.7	8.4	24	303	99	42	140
1991	41	1.6	8.1	29	315	96	45	142
1992	43	1.5	7.7	34	327	100	49	151
1993	45	1.3	8.2	39	338	110	51	156
1994	47	1.3	8.5	43	351	110	53	162
1995	48	1.2	8.2	46	363	110	56	166
1996	47	1.2	7.9	48	375	100	57	160
1997	48	1.2	7.6	51	388	100	59	160
1998	45	1.3	8.9	53	401	95	61	155
1999	51	1.3	8.5	57	417	99	63	161
2000	52	1.3	8.3	59	433	100	65	168
2001	48	1.3	7.7	60	448	83	67	150
2002	50	1.3	8.5	62	465	91	68	159
2003	46	1.3	7.3	64	481	72	70	142
2004	53	1.3	7.2	66	498	92	71	163
2005	52	1.3	6.8	67	514	86	73	159
2006	47	1.3	6.7	66	529	72	73	146
2007	42	1.4	6.6	61	541	68	72	140
2008	35	1.3	6.8	56	547	69	71	140
2009	30	1.3	6.6	51	547	66	69	134
2010	36	1.2	7.0	51	552	79	67	146
2011	38	1.3	7.0	53	557	84	66	150
2012	39	1.3	7.0	52	562	87	66	152
2013	39	1.3	8.1	55	571	81	65	145

Notes:

1. Totals may not add up due to rounding. Annex 9 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.D under subcategories related to Forest Conversion, if using instant oxidation approach for HWP.

3. Carbon associated with the proportion of residential firewood estimated in the Energy Sector that is additional to firewood and fuelwood statistics coming from NFDP and used in the CBM-CFS3 model.

4. Since inputs to the model consider harvest since 1941, net stocks over the reporting period may include C harvested before 1990.

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For this submission, it is important to note the significant impact that the implementation of the HWP pool has on the forest harvest and forest conversion estimates, with a consequent repercussion on the sectoral totals. In general, the inclusion of HWP dampens and slightly delays the effect of these activities on the emissions (Figure 6–5).

For the period 1990–2007, emissions resulting from the inclusion of the HWP pool are lower than the emissions that would result from using an instant oxidation approach, as used in previous submissions (dotted line in Figure 6–5), with reductions fluctuating between 13.5 Mt in 1993 and 37 Mt in 2004 (highest harvest year). This decrease occurs because carbon in wood removed from the forests in the reporting year was greater 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, lower harvest rates and the inclusion of the HWP in-use pool result in emissions increased by amounts that fluctuate between 5 Mt in 2008 and 21 Mt in 2009 (lowest harvest year). This increase in emissions is due to higher amounts 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.

Figure 6–5   Emissions from HWP Pool Using the Production Approach vs. Instant Oxidation
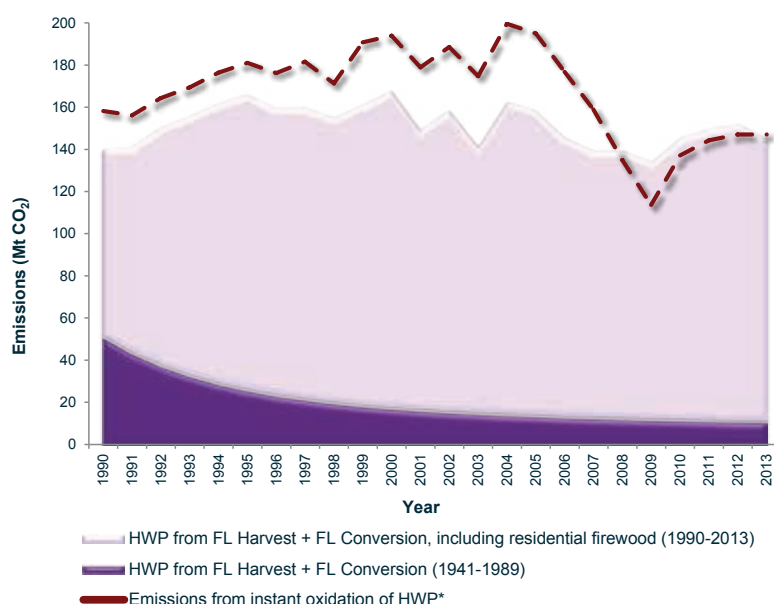
* This line represents an alternative estimate of emissions from HWP using an instant oxidation approach and is presenwwted here only for information purposes.

6.9.2.   Uncertainties and Time-Series Consistency

Efforts are being made to produce uncertainty estimates, and a formal assessment is planned for the next inventory submission. For this submission, in the assessment of total inventory uncertainty (see Annex 2), the uncertainty estimate for Forest Land CO_2 has been used as a proxy to provide a preliminary uncertainty value for HWP estimates.

6.9.3.   Recalculations

Given that this is the first time that Canada reports emissions from this source, there are no recalculations in this category.

6.9.4.   Planned Improvements

A formal uncertainty assessment is planned to be conducted for the next inventory submission. Work is ongoing to develop other country-specific half-lives, to incorporate the effects of wood and paper waste in solid waste disposal sites, to improve the integration of residential firewood consumption, and to expand the temporal coverage, currently limited by available data.

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 on land (landfills), wastewater treatment and waste incineration. The scope includes CH_4 emissions from solid waste disposal on land, CH_4 and N_2O emissions from wastewater treatment, and CO_2, CH_4 and N_2O emissions from waste incineration.

Much of the waste treated or disposed of is derived from biomass. CO_2 emissions attributable to such wastes are not included in inventory totals, but are reported in the inventory as a memo item. CO_2 emissions of biogenic origin are not reported if they are reported elsewhere in the inventory or if the corresponding CO_2 uptake is not reported in the inventory (e.g. annual crops). Therefore, under these circumstances, the emissions are not included in the inventory emission totals, since the absorption of CO_2 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_2 emissions from wood and wood products are not included, because CO_2 removals in the Land Use, Land-use Change and Forestry (LULUCF) Sector are excluded from national totals. In contrast, CH_4 emissions from anaerobic decomposition of wastes are included in inventory totals as part of the Waste Sector.

In 2013, the greenhouse gas (GHG) emissions from the Waste Sector contributed 25 Mt to total national emissions, compared to 24 Mt for 1990—an increase of 5.9%. The emissions from this sector represented 3.9% and 3.6% of the overall Canadian GHG emissions in 1990 and 2013, respectively.

Emissions from the Solid Waste Disposal sub-sector, which consists of the combined emissions from municipal solid waste (MSW) landfills and wood waste landfills, accounted for 24 Mt or 94% of the emissions from this sector in 2013. The chief contributor to the Waste Sector emissions is the CH_4 released from MSW landfills, which for 2013 amounted to 21 Mt (0.83 Mt CH_4). This net emission value is determined by subtracting the amount of CH_4 captured from the total estimated CH_4 generated within the landfill, then adding the quantity of the captured CH_4 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 36% of the CH_4 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.

Overall, the increase in the CH_4 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 nonhazardous waste (residential, institutional, commercial, industrial, construction and demolition) were generated. Waste diversion initiatives began in the early 1990s and, based upon the national figures for 2010, approximately 24% of the waste generated is diverted from disposal (landfill or incineration) (Statistics Canada 2013a) compared to 21% in 2000. Municipal and provincial government initiatives have resulted in significant quantities of residential wastes being diverted from final disposal. From 2000 to 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   Waste Sector GHG Emission Summary, Selected Years

GHG Source Category	GHG Emissions (Mt CO_2 eq)							
	1990	2000	2005	2009	2010	2011	2012	2013
Waste Sector	24	26	28	28	27	26	26	25
Solid Waste Disposal on Land	22	25	26	27	25	25	24	24
Wastewater Handling	0.87	0.95	0.98	1.02	1.03	1.04	1.04	1.05
Waste Incineration	0.73	0.74	0.69	0.64	0.66	0.64	0.71	0.55

Note: Totals may not add up due to rounding.

Table 7–2   Summary of Recalculation in the Waste Sector for Selected Years (kt CO$_2$ eq)

	1990	1995	2000	2005	2009	2010	2011	2012
Previous submission (2014 NIR)	19 007	19 999	20 593	21 772	21 701	20 332	20 350	20 572
Current submission (2015 NIR)	23 936	25 419	26 440	28 132	28 195	26 644	26 374	25 608
Total change:								
	4 928	5 420	5 847	6 360	6 494	6 311	6 024	5 036
%	25.9%	27.1%	28.4%	29.2%	29.9%	31.0%	29.6%	24.5%
Change due to new GWPs:								
CH$_4$	3 635	3 846	4 016	4 291	4 306	4 055	4 014	3 880
N$_2$O	-29	-32	-33	-33	-33	-33	-33	-34
combined	3 607	3 814	3 983	4 258	4 273	4 021	3 980	3 845
combined %	19.0%	19.1%	19.3%	19.6%	19.7%	19.8%	19.6%	18.7%
Change due to new methods:	Normalization Factor and 2006 GL DOCs - 2006 GL relating to CH$_4$ from Solid Waste Disposal							
	1 322	1 606	1 864	2 104	2 233	2 280	2 120	2 279
%	7.0%	8.0%	9.1%	9.7%	10.3%	11.2%	10.4%	11.1%
Change due to updates in activity data:	Population, Surveys: Landfill Gas Collection, MSW Exports, Hazardous Waste Incineration, Industrial Wastewater							
CO$_2$	0.0000	0.0000	0.0000	-5.2674	-23.7980	-14.4989	-15.6727	21.0397
CH$_4$	0.0000	0.0000	0.0027	4.2934	20.5241	26.5733	-57.7053	-1129.2041
N$_2$O	0.0000	0.0000	0.0000	-0.8233	-8.6889	-2.2663	-2.4499	19.9401
combined	0.0000	0.0000	0.0027	-1.7973	-11.9628	9.8082	-75.8279	-1088.2243
combined %	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	-0.4%	-5.3%

Note:
DOC is the degradable organic carbon and the 2006 GL refers to the IPCC 2006 Guidelines.

