Environment and Climate Change Canada
Environnement et Changement climatique Canada

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

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

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LIST OF COMMON ACRONYMS, ABBREVIATIONS AND UNITS

Acronymns and Abbreviations

CAC	Criteria Air Contaminant
CANSIM	Statistics Canada's key socioeconomic database
CEPA 1999	*Canadian Environmental Protection Act, 1999*
CESI	Canadian Environmental Sustainability Indicators
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
ECCC	Environment and Climate Change Canada
EF	emission factor
GDP	gross domestic product
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
HFC	hydrofluorocarbon
HWP	harvested wood products
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Proccesses and Product Use
LULUCF	Land Use, Land-use Change and Forestry
N/A	not available
MSW	municipal solid waste
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
NPRI	National Pollutant Release Inventory
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
PFC	perfluorocarbon
POP	persistent organic pollutant
QA	quality assurance
QC	quality control
RESD	Report on Energy Supply and Demand in Canada
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

Chemical Formulas

Al	aluminium
Al_2O_3	alumina

CaC_2	calcium carbide
$CaCO_3$	calcium carbonate; limestone
$CaMg(CO_3)_2$	dolomite (also $CaCO_3 \cdot MgCO_3$)
CaO	lime; quicklime; calcined limestone
CF_4	carbon tetrafluoride
C_2F_6	carbon hexafluoride
CH_3OH	methanol
CH_4	methane
C_2H_6	ethane
C_3H_8	propane
C_4H_{10}	butane
C_2H_4	ethylene
C_6H_6	benzene
$CHCl_3$	chloroform
CO	carbon monoxide
CO_2	carbon dioxide
CO_2 eq	carbon dioxide equivalent
H_2	hydrogen
H_2O	water
H_2S	hydrogen sulphide
HCFC	hydrochlorofluorocarbon
HCl	hydrochloric acid
HF	hydrogen fluoride
HNO_3	nitric acid
K_2CO_3	potassium carbonate
Mg	magnesium
$MgCO_3$	magnesite; magnesium carbonate
MgO	magnesia; dolomitic lime
N	nitrogen
N_2	nitrogen gas
Na_2CO_3	sodium carbonate; soda ash
Na_3AlF_6	cryolite
NF_3	nitrogen trifluoride
NH_3	ammonia
NH_4+	ammonium
NH_4NO_3	ammonium nitrate
N_2O	nitrous oxide
N_2O-N	Nitrous oxide emissions represented in terms of nitrogen
NO	nitric oxide
NO_2	nitrogen dioxide
NO_3-	nitrate

NO_x	nitrogen oxides
O_2	oxygen
SF_6	sulphur hexafluoride
SiC	silicon carbide
SO_2	sulphur dioxide
SO_x	sulphur oxides

Notation Keys

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

Units

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

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Annex 1

KEY CATEGORIES

A1.1. Key Categories—Methodology

This annex presents the use of an IPCC Tier 1 key category analysis and results for Canada's inventory submission. The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) recommend as good practice the identification of key categories of emissions and removals. The intent is to help inventory agencies prioritize their efforts to improve overall estimates. A key category is defined as "one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level of emissions and removals, the trend in emissions and removals, or uncertainty in emissions and removals" (IPCC 2006); this term is used in reference to both source and sink categories.

Good practice first requires that inventories be disaggregated into categories from which key sources and sinks may be identified. Source and sink categories are defined according to the following guidelines:

- IPCC categories should be used with emissions expressed in CO_2 equivalent units according to standard global warming potentials (GWPs).
- A category should be identified for each gas emitted or removed, since the methods, emission factors, and related uncertainties differ for each gas.
- Categories that use the same emission factors based on common assumptions should be aggregated before analysis.

The IPCC Tier 1 quantitative approach is used to identify key categories from two perspectives: their contribution to the overall emissions and their contribution to the emission trend. The level assessment analyzes the emission contribution that each category makes to the national total (with and without LULUCF). The trend assessment uses each category's relative contribution to the overall emissions, but assigns greater weight to the categories whose relative trend departs from the overall trend (with and without LULUCF). In this assessment, trends are calculated as the absolute changes between the base and most recent inventory years.

The percent contributions to both levels and trends in emissions are calculated and sorted from greatest to least. A cumulative total is calculated for both approaches. A cumulative contribution threshold of 95% for both level and trend assessments is a reasonable approximation of 90% uncertainty for the Tier 1 method of determining key categories (IPCC 2006). This threshold has therefore been used in this analysis to define an upper boundary for key category identification. Hence, when source and sink contributions are sorted in decreasing order of importance, those largest ones that together contribute to 95% of the cumulative total are considered quantitatively to be key.

Level Assessment

Level contribution of each source or sink is calculated according to Equation A1–1, which follows IPCC (2006):

Equation A1–1: for source/sink category level assessment:

$$L_{x,t} = \frac{|E_{x,t}|}{\sum_y |E_{y,t}|}$$

where:

$L_{x,t}$	=	level assessment for source or sink x in latest inventory year (year *t*)
$\|E_{x,t}\|$	=	the absolute value of emission or removal estimate of source or sink category *x* in year *t*
$\Sigma_y \|E_{y,t}\|$	=	total contribution, which is the sum of the absolute values of emissions and removals in year *t* calculated using the aggregation level chosen by the country for key category analysis; because both emissions and removals are entered with positive sign, the total contribution/level can be larger than a country's total emissions less removals

Trend Assessment

The trend contribution of each source and sink is calculated according to Equations A1-2 and A$_1$-3 following IPCC (2006). Note that the use of Equation A1-3 only applies to source and sink categories where there are zero emissions in the base year.

Equation A1–2: for source/sink category trend assessment:

$$T_{x,t} = L_{x,0} \bullet \left| \left[\frac{(E_{x,t} - E_{x,0})}{|E_{x,0}|} \right] - \left[\frac{(\sum_y E_{y,t} - \sum_y E_{y,0})}{|\sum_y E_{y,0}|} \right] \right|$$

where:

$T_{x,t}$	=	trend assessment of source or sink category x in year t as compared to the base year (year 0)
$L_{x,0}$	=	the level assessment for source or sink category x in year 0 (derived in Equation A1–1)
$E_{x,t}$ and $E_{x,0}$	=	real values of estimates of source or sink category x in years t and 0, respectively
$\Sigma_y E_{y,t}$ and $\Sigma_y E_{y,0}$	=	total inventory estimates in years t and 0, respectively

Equation A1–3: for source and sink category trend assessment with zero base year emissions:

$$T_{x,t} = \left| \frac{E_{x,t}}{\sum_y |E_{y,0}|} \right|$$

where:

$T_{x,t}$	=	trend assessment of source or sink category *x* in year *t* as compared to the base year (year 0)
$E_{x,t}$	=	real values of estimates of source or sink category *x* in year t
$\Sigma_y \|E_{y,0}\|$	=	total inventory estimates in year 0

The overall purpose of identifying key categories is the institution of best practices in greenhouse gas inventory development. The appropriate aggregation of categories is crucial to reflect not only actual sources and sinks but also identical estimation procedures. Thus, while the UNFCCC common reporting format (CRF) categories provide a basis for identifying sources and sinks, some aggregation of these sources and sinks can occur when using the same emission factors based on common estimation assumptions. In this analysis, sectors and major categories such as Fuel Combustion, Fugitive Emissions, Industrial Processes and Product Use (IPPU), Agriculture and Waste are in keeping with the CRF. Within these major categories, the aggregation of subcategories occurs when estimates are made based on common assumptions with respect to emission factors and common activity data.

A1.1.1. Summary Assessment

Key categories were assessed for the 2015 inventory year using level and trend criteria and for the base year using the level criterion only.

There were 34 level key categories in 1990, while in 2015 there were 40 with all combined criteria. Results are shown in TableTable A$_1$–1.

Table A1–1 Key Category Analysis Summary, 2015 Inventory Year

Source Table	IPCC Category	Direct Greenhouse Gas	Key Category (1990/2015)	Criteria 1990 / 2015 L: Level, T: Trend
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	Yes / Yes	L / L , T
1-A*	Stationary Fuel Combustion - Solid Fuels	CH_4	No / No	
1-A*	Stationary Fuel Combustion - Solid Fuels	N_2O	No / No	
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	Yes / Yes	L / L , T
1-A*	Stationary Fuel Combustion - Liquid Fuels	CH_4	No / No	
1-A*	Stationary Fuel Combustion - Liquid Fuels	N_2O	No / No	
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	Yes / Yes	L / L , T
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CH_4	No / No	
1-A*	Stationary Fuel Combustion - Gaseous Fuels	N_2O	No / No	
1-A*	Stationary Fuel Combustion - Other Fuels	CO_2	No / No	
1-A*	Stationary Fuel Combustion - Other Fuels	CH_4	No / No	
1-A*	Stationary Fuel Combustion - Other Fuels	N_2O	No / No	
1-A*	Stationary Fuel Combustion - Fugitives	CO_2	No / No	
1-A*	Stationary Fuel Combustion - Fugitives	CH_4	No / No	
1-A*	Stationary Fuel Combustion - Fugitives	N2O	No / No	
1-A*	Stationary Fuel Combustion - Biomass	CO2	No / No	
1-A*	Stationary Fuel Combustion - Biomass	CH4	Yes / Yes	L / T
1-A*	Stationary Fuel Combustion - Biomass	N2O	No / No	
1-A-2-g	Fuel Combustion - Manufacturing Industries and Construction/Other/ Off-Road Vehicles and Other Machinery	CO2	Yes / Yes	L / L
1-A-2-g	Fuel Combustion - Manufacturing Industries and Construction/Other/ Off-Road Vehicles and Other Machinery	CH4	No / No	
1-A-2-g	Fuel Combustion - Manufacturing Industries and Construction/Other/ Off-Road Vehicles and Other Machinery	N2O	No / No	
1-A-3-a	Fuel Combustion - Domestic Aviation	CO2	Yes / Yes	L / L
1-A-3-a	Fuel Combustion - Domestic Aviation	CH4	No / No	
1-A-3-a	Fuel Combustion - Domestic Aviation	N2O	No / No	
1-A-3-b	Fuel Combustion - Road Transportation	CO2	Yes / Yes	L / L , T
1-A-3-b	Fuel Combustion - Road Transportation	CH4	No / No	
1-A-3-b	Fuel Combustion - Road Transportation	N2O	Yes / Yes	L / T
1-A-3-c	Fuel Combustion - Railways	CO2	Yes / Yes	L / L
1-A-3-c	Fuel Combustion - Railways	CH4	No / No	
1-A-3-c	Fuel Combustion - Railways	N2O	No / No	
1-A-3-d	Fuel Combustion - Domestic Navigation	CO2	Yes / Yes	L / L , T
1-A-3-d	Fuel Combustion - Domestic Navigation	CH4	No / No	
1-A-3-d	Fuel Combustion - Domestic Navigation	N2O	No / No	
1-A-3-e-ii	Fuel Combustion - Other Transport (Off Road)	CO2	Yes / Yes	L / T
1-A-3-e-ii	Fuel Combustion - Other Transport (Off Road)	CH4	No / No	
1-A-3-e-ii	Fuel Combustion - Other Transport (Off Road)	N2O	No / No	
1-A-3-e-i	Fuel Combustion - Pipeline Transport	CO2	Yes / Yes	L / L
1-A-3-e-i	Fuel Combustion - Pipeline Transport	CH4	No / No	
1-A-3-e-i	Fuel Combustion - Pipeline Transport	N2O	No / No	
1-A-4-a	Fuel Combustion - Commercial Institutional/Off-Road Vehicles and Other Machinery	CO_2	No / No	
1-A-4-a	Fuel Combustion - Commercial Institutional/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-4-a	Fuel Combustion - Commercial Institutional/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-A-4-b	Fuel Combustion - Residential/Off-Road Vehicles and Other Machinery	CO_2	No / No	
1-A-4-b	Fuel Combustion - Residential/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-4-b	Fuel Combustion - Residential/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-A-4-c	Fuel Combustion - Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CO_2	Yes / Yes	L / L
1-A-4-c	Fuel Combustion - Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-4-c	Fuel Combustion - Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-B-1-a	Fugitive Emissions - Coal Mining and Handling	CH_4	Yes / Yes	L / T
1-B-2-(a+c)	Fugitive Emissions - Oil	CO_2	Yes / Yes	L / L
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	Yes / Yes	L / L , T
1-B-2-(a+c)	Fugitive Emissions - Oil	N_2O	No / No	
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	Yes / Yes	L / L , T
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH_4	Yes / Yes	L / L