Table 7–1 summarizes the Waste Sector and subsector GHG contributions for the following inventory years: 1990, 2000, 2005, 2009, 2010, 2011, 2012, and 2013.

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. Therefore, it has been assumed that all waste is disposed of in managed facilities. Residential, institutional, commercial and industrial wastes are disposed of in MSW landfills. Over the past 15 years, dedicated construction and demolition (C & D) landfills were established. Typically, these landfills do not require CH$_4$ collection systems, as the CH$_4$ 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, such as sawdust, wood shavings, bark and sludges. Some industries have shown increasing interest in waste-to-energy projects that produce steam and/or electricity by combusting these wastes. In recent years, residual wood previously regarded as a waste is now being processed as a value-added product—e.g., wood pellets for residential and commercial pellet stoves and furnaces, and hardboard, fibreboard and particle board. Wood waste landfills have been identified as a minor source of CH$_4$ emissions in comparison with MSW landfills.

The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) first-order decay (FOD) 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$_4$ 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 the IPCC 2006.

Landfill gas, which is composed mainly of CH_4 and CO_2, 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_4 and CO_2 gases are generated within 20 years of landfilling, emissions can continue for 100 years or more (Levelton 1991).

A number of important site-specific factors contribute to the generation of gases within a landfill, including the following:

- *Waste composition*: Waste composition is probably the most important factor affecting landfill gas generation rates and quantities. The amount of landfill gas produced is dependent on the amount of organic matter landfilled. 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. Therefore, landfill temperatures may be higher than ambient air temperatures. The extent to which ambient air temperatures influence the temperature of the landfill and gas generation rates depends mainly on the depth of the landfill. Temperature variations can affect microbial activity, subsequently affecting their ability to decompose matter (Maurice and Lagerkvist 2003).

- *pH and buffer capacity*: The generation of CH4 in landfills is greatest when neutral pH conditions exist. The activity of methanogenic bacteria is inhibited in acidic environments.

- *Availability of nutrients*: Certain nutrients are required for anaerobic digestion. These include carbon, hydrogen, nitrogen and phosphorus. In general, MSW contains the necessary nutrients to support the required bacterial populations.

- *Waste density and particle size*: The particle size and density of the waste also influences gas generation. Decreasing the particle size increases the surface area available for degradation and therefore increases the gas production rate. The waste density, which is largely controlled by compaction of the waste as it is placed in the landfill, affects the transport of moisture and nutrients through the landfill, which also affects the gas generation rate.

7.2.2.   Methodological Issues

The use of a first-order decay model to estimate CH_4 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_4 emissions are determined by calculating the amount of CH_4 generated from landfill waste decomposition (Equation 7–1) through the Scholl Canyon model, subtracting the CH_4 captured

through landfill gas recovery systems, then adding the quantity of uncombusted CH_4 emitted by the flares for those locations where a portion or all of the recovered landfill gas is burned without energy recovery. The GHG emissions associated with the combustion of that portion of the landfill gas that is captured and utilized for energy generation purposes are accounted for in the Energy Sector. Annex 3.5 provides detailed information on the methodologies used for various categories covered by this subsector.

7.2.2.1.   CH$_4$ Generation

Equation 7–1:

$$Q_{T,x} = kAM_x L_o e^{-k(T-x)}$$

where:

$QT_{,x}$	=	amount of CH_4 generated in the current year (T) by the waste Mx, kt CH_4/year
x	=	the year of waste input
Mx	=	the amount of waste disposed of in year x, Mt
k	=	CH_4 generation rate constant, year^{-1}
A	=	normalization factor $((1/e^{-k})-1)/k)$
L_0	=	CH_4 generation potential, kg CH_4/t waste
T	=	current year

Equation 7–2:

$$Q_T = \sum Q_{T,x}$$

where:

Q_T	=	amount of CH_4 generated in the current year (T), kt CH_4/year

To calculate the net emissions for each year, the sum of QT,x 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_4 emission value is the summation of emissions from all regions.

Waste Disposed of Each Year or the Mass of Refuse (Mx)

MSW Landfills

For the purposes of the inventory, MSW includes residential; institutional, commercial and industrial; 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 1941 through to 1990 were estimated by B.H. Levelton (1991). For the years 1998,

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2000, 2002, 2004, 2006, 2008 and 2010, MSW disposal data were obtained from the *Waste Management Industry Survey* that is conducted by Statistics Canada on a biennial basis (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010b, 2013a). For the intervening odd years (1999, 2001, 2003, 2005, 2007 and 2009), the MSW disposal values, including both landfilled and incinerated MSW, were obtained by taking an average of the adjacent even years. Quantities of waste landfilled for 2011, 2012 and 2013 were extrapolated from values derived from the Statistics Canada waste management survey. Incinerated and exported waste quantities were subtracted from the Statistics Canada disposal values in order to obtain the amounts of MSW landfilled for 1998–2013. Exported waste quantities are provided in Annex 3.5. 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 B.H. 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 1991–2013 are obtained by trending historical landfill data with the provincial populations for 1971–2013 (Statistics Canada 2006, 2014). Waste quantities imported into Canada are accounted for within the Statistics Canada *Waste Management Industry Survey* since the facilities report all wastes being disposed of in their facility, whether of domestic or international origin.

Wood Waste Landfills

British Columbia, Quebec, Alberta and Ontario together landfill 93% of the wood waste in Canada (NRCan 1997). The amount of wood waste landfilled in the years 1970 through to 1992 has been 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 1999–2013.

CH$_4$ Generation Rate Constant (k)

The CH$_4$ kinetic rate constant (k) represents the first-order rate at which CH$_4$ is generated after waste has been landfilled. The value of k is affected by four major factors: moisture content, temperature, availability of nutrients and pH. It is assumed that, in a typical MSW landfill, the nutrient and pH conditions are 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 atmo-

spheric 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$_4$ production occurs between the winter and summer seasons (Bingemer and Crutzen 1987; Thompson and Tanapat 2005). Therefore, of all these factors, moisture content is the most influential parameter for Canadian landfills and is largely determined by the annual precipitation received at the landfills.

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 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 2013.

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 2013 are presented in Table 7–3.

Wood Waste Landfills

Based upon the default value for estimating wood products industry landfill 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 CH$_4$ generation rate constant k for all of the wood waste landfills in Canada (NCASI 2003).

Time Series	N.L.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	N.W.T. & Nvt.	Yk.
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
1990–2013	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 2013 period remain constant.

CH₄ 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 CH₄/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 2013, three different L0s 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 Lo accounted for the characteristics of the three MSW sources: residential; institutional, commercial and industrial; and construction and demolition wastes. 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 1990–2013. These time intervals coincide with those employed for the calculation of the CH₄ 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 1990–2013. 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 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:

Table 7–4   CH₄ 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 CH₄/t waste)	DOC	L_0 (kg CH₄/t waste)	DOC	L_0 (kg CH₄/t Waste)
Newfoundland	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 (Yk., N.W.T. and Nvt.)	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.

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Equation 7–3:

$$L_o = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \times \frac{1000\,kg\,CH_4}{t\,CH_4}$$

where:

L_0	=	CH_4 generation potential (kg CH_4/t waste)
MCF	=	CH_4 methane correction factor (fraction)
DOC	=	degradable organic carbon (t C/t waste)
DOC_F	=	fraction DOC dissimilated
F	=	fraction of CH_4 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_4 emitted from a landfill ranges from 0.4 to 0.6 and was assumed to be 0.5. A DOC_F value of 0.6 was selected from a default range of 0.5 to 0.6 in IPCC (2000). This DOC_F 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 (IPCC 2006) where the default DOC content in percent of wet waste was obtained from Table 2.4 (IPCC 2006) (Equation 7–4):

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_4/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_4 in the landfill gas (F = 0.5); and the fraction of DOC dissimilated (DOC_F = 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_4 in the landfill gas to CO_2, thus reducing the CH_4 emissions. To calculate the net CH_4 emissions from landfills, the amount of CH_4 captured, as provided by the landfill facilities, is subtracted from the quantity of CH_4 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_4 that passes through 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_4 in landfill gas of 99.7% was used to determine the quantity of CH_4 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 1996 were obtained from a personal communication.[1] Data for the 1997 to 2003 period were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (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; therefore, 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).

7.2.3. Uncertainties and Time-Series Consistency

The following discussion on uncertainty for the categories within this sector is based upon 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, there have been modifications 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

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1 Personal communication with ME Perkin of Environment Canada's National Office of Pollution Prevention in 1998.

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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 CH_4 emissions from this key category include CH_4 emissions from MSW landfills and wood waste landfills. The level of uncertainty associated with the CH_4 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_4 emissions from MSW landfills. The level uncertainty range provided by the ICF Consulting study (2004) is only slightly larger than the ± 30% span estimated with a 90% confidence level by a previous study, which used a Tier 1 approach based upon 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_4 emissions from this key category in 2001 (Environment Canada 2003b). The uncertainty estimates for CH_4 emissions from MSW landfills seem to have been largely influenced by the uncertainty in the inventory values for L_0 for 1941–1989 and 1990–2001 and the CH_4 generation rate constant k, where the uncertainty for both k and L_0 were based upon 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_4 generation rate, carbon content of the waste landfilled, and the biodegradable fraction of the waste, where the uncertainties were assumed by ICF Consulting (2004) based upon 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 in the model. These included insertion of data obtained from the latest landfill gas capture and utilization survey and waste export data survey, the inclusion of the new degradable carbon default values from the 2006 IPCC Guidelines, and introduction of the normalization factor as corrected in the 2006 IPCC Guidelines. 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.

The two surveys mentioned above were also subject to a quality control process prior to the data being included in the model. To ensure completeness, provincial and territorial governments were solicited and municipal government requests for proposals, and council minutes available on-line, were reviewed to identify new, expanded or proposed landfill gas recovery units. All identified sites, having active landfill capture and/or utilization operations, were sent site-specific survey questionnaires, in which the historical data provided in earlier surveys were presented to allow respondents to review and either confirm or revise the values as required. For both the waste export and landfill gas capture and/or utilization surveys, the latest data were compared with those from the previous survey, and respondents were asked to confirm values where the values were found to be significantly different.