Table A1-1 Key Category Analysis Summary, 2015 Inventory Year

Source Table	IPCC Category	Direct Greenhouse Gas	Key Category (1990/2015)	Criteria 1990 / 2015 L: Level, T: Trend
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	N_2O	No / No	
1-C-1	CO2 Transport and Storage - Pipelines	CO_2	No / No	
2-A-1	IPPU - Cement Production	CO_2	Yes / Yes	L / L
2-A-2	IPPU - Lime Production	CO_2	No / No	
2-A-3	IPPU - Glass Production	CO_2	No / No	
2-A-4-b	IPPU - Other Uses of Soda Ash	CO_2	No / No	
2-A-4-c	IPPU - Other (Magnesite Use)	CO_2	No / No	
2-A-4-d	IPPU - Other (Limestone and Dolomite Use Other)	CO_2	No / No	
2-B-1	IPPU - Ammonia Production	CO_2	No / No	
2-B-2	IPPU - Nitric Acid Production	N_2O	No / No	
2-B-3	IPPU - Adipic Acid Production	N_2O	Yes / Yes	L / T
2-B-7	IPPU - Soda Ash Production	CO_2	No / No	
2-B-8	IPPU - Petrochemical and Carbon Black Production	CO_2	Yes / Yes	L / T
2-B-8	IPPU - Petrochemical and Carbon Black Production	CH_4	No / No	
2-B-8	IPPU - Petrochemical and Carbon Black Production	N_2O	No / No	
2-B-9-a	IPPU - Fluorochemical Production	HFCs	No / No	
2-C-1	IPPU - Iron and Steel Production	CO_2	Yes / Yes	L / L , T
2-C-1	IPPU - Iron and Steel Production	CH_4	No / No	
2-C-3	IPPU - Aluminium Production	CO_2	No / Yes	L , T
2-C-3	IPPU - Aluminium Production	PFCs	Yes / Yes	L / T
2-C-3	IPPU - Aluminium Production	SF_6	No / No	
2-C-4	IPPU - Magnesium Production	SF_6	No / Yes	T
2-C-7	IPPU - Other (Magnesium Casting)	SF_6	No / No	
2-D-1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	Yes / Yes	L / L , T
2-E-1	IPPU - Integrated Circuit or Semiconductor	PFCs	No / No	
2-E-1	IPPU - Integrated Circuit or Semiconductor	SF_6	No / No	
2-E-1	IPPU - Integrated Circuit or Semiconductor	NF_3	No / No	
2-E-5	IPPU - Other	PFCs	No / No	
2-F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	HFCs	No / Yes	L , T
2-F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	PFCs	No / No	
2-G-1	IPPU - Electrical Equipment	SF_6	No / No	
2-G-2	IPPU - SF6 and PFCs from Other Product Use	PFCs	No / No	
2-G-3-a	IPPU - Other (Medical Applications of N2O)	N_2O	No / No	
2-G-3-b	IPPU - Other (Use of N2O for Propellant)	N_2O	No / No	
2-G-4	IPPU - Other (Use of Urea in SCR vehicles)	CO_2	No / No	
3-A	Agriculture - Enteric Fermentation	CH_4	Yes / Yes	L / L , T
3-B	Agriculture - Manure Management	CH_4	Yes / Yes	L / L
3-B	Agriculture - Manure Management	N_2O	Yes / Yes	L / L
3-B-5	Agriculture - Indirect N2O Emissions	N_2O	No / No	
3-D-1	Agriculture - Direct N2O Emissions from Managed Soils	N_2O	Yes / Yes	L / L , T
3-D-2	Agriculture - Indirect N2O Emissions from Managed Soils	N_2O	No / Yes	L
3-F	Agriculture - Field Burning of Agricultural Residues	CH_4	No / No	
3-F	Agriculture - Field Burning of Agricultural Residues	N_2O	No / No	
3-G-1	Agriculture - Limestone CaCO3	CO_2	No / No	
3-H	Agriculture - Urea Application	CO_2	No / No	
3-I	Agriculture - Other Carbon-Containing Fertilizers	CO_2	No / Yes	T
4-A-1	LULUCF - Forest Land remaining Forest Land	CO_2	Yes / Yes	L / L , T
4-A-1	LULUCF - Forest Land remaining Forest Land	CH_4	No / No	
4-A-1	LULUCF - Forest Land remaining Forest Land	N_2O	No / No	
4-A-2	LULUCF - Land converted to Forest Land	CO_2	No / No	
4-B-1	LULUCF - Cropland remaining Cropland	CO_2	No / Yes	L , T
4-B-2	LULUCF - Land converted to Cropland	CO_2	Yes / Yes	L / T
4-B-2	LULUCF - Land converted to Cropland	CH_4	No / No	
4-B-2	LULUCF - Land converted to Cropland	N_2O	No / No	
4-D-1	LULUCF - Wetlands remaining Wetlands	CO_2	No / No	
4-D-1	LULUCF - Wetlands remaining Wetlands	CH_4	No / No	
4-D-1	LULUCF - Wetlands remaining Wetlands	N_2O	No / No	
4-D-2	LULUCF - Land converted to Wetlands	CO_2	Yes / Yes	L / T
4-D-2	LULUCF - Land converted to Wetlands	CH_4	No / No	
4-D-2	LULUCF - Land converted to Wetlands	N_2O	No / No	
4-E-2	LULUCF - Settlements remaining Settlements	CO_2	No / No	