7.2.5.   Recalculations

Emission estimations from MSW landfills were recalculated over the 1990–2012 time series to account for methodology changes: the use of DOC default values from IPCC 2006 and the incorporation of the normalization factor as presented in the Good Practice Guidance and corrected in the 2006 IPCC Guidelines. These combined changes resulted in increases varying from 7.0% to 11.2% over the complete time series.

Surveys conducted in 2014 resulted in activity data updates . The exported MSW waste quantities were revised for Ontario from 1995 to 2011, with most changes being minimal except for 2011, which saw a 53% increase. Ontario, Quebec and British Columbia values were updated for 2012. A correction was made in the linkages of the model to include 2012 waste export values, which had not been included in the 2014 submission. The landfill gas collection survey also resulted in data revisions for historical data and updates for 2012. Minor recalculations were conducted for Prince Edward Island and the three territories for 2012 to account for population revisions by Statistics Canada (2014), resulting in increases in emissions from 0% to 0.1%. The revised population resulted in a 0.006% decrease from last submission's national 2012 population.

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.

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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)

This source has not been estimated.

7.3.1. 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.

To our knowledge, anaerobic digestion of solid waste operations are limited to a pilot trial or two and have not become commercial enterprises as of yet. This category is considered as not occurring.

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 and sewage sludge 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_2, CH_4 and N_2O.

As per the 2006 IPCC Guidelines, CO_2 emissions from biomass waste combustion are not included in the inventory totals. The only CO_2 emissions detailed in this section are from fossil fuel-based carbon waste, such as plastics and rubber.

CH_4 emissions from Canadian MSW incinerators are negligible, based on the findings from a recent report commissioned by Environment Canada (CRA 2011).

7.4.1.2. Hazardous Waste Incineration

There are four hazardous waste incinerators in Canada located in Ontario and Alberta. CO_2, N_2O and CH_4 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_2, CH_4, and N_2O, as in the case of MSW incinerators; however, since the carbon present in the wastewater sewage sludge is of biological origin, the CO_2 emissions are not accounted for in the inventory totals from this source.

7.4.2. Methodological Issues

The emission estimation methodology depends on waste type and gas emitted. A more detailed discussion of the methodologies is presented in Annex 3.5.

7.4.2.1. CO_2 Emissions

MSW Incineration

A Tier 1 method that uses Equation 5.2 (IPCC 2006) is employed to calculate CO_2 emissions from the incineration of fossil fuel-based waste (such as plastics and rubber). The three-step method was developed for MSW incineration:

- *Calculating the amount of waste incinerated:* The amount of waste incinerated each year was estimated based on a regression analysis using data from an Environment Canada (1996) study, which contains detailed provincial incineration data for the year 1992, and from a study performed by A.J. Chandler & Associates Ltd. for Environment Canada, which provided incineration data for 1999, 2000 and 2001 (Environment Canada 2003c).

- *Developing emission factors*: Provincial CO_2 emission factors are founded on the assumption that the carbon contained in waste undergoes complete oxidation to CO2. The amount of fossil fuel-based carbon available in the waste incinerated has been determined using typical percent weight carbon content values (Tchobanoglous et al. 1993). The amount of

carbon per tonne of waste is estimated and converted to tonnes of CO_2 per tonne of waste by multiplying by the ratio of the molecular mass of CO_2 to that of carbon.

- Calculating CO_2 emissions: Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factor.

Hazardous Waste Incineration

CO_2 emissions were estimated from the quantities of hazardous wastes combusted over the 1990–2013 time series. The emission estimation method used the IPCC default carbon content and fossil carbon percent of total carbon of 50% and 90%, respectively, for hazardous waste (Table 5.6, IPCC 2000).

Sewage Sludge Incineration

CO_2 generated from the incineration of sewage sludge is not reported in the inventory emission totals, since the sludge consists solely of biogenic matter.

7.4.2.2. N$_2$O and CH$_4$ Emissions

MSW Incineration

Emissions of N_2O from MSW incineration were estimated using a Tier 1 method (IPCC/OECD/IEA 1997). An average emission factor was calculated assuming that the IPCC five-stoker facility factors were most representative. To estimate emissions, the calculated emission factor was multiplied by the amount of waste incinerated by each province. CH_4 emissions from Canadian MSW incinerators are negligible, based on the findings from a recent report commissioned by Environment Canada (CRA 2011).

Hazardous Waste Incineration

N_2O and CH_4 emissions were estimated from emission factors derived from site-specific data provided by a facility, which were deemed more representative than IPCC default values. Sitespecific data consisted of the quantities of hazardous waste processed at the facility and the cumulative measured N_2O and CH_4 emissions for 2009 (Environment Canada 2011b). The resulting emission factors were 3.16×10^{-3} kt N_2O/kt waste and 1.69×10^{-4} kt CH_4/kt of waste.

Sewage Sludge Incineration

Emissions generated from the incineration of sewage sludge are dependent on the amount of dried solids incinerated. To calculate the CH_4 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 2002–2013, a regression analysis was completed using the incineration values in the most recent study report.

CH_4 emissions are estimated based on emission factors obtained from the U.S. EPA publication *Compilation of Air Pollutant Emission Factors* (U.S. EPA 1995). It is assumed that sewage sludge incineration is conducted with fluidized bed incinerators. Therefore, the emission factor is 1.6 t CH_4/kt of total dried solids for fluidized bed sewage incinerators equipped with venture scrubbers. The national emissions were then determined as the summation of emissions for all provinces.

Emissions of N_2O from sewage sludge incineration were estimated using the IPCC default emission factor for fluidized beds, 0.8 kg N_2O/t of dried sewage sludge incinerated (IPCC 2000). To estimate emissions, the emission factor was multiplied by the amount of waste incinerated by each province. The national emissions were then determined as the summation of emissions for all provinces.

7.4.3. Uncertainties and Time-Series Consistency

The following discussion on uncertainty for the categories within this subsector is based upon 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, there have been modifications 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 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_2, CH_4 and N_2O) from incineration of wastes (comprising MSW and sewage sludge) was estimated to be in the range of about +10% to +11%. The inventory trend uncertainty was estimated at +10%. The extrapolation of trend uncertainty in 2001 to the 2013 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.

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.

The waste incineration survey was also subject to a quality control process prior to the data being included in the model. To ensure completeness, provincial and territorial governments were solicited and municipal government requests for proposals and council minutes available on-line were reviewed to identify new and closed waste incineration facilities in Canada. All identified active sites were sent site-specific survey questionnaires, in which the historical data provided in earlier surveys were presented to allow respondents to review and either confirm or revise the values as required. The latest data were compared with those from the previous survey, and respondents were asked to confirm values where the values were found to be significantly different.

7.4.5. Recalculations

Minor recalculations were conducted for MSW incineration to account for revised Statistics Canada population data for 2012. The revised population was a decrease of 0.006% in the national 2012 population. The activity data for hazardous wastes were updated for 2012 by the Waste Incineration Survey (Environment Canada 2014b).

7.4.6. Planned Improvements

Emissions from waste incinerators where there is energy 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.

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 waste-water produces CH_4, which is typically contained and combusted via anaerobic digestion systems. CH_4 emissions from aerobic systems are assumed to be negligible. Both types of treatment system generate N_2O through the nitrification and denitrification of sewage nitrogen.

CO_2 is also a product of aerobic and anaerobic wastewater treatment. However, as detailed in Section 7.1, CO_2 emissions originating from the decomposition of organic matter are not included with the national total estimates.

The emission estimation methodology for municipal wastewater handling is divided into two areas: CH_4 from anaerobic wastewater treatment and N_2O from human sewage.

7.5.2. Methodological Issues

Annex 3.5 provides additional information on the methodologies used for various categories covered by this subsector.

7.5.2.1. CH_4 Emissions

Municipal Wastewater Treatment

A country-specific method developed for Environment Canada (AECOM Canada 2010) 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_4, it was estimated that 1.97 kg CH_4/person per year could potentially be emitted from anaerobically treated wastewater. Additional information on the incorporated methodology is provided in Annex 3.5.

CH_4 emissions were calculated by multiplying the emission factor by the population of the respective province (Statistics Canada 2006, 2014) and by the fraction of wastewater that is treated anaerobically.

Industrial Wastewater Treatment

A survey was conducted by Environment Canada to obtain methane emissions from facilities that treated their effluent anaerobically on-site over the 1990–2011 time series. 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 3.5.

7.5.2.2. N_2O Emissions

Municipal Wastewater Treatment

An N_2O emission factor is calculated as the product of the annual per capita protein consumption, the assumed protein nitrogen

Table 7–5   N₂O Emission Factors

Year	Annual Per Capita Protein Consumption (kg protein/person per year)	N₂O Emission Factor (kg N₂O/ 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

Sources: [a]Statistics Canada (2007b), [b]Statistics Canada (2008b) and [c]Statistics Canada (2010a). The data have been adjusted to account for retail, household, cooking and plate loss.

content (16%), the quantity of N_2O-N produced per unit of sewage nitrogen (0.01 kg N_2O-N/kg sewage nitrogen) and the N_2O/ N_2O-N conversion factor (1.57). Protein consumption estimates, in kg/person per year, were obtained from an annual Food Statistics report published by Statistics Canada (2007b, 2008b, 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 2010–2013 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, 2014). 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 upon 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, there 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 would result in a reduction of the uncertainty for this subsector.

The overall level uncertainty associated with the wastewater treatment 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_4 and N_2O) from the wastewater treatment systems was estimated to be in the range of about +12% to +13%. The extrapolation of trend uncertainty in 2001 to the 2013 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.

The industrial wastewater survey was also subject to a quality control process prior to the data being included in the model. To ensure completeness, trade publications and provincial government installation/operation approvals available on-line were reviewed to identify new industrial wastewater treatment facilities in Canada. All identified active sites were sent site-specific survey questionnaires, in which the historical data provided in earlier surveys were presented to allow respondents to review and either confirm or revise the values as required. The latest data were compared with those from the previous survey, and

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respondents were asked to confirm values where the values were found to be significantly different.