Table A1-1 Key Category Analysis Summary, 2015 Inventory Year

Source Table	IPCC Category	Direct Greenhouse Gas	Key Category (1990/2015)	Criteria 1990 / 2015 L: Level, T: Trend
4-E-2	LULUCF - Land converted to Settlements	CO_2	Yes / Yes	L / L , T
4-E-2	LULUCF - Land converted to Settlements	CH_4	No / No	
4-E-2	LULUCF - Land converted to Settlements	N_2O	No / No	
4-C	LULUCF - Grassland	CH_4	No / No	
4-C	LULUCF - Grassland	N_2O	No / No	
4-G	LULUCF - Harvested Wood Products (HWP)	CO_2	Yes / Yes	L / L , T
5-A-1	Waste - Solid Waste Disposal	CH_4	Yes / Yes	L / L , T
5-B	Waste - Biological Treatment of Solid Waste	CH_4	No / No	
5-B	Waste - Biological Treatment of Solid Waste	N_2O	No / No	
5-C-1	Waste - Incineration and Open Burning of Waste	CO_2	No / No	
5-C-1	Waste - Incineration and Open Burning of Waste	N_2O	No / No	
5-C-1	Waste - Incineration and Open Burning of Waste	CH_4	No / No	
5-D-1	Waste - Wastewater Treatment and Discharge	CH_4	No / No	
5-D-1	Waste - Wastewater Treatment and Discharge	N_2O	No / No	

Notes: L = key category by level (for an individual year), T = key category by trend (between the base year and the current year)

Table A1–2 1990 Key Categories by Level Assessment With and Without LULUCF

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates ($kt\ CO_2\ eq$)		Level Assessment		Cumulative Total	
			Base Year 1990	Current Year 2015	without LULUCF	with LULUCF	without LULUCF	with LULUCF
4-A-1	LULUCF - Forest Land remaining Forest Land	CO_2	-251 669	-164 379	NA	0.246	NA	0.25
4-G	LULUCF - Harvested Wood Products (HWP)	CO_2	134 503	134 877	NA	0.131	NA	0.38
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	118 177	199 773	0.193	0.115	0.19	0.49
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	88 446	141 381	0.145	0.086	0.34	0.58
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	86 726	65 742	0.142	0.085	0.480	0.664
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	71 635	53 897	0.117	0.070	0.60	0.73
3-A	Agriculture - Enteric Fermentation	CH_4	22 815	25 005	0.037	0.022	0.63	0.76
5-A-1	Waste - Solid Waste Disposal	CH_4	21 520	22 147	0.035	0.021	0.67	0.78
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH_4	17 600	19 790	0.029	0.017	0.70	0.79
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	16 741	23 264	0.027	0.016	0.73	0.81
3-D-1	Agriculture - Direct N_2O Emissions from Managed Soils	N_2O	14 008	18 723	0.023	0.014	0.75	0.82
2-C-1	IPPU - Iron and Steel Production	CO_2	10 477	7 992	0.017	0.010	0.77	0.83
2-B-3	IPPU - Adipic Acid Production	N_2O	10 303	0	0.017	0.010	0.78	0.84
4-B-2	LULUCF - Land converted to Cropland	CO_2	9 284	2 542	NA	0.009	NA	0.85
1-A-4-c	Fuel Combustion - Agriculture Forestry Fishing/ Off-Road Vehicles and Other Machinery	CO_2	9 077	10 204	0.015	0.009	0.80	0.86
1-A-2-g	Fuel Combustion - Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	8 982	11 680	0.015	0.009	0.81	0.87
1-A-3-e-ii	Fuel Combustion - Other Transport (Off Road)	CO_2	8 182	3 576	0.013	0.008	0.83	0.88
2-C-3	IPPU - Aluminium Production	PFCs	7 558	954	0.012	0.007	0.84	0.89
1-A-3-a	Fuel Combustion - Domestic Aviation	CO_2	7 093	7 225	0.012	0.007	0.85	0.89
1-A-3-e-i	Fuel Combustion - Pipeline Transport	CO_2	6 685	7 892	0.011	0.007	0.86	0.90
4-E-2	LULUCF - Land converted to Settlements	CO_2	6 284	5 839	NA	0.006	NA	0.91
1-A-3-c	Fuel Combustion - Railways	CO_2	6 222	6 642	0.010	0.006	0.87	0.91
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	6 129	5 324	0.010	0.006	0.88	0.92
2-A-1	IPPU - Cement Production	CO_2	5 756	6 263	0.009	0.006	0.89	0.92
1-B-2-(a+c)	Fugitive Emissions - Oil	CO_2	5 477	7 328	0.009	0.005	0.90	0.93
2-D-1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	5 015	10 798	0.008	0.005	0.91	0.93
1-A-3-d	Fuel Combustion - Domestic Navigation	CO_2	4 741	4 299	0.008	0.005	0.92	0.94
1-A*	Stationary Fuel Combustion - Biomass	CH_4	4 628	3 225	0.008	0.005	0.92	0.94
4-D-2	LULUCF - Land converted to Wetlands	CO_2	3 530	589	NA	0.003	NA	0.95
3-B	Agriculture - Manure Management	CH_4	3 491	3 753	0.006	0.003	0.93	0.95
1-A-3-b	Fuel Combustion - Road Transportation	N_2O	3 253	2 478	0.005	0.003	0.93	NA
1-B-1-a	Fugitive Emissions - Coal Mining and Handling	CH_4	2 824	1 139	0.005	0.003	0.95	NA
2-B-8	IPPU - Petrochemical and Carbon Black Production	CO_2	3 125	2 459	0.005	0.003	0.94	NA
3-B	Agriculture - Manure Management	N_2O	3 073	3 620	0.005	0.003	0.94	NA

Note: NA = Not Applicable

A1.2. Key Category Tables

A1.2.1. Level Assessment With and Without LULUCF

Table A1–2 shows the 1990 key categories identified from level assessment with and without LULUCF.

Table A1–3 shows the 2015 key categories identified from level assessment with and without LULUCF.

A1.2.2. Trend Assessment With and Without LULUCF

Table A1–4 and Table A1–5 show the key categories indicated from the trend assessment with and without LULUCF, respectively. These tables also show the contribution of the key categories to the trend assessment.

The integration of the LULUCF Sector introduces additional key categories and alters the categories' relative contributions and overall trends, which causes a rearrangement in the ranking

Table A1–3 2015 Key Categories by Level Assessment With and Without LULUCF

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates ($kt CO_2 eq$)		Level Assessment		Cumulative Total	
			Base Year 1990	Current Year 2015	without LULUCF	with LULUCF	without LULUCF	with LULUCF
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	118 177	199 773	0.277	0.190	0.28	0.19
4-A-1	LULUCF - Forest Land remaining Forest Land	CO_2	-251 669	-164 379	NA	0.157	NA	0.35
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	88 446	141 381	0.196	0.135	0.47	0.48
4-G	LULUCF - Harvested Wood Products (HWP)	CO_2	134 503	134 877	NA	0.128	NA	0.61
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	86 726	65 742	0.091	0.063	0.56	0.67
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	71 635	53 897	0.075	0.051	0.64	0.72
3-A	Agriculture - Enteric Fermentation	CH_4	22 815	25 005	0.035	0.024	0.67	0.75
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	16 741	23 264	0.032	0.022	0.71	0.77
5-A-1	Waste - Solid Waste Disposal	CH_4	21 520	22 147	0.031	0.021	0.74	0.79
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH_4	17 600	19 790	0.027	0.019	0.76	0.81
3-D-1	Agriculture - Direct N_2O Emissions from Managed Soils	N_2O	14 008	18 723	0.026	0.018	0.79	0.83
4-B-1	LULUCF - Cropland remaining Cropland	CO_2	-887	-13 584	NA	0.013	NA	0.84
1-A-2-g	Fuel Combustion - Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	8 982	11 680	0.016	0.011	0.81	0.85
2-F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	11 011	0.015	0.010	0.82	0.86
2-D-1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	5 015	10 798	0.015	0.010	0.84	0.87
1-A-4-c	Fuel Combustion - Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CO_2	9 077	10 204	0.014	0.010	0.85	0.88
2-C-1	IPPU - Iron and Steel Production	CO_2	10 477	7 992	0.011	0.008	0.86	0.89
1-A-3-e-i	Fuel Combustion - Pipeline Transport	CO_2	6 685	7 892	0.011	0.008	0.87	0.90
1-B-2-(a+c)	Fugitive Emissions - Oil	CO_2	5 477	7 328	0.010	0.007	0.88	0.90
1-A-3-a	Fuel Combustion - Domestic Aviation	CO_2	7 093	7 225	0.010	0.007	0.89	0.91
1-A-3-c	Fuel Combustion - Railways	CO_2	6 222	6 642	0.009	0.006	0.90	0.92
2-A-1	IPPU - Cement Production	CO_2	5 756	6 263	0.009	0.006	0.91	0.92
4-E-2	LULUCF - Land converted to Settlements	CO_2	6 284	5 839	NA	0.006	NA	0.93
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	6 129	5 324	0.007	0.005	0.92	0.93
2-C-3	IPPU - Aluminium Production	CO_2	2 715	5 052	0.007	0.005	0.92	0.94
1-A-3-d	Fuel Combustion - Domestic Navigation	CO_2	4 741	4 299	0.006	0.004	0.93	0.94
3-D-2	Agriculture - Indirect N_2O Emissions from Managed Soils	N_2O	2 717	3 980	0.006	0.004	0.94	0.95
3-B	Agriculture - Manure Management	CH_4	3 491	3 753	0.005	0.004	0.94	0.95
3-B	Agriculture - Manure Management	N_2O	3 073	3 620	0.005	0.003	0.95	NA