7.5.5.   Recalculations

Very minor recalculations were conducted for wastewater treatment to account for revised Statistics Canada population data for 2012 (Statistics Canada 2014). The revised population resulted in a 0.006% decrease from last submission's national 2012 population.

Planned Improvements

The next biennial industrial wastewater treatment facility survey will be conducted during the summer of 2016.

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Chapter 8

Recalculations and Improvements

Canada's greenhouse gas (GHG) inventory undergoes a continuous process of updates, revisions and improvements in order to ensure that the most complete, consistent, comparable, accurate and transparent information possible is reported. Section 8.1 of this chapter provides an overview of the recalculations performed in this year's GHG inventory, including analysis by sector and by gas, in order to facilitate an integrated view of changes in, and impacts on, emission levels and trends. A summary of the major inventory improvements that were implemented this year can be found in Section 8.2 and planned improvements for future inventories are described in Section 8.3.

Further details on recalculations and improvements can be found within the individual chapters for each sector (Chapters 3-7).

8.1. Impact of Recalculations on Emission Levels and Trends

It is good inventory preparation practice for Annex I Parties to continually improve their national GHG inventories. Environment 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.

In addition this year is 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. This has resulted in recalculations due to the use of updated global warming potentials (GWPs) provided in the IPCC Fourth Assessment Report (AR4) (IPCC 2007), the reporting of additional GHGs (including nitrogen trifluoride (NF_3) along with a few new species of HFCs and PFCs, and the use of the *2006 Intergovernmental Panel on Climate Change Methodological Guidance* (2006 IPCC Guidelines) (IPCC 2006), which required several methodological changes. In addition, revisions were made to energy statistics provided by Statistics Canada, a key data source for the Energy and Industrial Processes and Product Use (IPPU) sectors of the inventory. As in most years, recalculations also occurred due to updates in activity data, reallocations of emissions, the correction of errors discovered since the previous submission, or minor incremental enhancements.

8.1.1. Estimated Impacts on Emission Levels and Trends

In this year's GHG inventory, total emissions were revised upwards for all years as shown in Figure 8–1. Upward recalculations are largely the result of the updated GWP values, changes in historical data and method changes due to the implementation of the 2006 IPCC Guidelines, while the continuous improvements implemented this year tended to cause downward revisions to estimates, especially in recent years. The trend between 1990 and 2012 is now reported as a 16.7% increase in total GHG emissions since 1990 instead of the previously reported 18.2% increase. The trend between 1990 and 2013 shows an 18.5% increase in GHG emissions.

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 due to the inclusion of long-term carbon storage in harvested wood products (HWP) and caused important downward revisions to emissions for the years 2000 to 2008. These recalculations do not correct the erratic emission pattern due to natural disturbances in managed forests.

The recalculations had the largest implications for the early years of the time series (1990-2000), which showed increases ranging from 22 Mt to 26 Mt (3.3% to 3.9%). For the years 2001 to 2004, the impact of the recalculations diminished from a 21 Mt

Figure 8–1   Comparison of Emission Trends (2014 NIR vs 2015 NIR)
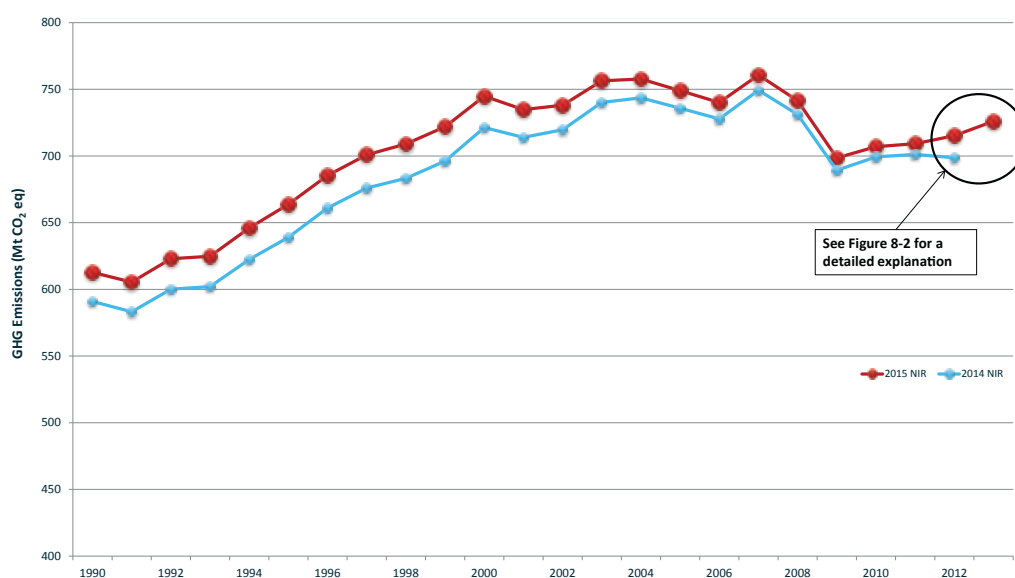
Table 8–1   Summary of Recalculations in the 2015 National Inventory (excluding LULUCF)

NATIONAL TOTAL	Annual Emissions (kt CO$_2$ eq)							Trend	
	1990	**2000**	**2005**	**2009**	**2010**	**2011**	**2012**	**(1990-2012)**	**(2005-2012)**
Previous Submission (2014 NIR)	590 908	721 362	735 829	689 313	699 302	701 212	698 626	18.2%	-5.1%
Current Submission (2015 NIR)	612 745	744 876	749 024	698 540	707 031	709 222	715 213	16.7%	-4.5%
Change in Emissions:	21 837	23 514	13 195	9 227	7 728	8 009	16 586	-	-
Use of Updated GWPs	13 850	17 655	16 948	15 609	15 107	15 131	15 313	-	-
Implementation of 2006 IPCC GLs	9 413	10 022	9 897	7 656	7 856	8 265	10 032	-	-
ERT Recommendations	1	7	10	8	7	7	7	-	-
Continuous Improvements	- 1 427	- 4 926	- 13 478	- 13 746	- 14 453	- 14 249	- 14 633	-	-
Revised Activity Data	1	756	-182	-301	-792	- 1 146	5 865	-	-
Reporting of New GHGs	0.3	0.2	0.2	1.3	2.8	2.9	3.0	-	-
Total Change: %	**3.7%**	**3.3%**	**1.8%**	**1.3%**	**1.1%**	**1.1%**	**2.4%**	**-**	**-**

(2.8%) upward recalculation in 2001 to a 14 Mt (1.9%) upward recalculation in 2004. This reduction was mainly due to continuous improvements in quantifying emissions from Fugitive Sources (which were implemented back to 2002). Between 2005 and 2011, recalculations resulted in total emission increases of between 7.7 Mt and 13.2 Mt, while in 2012, the revised national total was 16.6 Mt (2.4%) higher than what was reported in the 2014 NIR (715 Mt vs. 699 Mt), as shown in Table 8–1.

Looking more closely at the 16.6 Mt revision of the 2012 national total (as shown in Figure 8–2), approximately 10 Mt was due to the implementation of the 2006 IPCC Guidelines. Updates to methodologies within the Stationary Combustion subsector (including changes to the oxidation factor, method for estimating emissions from residential fuelwood, coal coke emission factor, still gas emission factor) as well changes in the oxidation factor in the Transport subsector resulted in increases of 5.9 Mt and 1.9 Mt respectively. There were also emission increases in the Agriculture Sector from recalculations due to the reporting of emissions from

several new animal categories, N$_2$O from soil carbon loss, and emissions from carbon-containing fertilizers. This was partially offset by a large decrease in indirect N$_2$O emissions from nitrogen that is leached from agricultural soils, leading to an overall increase of 2.0 Mt. In the Waste Sector, the combination of the use of default values for degradable organic carbon and the incorporation of normalization factors also resulted in an emission increase of 2.3 Mt. These increases were partially offset by downward revisions in the IPPU Sector, where new methods, including accounting for the CO$_2$ recovered from the ammonia production process (for use as raw material in urea production), resulted in a 2.5 Mt decrease.

All GWP values in AR4 were updated from those in the IPCC Second Assessment Report (SAR) (IPCC 1995), which had been used in previous inventories as required by earlier UNFCCC Reporting Guidelines. The use of the AR4 GWPs resulted in an increase in 2012 emissions of approximately 15.3 Mt, due mainly to the larger GWP value for methane (revised from 21 to 25). Although

Figure 8–2   Explanation of Changes from 2012 in Previous Submission to 2013 in Current Submission