Note: NA = Not Applicable

of key categories. For example, a single LULUCF category, Forest Land Remaining Forest Land (CO_2), is ranked as the second highest contributor in both the trend and level assessments.

The trend assessment without LULUCF identifies 23 key categories, while the same analysis with LULUCF results in 27 key categories, including six categories from the LULUCF Sector.

Table A1–4 Key Categories by Trend Assessment with LULUCF

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq) Base Year 1990	Current Year 2015	Trend Assessment	Contribution to Trend	Cumulative Total
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	118 177	199 773	0.060	0.177	0.18
4-A-1	LULUCF - Forest Land remaining Forest Land	CO_2	-251 669	-164 379	0.043	0.127	0.30
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	88 446	141 381	0.037	0.109	0.41
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	86 726	65 742	0.035	0.104	0.52
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	71 635	53 897	0.029	0.087	0.60
4-G	LULUCF - Harvested Wood Products (HWP)	CO_2	134 503	134 877	0.022	0.066	0.67
4-B-1	LULUCF - Cropland remaining Cropland	CO_2	-887	-13 584	0.013	0.037	0.71
2-B-3	IPPU - Adipic Acid Production	N_2O	10 303	0	0.012	0.035	0.74
2-F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	11 011	0.011	0.032	0.77
4-B-2	LULUCF - Land converted to Cropland	CO_2	9 284	2 542	0.008	0.024	0.80
2-C-3	IPPU - Aluminium Production	PFCs	7 558	954	0.008	0.023	0.82
1-A-3-e-ii	Fuel Combustion - Other Transport (Off Road)	CO_2	8 182	3 576	0.006	0.017	0.84
2-D-1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	5 015	10 798	0.005	0.014	0.85
2-C-1	IPPU - Iron and Steel Production	CO_2	10 477	7 992	0.004	0.012	0.86
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	16 741	23 264	0.004	0.010	0.87
4-D-2	LULUCF - Land converted to Wetlands	CO_2	3 530	589	0.003	0.010	0.88
2-C-4	IPPU - Magnesium Production	SF_6	2 738	0	0.003	0.009	0.89
5-A-1	Waste - Solid Waste Disposal	CH_4	21 520	22 147	0.003	0.009	0.90
3-D-1	Agriculture - Direct N_2O Emissions from Managed Soils	N_2O	14 008	18 723	0.002	0.007	0.91
1-A*	Stationary Fuel Combustion - Biomass	CH_4	4 628	3 225	0.002	0.006	0.91
1-B-1-a	Fugitive Emissions - Coal Mining and Handling	CH_4	2 824	1 139	0.002	0.006	0.92
2-C-3	IPPU - Aluminium Production	CO_2	2 715	5 052	0.002	0.005	0.93
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	6 129	5 324	0.002	0.005	0.93
3-A	Agriculture - Enteric Fermentation	CH_4	22 815	25 005	0.002	0.005	0.94
4-E-2	LULUCF - Land converted to Settlements	CO_2	6 284	5 839	0.001	0.004	0.94
1-A-3-b	Fuel Combustion - Road Transportation	N_2O	3 253	2 478	0.001	0.004	0.94
3-I	Agriculture - Other Carbon-Containing Fertilizers	CO_2	1 191	2 676	0.001	0.004	0.95