8.1.2.   Recalculations by Sector
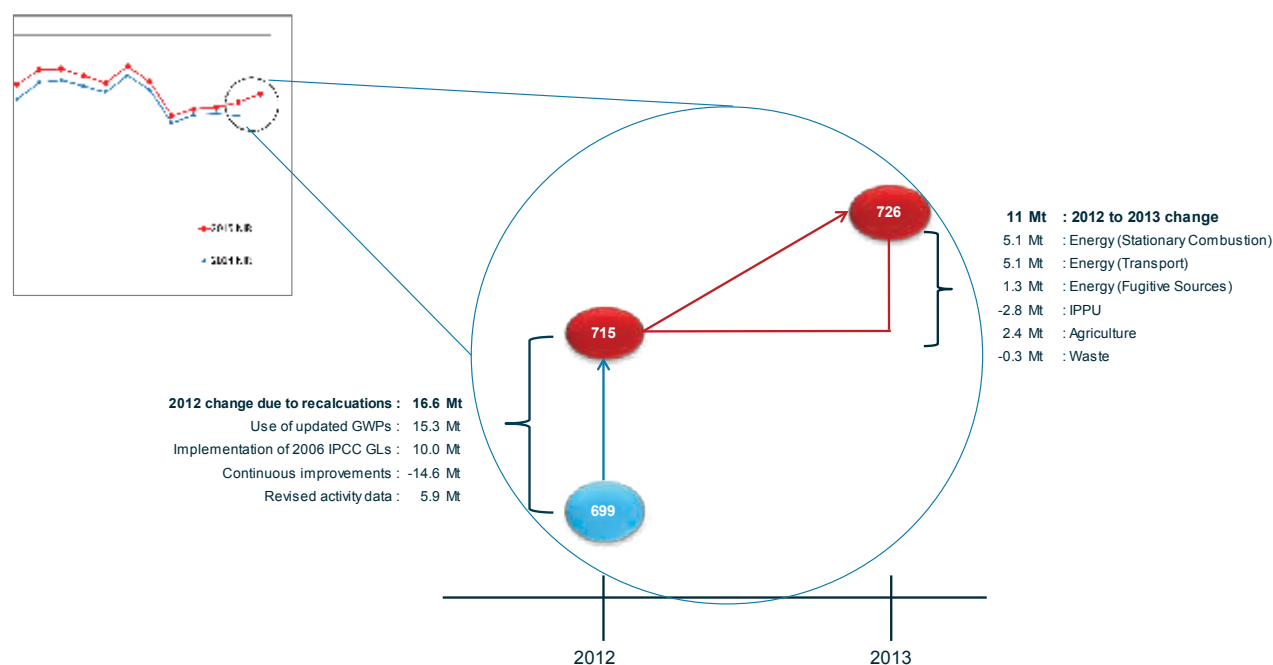
this increase reflects the increased effect of CH_4 emissions relative to CO_2 emissions, the change in GWP values does not mean more CH_4 was emitted. Major sources of methane are in the Energy Sector (Fugitive Sources category), Agriculture Sector and Waste Sector (Solid Waste Disposal on Land category).

Historical activity data updates also caused recalculations in this year's inventory of approximately 6 Mt. Revisions to energy statistics for 2012 from Statistics Canada have revised total emissions by approximately 8 Mt (~1%) – mainly in the Stationary Combustion and Transport subsectors, while the newly acquired landfill gas capture data results in a decrease in emissions (1.2 Mt) from the Waste Sector.

Finally, continuous improvements to established estimation methods led to a downward recalculation (14.6 Mt) of 2012 estimates. Significant updates to the fugitive emission estimation model and methodology were implemented based on a recent upstream oil and gas study which takes into account activities implemented by industry, leading to a decrease of 11 Mt. In the IPPU Sector, a refined approach to estimating HFCs has resulted in a downward recalculation of 1.6 Mt. In the Agriculture Sector, some continuous improvements counter-balanced the increase from use of AR4 GWPs and the 2006 IPCC Guidelines; in particular, a large decrease in N_2O emissions from indirect emissions from cattle grazing on pastures due to the implementation of country-specific emission factors led to a decrease of approximately 2.0 Mt.

As previously noted, good inventory preparation practice requires that methodological improvements and updates be applied to the entire time series of annual estimates (i.e. from 1990 to the most recent year reported). A consistent time series is required to avoid confounding a methodological change with an actual change in GHG emissions or removals.

Recalculations conducted this year have resulted in changes to previously reported emissions/removals information for all IPCC sectors (Energy, Industrial Processes and Product Use (IPPU), Agriculture, LULUCF and Waste) and Energy subsectors (Stationary Combustion, Transport and Fugitive Sources), as well as for all years in the time series (1990-2012).

Due to changes and improvements in the underlying data and quantification methodologies, recent years have seen recalculations resulting in increased emissions for all sectors, with the exception of Energy – Fugitive Sources, and IPPU (Table 8–2 and Figure 8–3). For example, revisions to 2012 energy statistics from Statistics Canada (a key data source for the Energy and IPPU Sectors of the inventory) have resulted in an upward revision to total emissions in 2012 by approximately 8 Mt (~1%) — mainly in the Stationary Combustion and Transport subsectors.

Table 8–2   Summary of Recalculations by Category

	Annual Emissions (kt CO_2 eq)							Trend	
	1990	**2000**	**2005**	**2009**	**2010**	**2011**	**2012**	**(1990-2012)**	**(2005-2012)**
ENERGY (Stationary Combustion)									
Previous Submission (2014 NIR)	280 305	347 422	338 115	312 902	313 236	315 785	309 461	10.4%	-8.5%
Current Submission (2015 NIR)	287 962	354 662	344 178	317 750	318 471	321 042	320 174	11.2%	-7.0%
Change in Emissions: kt CO_2 eq	7 657	7 240	6 063	4 848	5 234	5 257	10 713	-	-
%	2.7%	2.1%	1.8%	1.5%	1.7%	1.7%	3.5%	-	-
ENERGY (Transportation)									
Previous Submission (2014 NIR)	146 515	180 318	193 534	188 215	197 854	197 550	195 191	33.2%	0.9%
Current Submission (2015 NIR)	147 871	181 882	195 255	189 971	199 688	199 303	198 991	34.6%	1.9%
Change in Emissions: kt CO_2 eq	1 356	1 564	1 721	1 756	1 834	1 753	3 799	-	-
%	0.93%	0.87%	0.89%	0.93%	0.93%	0.89%	1.95%	-	-
ENERGY (Fugitive)									
Previous Submission (2014 NIR)	42 364	63 042	63 384	58 837	58 461	59 591	61 107	44.2%	-3.6%
Current Submission (2015 NIR)	48 803	69 851	61 103	55 672	54 610	55 590	57 377	17.6%	-6.1%
Change in Emissions: kt CO_2 eq	6 439	6 809	- 2 281	- 3 165	- 3 851	- 4 002	- 3 730	-	-
%	15.2%	10.8%	-3.6%	-5.4%	-6.6%	-6.7%	-6.1%	-	-
IPPU									
Previous Submission (2014 NIR)	55 885	54 242	60 813	52 025	54 334	54 900	56 767	1.6%	-6.7%
Current Submission (2015 NIR)	55 087	53 447	58 809	49 072	50 730	50 879	55 014	-0.1%	-6.5%
Change in Emissions: kt CO_2 eq	- 798	- 795	- 2 005	- 2 953	- 3 603	- 4 021	- 1 753	-	-
%	-1.43%	-1.47%	-3.30%	-5.68%	-6.63%	-7.32%	-3.09%	-	-
AGRICULTURE									
Previous Submission (2014 NIR)	46 832	55 746	58 211	55 633	55 085	53 036	55 529	18.6%	-4.6%
Current Submission (2015 NIR)	49 086	58 594	61 547	57 880	56 889	56 033	58 048	18.3%	-5.7%
Change in Emissions: kt CO_2 eq	2 254	2 848	3 336	2 247	1 803	2 997	2 520	-	-
%	4.8%	5.1%	5.7%	4.0%	3.3%	5.7%	4.5%	-	-
WASTE									
Previous Submission (2014 NIR)	19 007	20 593	21 772	21 701	20 332	20 350	20 572	8.2%	-5.5%
Current Submission (2015 NIR)	23 936	26 440	28 132	28 195	26 644	26 374	25 608	7.0%	-9.0%
Change in Emissions: kt CO_2 eq	4 928	5 847	6 360	6 494	6 311	6 024	5 036	-	-
%	25.9%	28.4%	29.2%	29.9%	31.0%	29.6%	24.5%	-	-
LULUCF									
Previous Submission (2014 NIR)	- 71 020	- 51 512	53 412	- 27 477	75 743	76 809	40 860	-	-
Current Submission (2015 NIR)	- 87 499	- 76 599	16 424	- 7 856	81 381	82 203	60 093	-	-
Change in Emissions: kt CO_2 eq	- 16 479	- 25 087	- 36 988	19 621	5 638	5 393	19 233	-	-
%	23.20%	48.70%	-69.25%	-71.41%	7.44%	7.02%	47.07%	-	-

Figure 8–3   Inventory Recalculations by Sector

Note*: Recalculated emissions/removals from LULUCF Sector not included as part of the national total.

8.1.3. Recalculations Due to Additional GHGs and Updated GWPs

As previously noted, the implementation of the revised UNFCCC Reporting Guidelines requires the reporting of several additional GHGs, including NF_3, and several additional species of PFCs and HFCs, as well as the use of updated AR4 GWPs. 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 in gases already existing in the atmosphere and changing atmospheric conditions. Chapter 1, Section 1.1.2, of this report provides more information on the GHGs reported in Canada's inventory and their associated GWP values.

Recalculations due to the inclusion of additional gases showed increases across the time series, ranging from 0.3 kt in 1990 to 3.0 kt in 2012 (Table 8–1). A summary of the changes to emission estimates due to the use of updated GWP values from the IPCC's Fourth Assessment Report is presented in Table 8–3. It should be noted that the recalculations due to updated GWPs affect the entire time series but not the trends. The impact of the updated GWPs ranges from an increase of 16 to 19 Mt CO_2 eq (2.3 to 2.7%) in total emissions for any given year throughout the time-series. Further details on the change in GWPs including their impact on trends can be found in Chapter 2, Section 2-1.