Table A1–5 Key Categories by Trend Assessment without LULUCF

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq) Base Year IPCC Category	Current Year 2015	Trend Assessment	Contribution to Trend	Cumulative Total
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	118 177	199 773	0.000	0.000	0.24
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	88 446	141 381	0.001	0.004	0.39
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	86 726	65 742	0.029	0.078	0.53
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	71 635	53 897	0.000	0.000	0.65
2-B-3	IPPU - Adipic Acid Production	N_2O	10 303	0	0.004	0.012	0.70
2-F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	11 011	0.000	0.000	0.74
2-C-3	IPPU - Aluminium Production	PFCs	7 558	954	0.000	0.000	0.78
1-A-3-e-ii	Fuel Combustion - Other Transport (Off Road)	CO_2	8 182	3 576	0.000	0.000	0.80
2-D-1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	5 015	10 798	0.000	0.000	0.82
2-C-1	IPPU - Iron and Steel Production	CO_2	10 477	7 992	0.000	0.000	0.84
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	16 741	23 264	0.001	0.003	0.85
5-A-1	Waste - Solid Waste Disposal	CH_4	21 520	22 147	0.000	0.000	0.86
2-C-4	IPPU - Magnesium Production	SF_6	2 738	0	0.000	0.000	0.88
1-A*	Stationary Fuel Combustion - Biomass	CH_4	4 628	3 225	0.000	0.000	0.89
1-B-1-a	Fugitive Emissions - Coal Mining and Handling	CH_4	2 824	1 139	0.000	0.000	0.89
3-D-1	Agriculture - Direct N_2O Emissions from Managed Soils	N_2O	14 008	18 723	0.001	0.002	0.90
3-A	Agriculture - Enteric Fermentation	CH_4	22 815	25 005	0.000	0.000	0.91
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	6 129	5 324	0.000	0.000	0.92
2-C-3	IPPU - Aluminium Production	CO_2	2 715	5 052	0.000	0.000	0.93
1-A-3-b	Fuel Combustion - Road Transportation	N_2O	3 253	2 478	0.000	0.000	0.93
1-A-3-d	Fuel Combustion - Domestic Navigation	CO_2	4 741	4 299	0.001	0.002	0.94
3-I	Agriculture - Other Carbon-Containing Fertilizers	CO_2	1 191	2 676	0.007	0.019	0.94
2-B-8	IPPU - Petrochemical and Carbon Black Production	CO_2	3 125	2 459	0.001	0.003	0.95

Annex 2

UNCERTAINTY

A2.1. Introduction

All Annex I Parties to the United Nations Framework Convention on Climate Change are required to report estimated uncertainties associated with both annual estimates of emissions and emission trends over time in their respective national inventory reports. Uncertainty analysis helps to prioritize improvements of future inventories and to guide decisions on methodological choice (IPCC 2006).

In this submission, Canada used the error propagation method (Approach 1) for combining uncertainties, as outlined in Volume 1 (Chapter 3) of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006), to assess the uncertainty in emission estimates for 2015. Uncertainty estimates were combined by completing Table 3.3 at the source category level. Uncertainty estimates for each source/sink category were either retained from previous studies (e.g. a comprehensive Monte Carlo analysis (Approach 2) conducted in 2003/2004), improved upon on the basis of these studies, or derived independently as in the Agriculture (methane and nitrous oxide), Energy (some fuel combustion categories and fugitive emissions), Industrial Processes and Product Use (IPPU) and Land Use, Land-use Change and Forestry (LULUCF) Sectors. For details on uncertainty related to specific sectors, refer to the uncertainty sections throughout Chapters 3 to 7.

A2.2. Interpretation of Uncertainty about Inventory Estimates

Often uncertainty about GHG estimates is incorrectly interpreted as a measure of accuracy or reliability. In fact, accuracy (or its inverse, bias) can only be quantified by measuring departure from the truth. Uncertainty estimation for inventories is not designed as a measure of accuracy, rather in the context of national inventories, the process of uncertainty estimation mostly aims to quantify precision. High uncertainty about a category estimate suggests it would be difficult to obtain agreement among repeated measurements. This can arise from many factors, including true heterogeneity over time and space: variability is an inherent property of many systems, including nature.

In IPCC good practice guidance, uncertainty information is primarily a "means to help prioritise efforts to improve the accuracy of inventories in the future and guide decisions on methodological choice, …" (IPCC, 2006 vol 1, chapter 3). Minimizing bias and obtaining reliable estimates are better achieved by implementing good practice in estimate development.

A2.3. Uncertainty Assessment on 2015 Greenhouse Gas Emissions and Removals

Separate analyses were conducted for the inventory as a whole with and without LULUCF. The 2015 national emission estimate (not including the

LULUCF Sector) of 722 Mt CO_2 eq lies within an uncertainty range of 701 Mt CO_2 eq to 742 Mt CO_2 eq (±3%) (Table A2–1). The Energy Sector has the lowest uncertainty, at ±2%, while the Waste Sector has the highest uncertainty, at ±41%. The IPPU Sector and the Agriculture Sector have uncertainties of ±9, and ±17%, respectively. The emission source categories that made the largest contributions to uncertainty at the national level when LULUCF is not included were:

a) Waste – Solid Waste Disposal - Managed Waste Disposal Sites, CH_4;
b) Waste – Solid Waste Disposal - Uncategorized Waste Disposal Sites - Wood Waste Landfills, CH_4;
c) Agriculture – Direct Agriculture Soils, N_2O;
d) Agriculture – Enteric Fermentation, CH_4; and
e) Fugitives Sources – Oil & Gas, CH_4

The 2015 national emission estimate, including LULUCF emissions and removals of 688 Mt CO_2 eq, lies within an uncertainty range of 604 Mt CO_2 eq to 772 Mt CO_2 eq (±12%) (Table A2–2). The top five contributors influencing the national uncertainty when LULUCF is included were:

a) LULUCF – Forest Land Remaining Forest Land, CO_2
b) LULUCF – Harvested Wood Products (HWP), CO_2;
c) Waste – Solid Waste Disposal - Managed Waste Disposal Sites, CH_4 and
d) Waste – Solid Waste Disposal – Uncategorized Waste Disposal Sites – Wood waste Landfills, CH_4; and
e) Agriculture – Direct N_2O emissions from Managed Soils, N_2O

The calculation of trend uncertainty was performed with and without the LULUCF Sector. The trend uncertainty, excluding LULUCF, was found to be 0.9%. Therefore, the total increase in emissions since 1990 of 111 Mt CO_2 eq (+18%) falls within an uncertainty range of a minimum of +105 Mt CO_2 eq to a maximum of +117 Mt CO_2 eq (+17% to +19%). The trend uncertainty, including LULUCF, was found to be 15%.