Table 8–3   Summary of Recalculations by Greenhouse Gas

GHG Emissions by Gas		Year							Trend	
		1990	2000	2005	2009	2010	2011	2012	(1990-2012)	(2005-2012)
CO_2										
Previous NIR (2014)	kt	459 038	567 738	576 741	542 521	554 408	557 290	550 547	19.9%	-4.5%
Current NIR (2015)	kt	462 703	572 023	580 186	544 634	556 401	558 944	562 009	21.5%	-3.1%
Total change:	kt	3 665	4 285	3 445	2 113	1 992	1 654	11 463		
	%	0.8%	0.8%	0.6%	0.4%	0.4%	0.3%	2.1%		
CH_4										
Previous NIR (2014)	kt	3 429	4 509	4 695	4 326	4 219	4 218	4 313	25.8%	-8.2%
GWP (21)	kt CO_2 eq	72 003	94 680	98 601	90 851	88 598	88 579	90 563	25.8%	-8.2%
Current NIR (2015)	kt	3 841	4 851	4 677	4 285	4 167	4 167	4 215	9.7%	-9.9%
GWP (25)	kt CO_2 eq	96 036	121 275	116 931	107 127	104 186	104 164	105 370	9.7%	-9.9%
Total change:	kt	413	342	-18	-41	-52	-51	-98		
	%	12.0%	7.6%	-0.4%	-1.0%	-1.2%	-1.2%	-2.3%		
Total change:	kt CO_2 eq	24 033	26 595	18 331	16 276	15 588	15 585	14 806		
	%	33.4%	28.1%	18.6%	17.9%	17.6%	17.6%	16.3%		
N_2O										
Previous NIR (2014)	kt	159	157	163	152	152	148	154	-2.9%	-5.3%
GWP (310)	kt CO_2 eq	49 169	48 645	50 382	47 070	47 157	45 918	47 733	-2.9%	-5.3%
Current NIR (2015)	kt	142	135	139	128	129	128	132	-6.6%	-4.7%
GWP (298)	kt CO_2 eq	42 251	40 100	41 385	38 239	38 400	38 106	39 442	-6.6%	-4.7%
Total change:	kt	-17	-22	-24	-24	-23	-20	-22		
	%	-10.6%	-14.2%	-14.5%	-15.5%	-15.3%	-13.7%	-14.0%		
Total change:	kt CO_2 eq	- 6 918	- 8 546	- 8 997	- 8 830	- 8 756	- 7 812	- 8 292		
	%	-14.1%	-17.6%	-17.9%	-18.8%	-18.6%	-17.0%	-17.4%		
HFCs										
Previous NIR (2014)	kt CO_2 eq	767	2 936	5 296	6 306	7 073	7 547	7 783	914.4%	46.9%
Current NIR (2015)	kt CO_2 eq	971	3 588	5 265	5 656	5 746	5 924	6 156	534.3%	16.9%
Total change:	kt CO_2 eq	203	652	- 32	- 651	- 1 327	- 1 623	- 1 627		
	%	26.5%	22.2%	-0.6%	-10.3%	-18.8%	-21.5%	-20.9%		
PFCs										
Previous NIR (2014)	kt CO_2 eq	6 539	4 311	3 317	2 172	1 608	1 456	1 552	-76.3%	-53.2%
Current NIR (2015)	kt CO_2 eq	7 558	4 986	3 839	2 511	1 859	1 687	1 799	-76.2%	-53.2%
Total change:	kt CO_2 eq	1 019	674	522	339	252	231	247		
	%	15.6%	15.6%	15.7%	15.6%	15.7%	15.9%	15.9%		
SF_6										
Previous NIR (2014)	kt CO_2 eq	3 392	3 052	1 492	393	459	422	449	-86.8%	-69.9%
Current NIR (2015)	kt CO_2 eq	3 227	2 905	1 417	374	439	396	437	-86.5%	-69.2%
Total change:	kt CO_2 eq	-165	-147	-75	-19	-20	-27	-11		
	%	-4.9%	-4.8%	-5.0%	-4.9%	-4.4%	-6.3%	-2.6%		
NF_3										
Previous NIR (2014)	kt CO_2 eq	0	0	0	0	0	0	0	-	-
Current NIR (2015)	kt CO_2 eq	0.324	0.238	0.194	0.160	0.151	0.151	0.151	-53.4%	-22.3%
Total change:	kt CO_2 eq	0.324	0.238	0.194	0.160	0.151	0.151	0.151		
	%	-	-	-	-	-	-	-		

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 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), implementation of the 2006 IPCC Guidelines, or internal continuous improvement activities.

8.2.1. ERT Recommendations

Canada's inventory submission is reviewed annually by an expert review team (ERT) following agreed-upon UNFCCC review guidelines. 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.

In the 2013 ARR,[1] the ERT recommended several 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 2014 ARR was finalized after development of the inventory and preparation of the 2015 NIR, and therefore recommendations arising from last year's review will be considered for the 2016 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. These guidelines were developed by the IPCC at the invitation of the UNFCCC. They replace the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 1997), the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000), and the Good Practice Guidance for Land Use, Land-use Change and Forestry (IPCC 2003), which were previously used to produce GHG inventories.

Compared to the other IPCC Inventory Guidelines and Good Practice Guidance, the 2006 IPCC Guidelines allow for more complex modelling approaches and provide refined methodologies for estimating emissions, particularly at higher tiers. They also include new reporting requirements (e.g. Harvested Wood Products, CH_4 emissions from underground abandoned mines), improved default emission factors and parameters (e.g. updated oxidation factors), and changes to reported source/sink categories.

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 updating the Tier 3 fugitive upstream oil and gas model to more accurately capture the impact of new technology and practices within the oil and gas industries.

Table 8–4 provides additional information and justification regarding the improvements implemented this year.

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1   Canada's 2013 ARR report entitled Canada. Report of the individual review of the inventory submission of Canada submitted in 2013 is available on the UNFCCC website at http://unfccc.int/documentation/documents/advanced_search/items/6911.php?priref=600007830.

Table 8–4   Improvements to Canada's 2015 NIR

Sector	Category	Reason for Change	Description	Section in NIR for more details
Agriculture	Enteric Fermentation, Manure Management Agricultural Soils (CRF 3.A., 3.B., and 3.D)	ERT Recommendation	Integrated consistent bison weights for N_2O and CH_4 manure management models, based on ERT recommendations from 2014 review.	Sections A3.4.3 and A3.4.4
LULUCF	Land converted to Grassland (CRF 4.C.2); Land converted to Wetlands (CRF 4.D.2); Land converted to Other Land (CRF 4.F.2)	ERT Recommendation	Previous ERTs have recommended that Canada improve on its reporting of carbon pools for subcategories reported as "NE" (ARR 2011, 98; ARR 2012, 90). Improvements have been made for many of these subcategories in this submission by using alternative notation keys "IE" and "NO", considering recent ERT recommendations (ARR 2014, 61). Land converted to Grassland is now reported as "NO", given land category definitions for Canada's LULUCF Sector. The conversion of non-forest lands to Wetlands is reported as "IE", as the conversion of all non-forest land to Wetlands is reported under Other Land converted to Wetlands. The loss of carbon from biomass and DOM pools under Land converted to Flooded Lands (Wetlands) is now reported as "IE", as carbon loss from all pools is reported under net carbon stock changes in soils. Other Land converted to Settlements and Land converted to Other Land is now reported as "NO", given land category definitions for Canada's LULUCF Sector.	Section 6.2, 6.5 and 6.6
Energy	Category 1.A	2006 IPCC Guidelines	Implementation of 2006 IPCC Guideline's default oxidation factor of 100% where country-specific factors were unavailable. Refer to Annex 6 for additional detail.	Annex 6
Energy	Fugitive Emissions: Abandoned Underground Coal Mines (CRF 1.B.1.a.i.3.)	2006 IPCC Guidelines	**New Source:** Implementation of the 2006 IPCC Tier Guideline's 2 and Tier 3 approach. Refer to section 3.3.1 Solid Fuels for additional detail.	Section 3.3.1
Energy	Fugitive Emissions: Pipeline CO_2 Transport and Storage (CRF 1.C)	2006 IPCC Guidelines	**New Source:** Implementation of the 2006 IPCC Guideline's Tier 1 approach. Refer to section 3.4 Co2 Transport and Storage for additional detail.	Section 3.4
IPPU	Cement (CRF 2.A.1)	2006 IPCC Guidelines	The ERT has strongly recommended the use of a Canadian-specific emission factor to estimate CO_2 process emissions from cement as well as account for the emissions caused by total organic carbon in the raw meal in accordance with the 2006 IPCC Guidelines. The Cement Association of Canada (CAC) has provided EC with data on clinker production, mass of mineral feeds, bypass dust leaving the kiln, clinker kiln dust (CKD) leaving the kiln, organic carbon content in the feed, raw meal:clinker ratio, and a CS calcination emission factor corrected for CaO and MgO imports. PIRD has used this information to develop a country-specific EF.	Section 4.2
IPPU	Ammonia Production (CRF 2.B.1)	2006 IPCC Guidelines	The 2006 IPCC GLs requires the emissions of CO_2 from ammonia production to be adjusted to account for the use of some of the CO_2 - produced from ammonia production - as raw material in the production of urea. Accounting for the CO_2 recovered from process and used for Urea production reduces the total emissions from Ammonia production	Section 4.5
IPPU	Integrated Circuit or Semiconductor (CRF 2.E.1)	2006 IPCC Guidelines	New Source & Gas (NF_3): The method change is triggered by the IPCC 2006 Guidelines requirement to include emissions and by-product emissions from the Semiconductor and Photovoltaic Industries. The revised reporting guidelines also require the reporting of Nitrogen Trifluoride (NF_3). The 2014 Cheminfo report on NF_3 was used to support the development of the methodology, as well as older research conducted by Environment Canada.	Section 4.13
IPPU	Product Uses as Substitutes for Ozone Depleting Substances (CRF 2.F)	2006 IPCC Guidelines	The ERT has recommended that Canada increase the accuracy of its reporting of HFC emissions from Product Uses as Substitutes for Ozone Depleting Substances by developing country-specific EFs in accordance with the 2006 IPCC Guidelines. The HFC EFs for Air Conditioning and Refrigeration developed from the study were circulated to experts for their input and agreement, and the EFs finalized. These emission factors have considered technology, practices and the regulatory environment since 2010. Prior to the inception of regulations (1999), the IPCC defaults are used with linear interpolations between the 2 two endpoints.	Section 4.14
IPPU / Energy (Transport)	Other Product Manufacture and Use (Use of Urea in SCR Vehicles) (CRF 2.G.4)	2006 IPCC Guidelines	New Source: Under the 2006 UNFCCC reporting guidelines, CO_2 emissions from the use of urea-based additives in catalytic converters must now be reported. This emission control technology is also known in the automotive industry as Sselective Ccatalytic Rreduction (SCR).	Section 4.5
Agriculture	Enteric Fermentation, Manure Management Agricultural Soils (CRF 3.A., 3.B., and 3.D)	2006 IPCC Guidelines	The 2006 IPCC Guidelines provide default parameters to estimate emissions from a number of alternative livestock, including deer, elk, wild boars, mink, fox and rabbit, for which Statistics Canada collects information in the Census of Agriculture. For completeness, it is necessary to report these emissions.	Sections A3.4.1, A3.4.2.3, A3.4.3 and A3.4.4.
Agriculture	Enteric Fermentation (CRF 3.A)	2006 IPCC Guidelines	Implementation of enteric fermentation equations from the 2006 IPCC Guidelines,: including changes to: i) 10.2/10.3-net energy of maintenance, ii) 10.6 - net energy of growth, iii) summation of gross energy (10.16) with the removal of NE gain from weight loss, and iv) change of Ym from 6% to 6.5%.	Sections A3.4.2.1.1

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Table A8-4 Improvements to Canada's 2015 NIR (cont'd)

Sector	Category	Reason for Change	Description	Section in NIR for more details
Agriculture	Manure Management (CRF 3.B.1)	2006 IPCC Guidelines	Implementation of 2006 IPCC Guidelines, manure management Equation 10.24 volatile solid excretion rates and recalculation of all regional CH_4 manure management emission factors for animal categories other than cattle, based on new volatile solid excretion rates, where previously all non-cattle emission factors were calculated based on the regional population distribution in 2001.	Sections A3.4.3
Agriculture	Manure Management, Indirect Emissions 3.B.2	2006 IPCC Guidelines	**New source:** A new requirement of the 2006 IPCC Guidelines is the reporting of the indirect emissions of leaching of N from stored manure. Previously this source was not reported. The 2006 IPCC Guidelines provide default parameters to calculate volatilisation from stored manure. Indirect emissions from manure storage occur through volatilisation (loss of NH_3 as an air emission) or from the leaching of N into saturated zones where N_2O is emitted as a by-product of denitrification. In the previous IPCC Guidelines, indirect emissions were only calculated from N leached from the application of manure, crop residues and fertilizers to agricultural soils. However it is understood that leaching also occurs from stored manure.	Section A3.4.4.2
Agriculture	Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter (CRF 3.D.1.5.)	2006 IPCC Guidelines	**New Source:** In addition to nitrogen inputs from animal manure, synthetic nitrogen fertilizers and crop residues, the 2006 IPCC Guidelines have added another source of nitrogen input – "annual amount of nitrogen in mineral soils that is mineralized in association with loss of soil organic matter as a result of changes to land management practices". This change results in additional nitrous oxide emissions from Cropland remaining Cropland reported in the Agriculture Sector.	Section A3.4.5.1
Agriculture	Indirect N_2O emissions from Managed Soils - Nitrogen Leaching and Runoff (CRF 3.D.b.2.)	2006 IPCC Guidelines	Implementing the 2006 IPCC Guidelines requires the adoption of a new default emission factor for leaching, erosion and runoff of N (EF_{LEACH}=0.75%). The previous factor used was EF_{LEACH}=2.5% (IPCC 2000).	Section A3.4.5.2
Agriculture	CO_2 Emissions from Urea Application and Other Carbon Containing Fertilizers (CRF 3.H.)	2006 IPCC Guidelines	New Source: Quantity of CO_2 released to the atmosphere upon hydrolysis of urea or urea-based nitrogen fertilizers must now be accounted for as emissions according to the 2006 IPCC Guidelines.	Section A3.4.8
Agriculture	CO_2 Emissions from Liming (CRF 3.G.)	2006 IPCC Guidelines	Change in reporting: CO_2 emissions from liming are now reported in the Agriculture sector instead of LULUCF. Although the method for the emission estimation remains unchanged, a new data source covering a full time series of activity data has been identified.	Section A3.4.8
LULUCF	Wetlands, peat extraction (CRF 4.D.1.1, 4.D.2.1)	2006 IPCC Guidelines	Estimates of CO_2 emissions from the decay of peat transported off-site from peat extraction fields are reported for the first time in this submission. Emissions are reported under Land converted to Wetlands for the first 20 years after conversion and under Wetlands remaining Wetlands thereafter. A Tier 2 approach, consistent with guidance presented in Chapter 7, Volume 4 of the 2006 IPCC Guidelines (IPCC 2006), was used to estimate the decay of peat for non-energy uses such as horticulture.	Sections 6.6.1 and A3.5.5.1
LULUCF	Settlements, urban trees (CRF 4.E.1)	2006 IPCC Guidelines	The approach used to estimate the net CO_2 removals by urban trees was revised this submission. A Tier 2A approach, consistent with guidance presented in Chapter 8, Volume 4 of the 2006 IPCC Guidelines (IPCC 2006), was used to estimate carbon sequestration by urban trees based on tree crown cover estimates. Uncertainty estimates were developed for revised removal estimates.	Sections 6.7.1 and A3.5.6.1
LULUCF	Cross-cutting (CRF 4.A,4.B,4.D,4.E)	2006 IPCC Guidelines	Estimates of emissions from harvested wood products (HWP) resulting from forest conversion to other land uses were removed from the Cropland, Wetlands and Settlements categories in this submission. In previous submissions, the approach used to estimate these emissions assumed that carbon in HWP was released immediately as CO_2; these estimates were reported in the final land use categories. Emissions from HWP are now estimated using a new approach and reported in the Harvested Wood Products category.	Sections 6.3.1, 6.4.2, 6.6.2, 6.8
LULUCF	Harvested Wood Products (HWP) (CRF 4.G.)	2006 IPCC Guidelines	Emissions from HWP are reported in this submission as a new category (4.G) in accordance with the new UNFCCC reporting guidelines on annual inventories and following the Production Approach described in the Annex to Vol. 4, Ch. 12 of the 2006 IPCC Guidelines (IPCC 2006), which considers the long term use and subsequent disposal of forest products instead of the instant oxidation approach used for previous submissions. Emissions from pre-1990 harvest (inherited emissions) are reported and HWP combusted for energy (both residential and industrial) are also reported based on aligned activity data with the Energy Sector. Products disposed of at the end of their useful life are assumed to be immediately oxidized.	Sections 6.9 and A3.5.7
Waste	Solid Waste Disposal (CRF 5.A)	2006 IPCC Guidelines	The methodology for estimating methane emissions from municipal solid waste landfills was revised based on the implementation of DOC default values from the IPCC 2006 Guidelines and a recommendation by the 2013 centralized and the 2014 in-country ERTs to use a normalization factor within the Scholl Canyon Model in accordance with the 2006 IPCC Guidelines. The normalization factor corrects for the fact that the evaluation for a single year is a discrete time estimate, rather than a continuous time estimate.	Section 7.2

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Table A8-5   Improvements to Canada's 2015 NIR (cont'd)

Sector	Category	Reason for Change	Description	Section in NIR for more details
Energy	Fuel Combustion: Residential - Biomass (CRF 1.A.4.B)	Continuous Improvement	To increase the accuracy of the emission estimates for residential biomass, improvements to the biomass model were implemented in consideration of new survey results and study findings such as quanity quantity of wood consumed, density, and combustion technology. Refer to section 3.2.7 Other Sectors and Annex 3.1 Combustion Methodology for additional detail.	Section 3.2.7 and Annex 3.1
Energy	Coke Combustion: CO_2 Emission Factor Change	Continuous Improvement	Implementation of a country-specific emission factor rather than the default 1996 IPCC guideline for combustion of coke based on information provided by integrated Canadian steel mills. Refer to Annex 6 for more detail.	Annex 6
Energy	Fugitive Emissions: Coal Mining (CH_4)	Continuous Improvement	Update of CH_4 fugitive emission factors for surface mining to reflect new field measured data to improve the accuracy of the emission estimates by taking account of new measurement methods and the state of coal mining since the last study that was completed in the 80's. Refer to Annex 3.2 Fugitive Methodologies for additional details.	Annex 3.2
Energy	Fugitive Upstream Oil and Gas (1.B.2.A – Fugitive Emissions from Fuels – Oil 1.B.2.B – Fugitive Emissions from Fuels – Natural Gas)	Continuous Improvement	"Updated the Tier 3 fugitive upstream oil and gas model based on results from a study to update the conventional upstream oil and gas industry to try to accurately capture the impact of new technology and practices make by the industries.	Annex 3.2
Energy (Transport)	Civil Aviation (1.A.3a); International Bunkers and Multilateral Operations (1.C), International Bunkers (1.C.1), Aviation Bunkers (1.C.1a)	Continuous Improvement	This change in methodology for the aviation gasoline portion of the aviation sector consists of an expanded development of AGEM which is a flight-by-flight based, aircraft specific and route parameter conscious model (AGEM was originally developed for Aviation Turbo Fuel alone). Using individual flight data improves the accuracy of domestic emissions (i.e. the origin and destination airport are both within Canada).	Annex 3.1.4.2.3
IPPU	Product Uses as Substitutes for Ozone Depleting Substances (CRF 2.F)	Continuous Improvement	A mandatory survey of bulk importers was performed for the data years 2008 to 2012 which has been QC'd and used in the HFC Inventory. To meet the needs of the country-specific emissions factors, aggregate information (1995 - 2012) was broken down to the subcategories to allow for estimation at finer resolution. This breakdown was performed based on detailed information reported for that specific year or the nearest year with sufficient detail.	Section 4.14
Agriculture	"Urine and Dung Deposited by Grazing Animals (CRF 3.D.1.3.)"	Continuous Improvement	Animal manure deposited on pasture, range and paddock (PRP) by grazing dairy and beef cattle represents a major source of nitrous oxide emissions (N_2O) in Canada. Previouslsy, emissions from PRP have been estimated using the IPCC Tier-1 method with high uncertainty. In order to improve the accuracy of these estiamates, Environment Canada funded a rmulti-year research project with scientists from Agriculture and Agri-Food Canada to quantify N_2O emissions from dairy and beef excreta deposited on pasture. and the results from of this study have been implemented as a Tier -2 country-specific emission factors to estimate emissions.	Section A3.4.5.1
Agriculture and LULUCF	Direct Soil N_2O emissions, Cropland and Grassland (CRF 3.D., CRF 4.B and 4.C)	Continuous Improvement	A major improvement was made through the incorporation of cropland and agricultural grassland activity data based on land use mapping for agricultural regions derived from Earth Observation (EO) information. A series of land use maps were generated for 1990, 2000 and 2010 using several spatial data sets which were integrated using rule sets. The resulting maps classed 30-metre meter pixels into seven primary land cover categories; cropland, grassland, forest, settlement, wetland, water and other land. The map-based data were then aggregated to cropland SLC polygons. The Census of Agriculture provided apportioning ratios for cropland area attributes which could be applied to the map-based cropland area estimates on an SLC polygon basis. As a result of this improvement, estimates of cropland areas, and the distribution of these areas on in the landscape, along with their attributes, changed (tillage practices, summerfallow, and perennial and annual crop conversion).	Sections A3.5.3 and A3.5.4
LULUCF	Forest Land (CRF 4.A.1)	Continuous Improvement	Several changes to activity data for Forest Land remaining Forest Land were incorporated into this submission (areas disturbed by wildfire in Ontario, slash burning and harvest activity data) to capture updates to the most recent statistics for these components.	Sections 6.3.1 and A3.5.2

8.3.   Planned Inventory Improvements

Canada has identified planned improvements in Table 8–5 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,

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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 8–5   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
	Road Transportation (CRF 1.A.3.e.ii Other (Off-road))	Improved, bottom-up methodology for off-road GHGs	The planned improvement will lead to more accurate GHG estimation by using purchased activity data and calculating GHG emissions estimate using NON-ROAD. This would be an improvement of the current method of using residual RESD fuel allocations. While the estimates will continue to be normalized by the RESD, the partition between off-road and on-road will be based on calculated estimates (not residuals). A secondary benefit improved allocation of emissions to economic sectors.	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, a migration from MGEM to the US EPA MOVES model is being considered to create a single model for all GHG and air pollutant (AP) emissions for on-road; this will ensure a consistent set of fleet activity data for AP and GHG. While the overall approach will be the same (AD x EF), the impacts of changing models needs to be investigated. Further, changing the provincial distribution of emissions estimates from a fuel basis to an equipment/fleet basis will be explored.	Continuous improvement	Alternative methods being considered
IPPU					
	Glass Production (CRF 2.A.3)	Allocate glass production CO_2 emissions separately.	Limestone and soda ash are both consumed in the production of glass in Canada. The CO_2 emissions associated with glass production are currently included in the estimates for Limestone and Dolomite Use, and Other Uses of Soda Ash. In order to improve transparency, glass production emissions will be reported separately in the next NIR.	Continuous Improvement	No significant progress made
	Iron and Steel Production (CRF 2.C.1)	Allocate coal emissions associated with manufacturing iron and steel to Iron and Steel Production instead of Non-energy Products from Fuels and Solvent Use.	A smaller part of the process CO_2 emissions associated with Iron and Steel Production originates from the use of reductants other than metallurgical coke. A fraction of coal, shown in the RESD's non-energy line, is used in iron and steel making and is currently reported under the Non-energy Products from Fuels and Solvent Use sub-sector. It is planned to allocate the aforementioned emissions to Iron and Steel Production. The allocation of CO_2 emissions associated with the use of other reductants (i.e. other than coke and coal) to the Energy Sector will not change.	Continuous Improvement	No significant progress made
	Integrated Circuit or Semiconductor (CRF 2.E.1), Product Uses as Substitutes for Ozone Depleting Substances (CRF 2.F) and PFC Emissions from Other Contained Product Uses (CRF 2.G.4)	Update the PFC estimation model.	Need to update and improve the PFC estimation model as per the IPCC 2006 Guidelines for Canada's next National Inventory Submission. These CRF categories are all estimated within the same model.	2006 IPPC IPCC Guidelines	Literature search underway
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 cattle in Canada is lower than the default 2006 IPCC Guidelines. A new factor can be derived from recent literature and related more closely to animal diet. Methodology has been reviewed and options identified to be presented to expert livestock committee for review	Continuous Improvement	New parameters are under development
	Enteric Fermentation/ Manure Management (CRF 3.A/3.B)	Integrate new information on animal nutrition.	Based on a compilation of multiple data sources, a time series of nutrition data for dairy cattle and swine is being derived which will affect the fraction of digestible energy of feed as well as nitrogen excretion rates for animals. Data has been collected, and analyszed. Requires approval and alignment with AAFC methodologies are required, to be followed by database implementation.	Continuous improvement	New parameters are under development

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Table A-5   Summary of Canada's Inventory Improvement Plan (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
Agriculture *(cont'd)*					
	Enteric Fermentation / Manure Management (CRF 3.A / 4B)	Revision of beef production model.	Currently the beef production model is considered to be static in the Canadian emission model. An in-depth survey of beef production was carried out, and in combination with other surveys a consistent representation of the changes in production systems over the reporting period is being developed to improve the accuracy of emisson estimates and trends.	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.	Continuous improvement	New parameters are under development
	Agricultural Soils (CRF 3.D)	Revision of renewal parameters for improved pasture	Refine estimates of average years of renewal for improved pasture in order to improve estimates of crop residue N when the improved pasture is turned over. Data will be collected by region and improved pasture types through consultations.	Continuous Improvement	Initiated data collection / study
	Agricultural Soils (CRF 3.D)	Improve estimates of crop residue N	Data on how crop residues are managed are available through the Census of Agriculture or Farm Environmental Management Survey, but these survey results have not been used for estimating crop residue N actually returned to soils.	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 sub-categories with estimates reported as "NE"	Previous ERTs have recommended that Canada improve on its reporting of carbon pools for subcategories reported as "NE" (Annual Review Report 2011, paragraph 98; Annual Review Report 2012, paragraph 90). Improvements have been made for many of these subcategories in previous and the current submission. Currently, estimates for Grassland (GL) remaining GL, Wetlands (WL) and Settlements (SL) converted to Cropland (CL) and CL and WL converted to SL and estimates for some pools in SL remaining SL are reported as "NE". Information on soil organic carbon for GL remaining GL is reported as "NE". 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 category using the IPCC Tier 1 method based on no change in management practices since 1990. Emissions due to grassland burning are reported in CRF Table 4(V). If conversion of WL and SL to CL occurs, it is assumed to be minor. There is no activity data available to verify/revise this assumption. Historic loss of peat forming wetlands to agriculture is reported in the CL category and the Agriculture Sector respectively, as cultivation of organic soils. There is no evidence that new organic soils are being brought into crop production. The Tier 1 approach utilised for this category develops estimates based on the total area of cultivated organic soils, which is assumed to be constant, rather than land-use change estimates. Conversion of CL and WL to SL may occur. However, there is insufficient activity data available to develop estimates for these land conversion subcategories. The resources required for collecting and developing activity data for WL and SL converted to CL, and CL and WL converted to SL would be considerable given that these categories are expansive and diverse. Furthermore, there is no specific guidance in the 2006 IPCC Guidelines for estimating emissions related to these conversion subcategories. However, alternative methodologies and data sources are being explored to verify and/or revise the reporting of these categories.	UNFCCC ERT Recommendation	Alternative methods being considered
	Forest Land Conversion LCL, LWL, LSL (CRF 4.B.2, 4.D.2, 4.E.2)	Updated forest conversion data	Addition of a new mapping time period (circa 2012) will reduce uncertainties associated with extrapolation of activity data. Other efforts such as ongoing quality control activities, addition of new sampling and enhanced mapping will also lead to improved estimates. Work in progress, by Canadian Forest Service partners. Status will be revised in next planning meeting	Continuous improvement	Data analysis underway
	Cross-cutting	Development of a plan and time frame for estimating and reporting uncertainties for all LULUCF subcategories.	Previous ERTs have encouraged Canada to perform an uncertainty analysis for all LULUCF subcategories and to provide details of this analysis in future submissions and recommended that Canada indicate its plan and time frame for estimating and reporting uncertainties for all LULUCF subcategories (ARR 2012, 93). 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. Options to update uncertainty estimates and develop uncertainty estimates for the remaining LULUCF sub-categories are being explored.	UNFCCC ERT recommendation	Alternative methods being considered

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Table 8-5   Summary of Canada's Inventory Improvement Plan (cont'd)

Sector	Category	Improvement	Description	Basis of Planned Improvement	Progress Update
LULUCF *(cont'd)*					
	Wetlands, peat extraction (CRF 4.D.1.1, 4.D.2.1)	Assess additional guidance applicable to peat extraction in the IPCC Wetlands Supplement	The 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement) provides additional guidance on drainage and rewetting of organic soils which is applicable for developing estimates of emissions and removals due to peat extraction. New guidance in the Wetlands Supplement 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)	Develop uncertainty estimates, improve integration of residential firewood data and estimate long-term emissions from solid waste disposal sites	Planned improvements for this category will focus on conducting a formal uncertainty assessment and on improving the integration of residential firewood consumption for the next inventory submission. Work is ongoing to develop other country-specific half-lives, to incorporate the effects of wood and paper waste in solid waste disposal sites, and to expand the temporal coverage, currently limited by available data. Integration of data related with to residential firewood and with solid waste disposal sites requires collaboration work with Energy and Waste sectors, to ensure consistency between LULUCF and those wsectors.	Continuous improvement	Initiated data collection / study
Waste					
	Solid Waste Disposal (CRF - 5.A)	Update waste composition data and associated degradable organic carbon values, with a view to improving the accuracy of the relevant emission estimates.	A multi-year study on waste composition and associated degradable organic carbon values has been initiated, and future improvements are likely in the 2016 NIR.	UNFCCC ERT recommendation	Initiated data collection / study
	Incineration and Open Burning of Waste (CRF 5.C)	Allocation of emissions from waste incineration	"Canada reports all waste incineration under the wWaste sSector, despite the fact that several waste incineration plants are operating with energy recovery. Reallocation is planned for waste incineration with energy recovery to the eEnergy sSector; consideration for the heat recovery facilities transferred to the Energy Sector in the 2016 Submission. Survey results waiting for examination of the heat recovering portion.	UNFCCC ERT Recommendation	Data analysis underway

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