A2.4. Planned Improvements

Continuous improvement is one of the principles upon which Canada develops its annual GHG inventory. Planned improvements associated with uncertainty assessment will likely build on previous methods and databases, including making use of the Monte Carlo simulation data and methods performed in 2003–2004. New methodological changes and refinements consider the impact on uncertainty prior to implementation and therefore provide a basis for regular incremental improvement to the uncertainty analysis. In addition, some sectors have plans to improve the uncertainty estimates within their respective areas of expertise. Chapter 8 provides a summary of planned improvements.

Table A2–1 Uncertainty Assessment Level and Trend without LULUCF

	IPCC Source Category	Gas	Base Year Emissions	2015 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2015 TOTAL	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
	TOTALS		**611 001**	**721 799**	**0.53**	**2.60**	**2.80**	**2.8**	*Assumption: Emission factors are fully correlated between years*	*Assumption: Activity data is fully correlated between years*	**0.90**
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CO_2	93 720	83 042	0.55	4.10	4.10	0.00	0.18	0.00	0.00
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CH_4	45	137	0.59	24.00	24.00	0.00	0.00	0.00	0.00
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	N_2O	515	523	0.50	140.00	140.00	0.00	0.02	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	CO_2	17 301	17 300	1.20	11.00	11.00	0.00	0.06	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	CH_4	11	8	0.95	180.00	180.00	0.00	0.00	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	N_2O	52	33	0.59	260.00	260.00	0.00	0.01	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO_2	32 176	47 632	0.96	5.40	5.40	0.00	0.08	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 856	2 148	1.30	150.00	150.00	0.00	0.01	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	N_2O	234	306	0.95	460.00	460.00	0.00	0.02	0.00	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CO_2	64 258	98 592	2.60	3.60	3.90	0.00	0.13	0.01	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CH_4	60	86	2.90	21.00	21.00	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	N_2O	572	876	2.70	42.00	42.00	0.00	0.01	0.00	0.00
1.A.3.a	Fuel Combustion - Domestic Aviation	CO_2	7 093	7 225	-	0.60	0.60	0.00	0.00	-	-
1.A.3.a	Fuel Combustion - Domestic Aviation	CH_4	11	8	-	59.00	59.00	0.00	0.00	-	-
1.A.3.a	Fuel Combustion - Domestic Aviation	N_2O	66	63	-	540.00	540.00	0.00	0.01	-	-
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CO_2	88 446	141 381	-	0.50	0.50	0.00	0.03	-	-
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CH_4	338	229	-	72.00	72.00	0.00	0.02	-	-
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	N_2O	3 253	2 478	-	29.00	29.00	0.00	0.07	-	-
1.A.3.c	Fuel Combustion - Railways	CO_2	6 222	6 642	-	1.70	1.70	0.00	0.00	-	-
1.A.3.c	Fuel Combustion - Railways	CH_4	9	10	3.00	150.00	150.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion - Railways	N_2O	718	780	3.00	200.00	200.00	0.00	0.02	0.00	0.00
1.A.3.d	Fuel Combustion - Domestic Navigation	CO_2	4 741	4 299	-	2.90	2.90	0.00	0.01	-	-
1.A.3.d	Fuel Combustion - Domestic Navigation	CH_4	11	10	3.00	50.00	50.00	0.00	0.00	0.00	-
1.A.3.d	Fuel Combustion - Domestic Navigation	N_2O	37	33	3.00	140.00	140.00	0.00	0.00	0.00	-

Table A2–1 Uncertainty Assessment Level and Trend without LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2015 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2015 TOTAL	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	CO_2	27 808	27 982	-	1.00	1.00	0.00	0.01	-	-
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	CH_4	228	182	2.50	740.00	200.00	0.00	0.11	0.00	0.00
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	N_2O	2 437	2 762	3.00	200.00	27.00	0.00	0.04	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	CO_2	6 685	7 892	1.00	0.96	1.40	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	CH_4	167	198	1.00	15.00	15.00	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	N_2O	54	63	0.99	490.00	490.00	0.00	0.00	0.00	0.00
1.A.4	Fuel Combustion - Other Sectors	CO_2	69 204	73 152	2.00	1.70	2.30	0.00	0.02	0.00	0.00
1.A.4	Fuel Combustion - Other Sectors	CH_4	4 644	3 223	5.70	16.00	16.00	0.00	0.06	0.00	0.00
1.A.4	Fuel Combustion - Other Sectors	N_2O	932	891	4.90	28.00	28.00	0.00	0.01	0.00	0.00
1.B.1.a	Fugitive Sources - Coal Mining and Handling	CH_4	2 824	1 139	-	57.00	57.00	0.00	0.20	0.00	0.00
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	CO_2	121	318	-	12.00	12.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	CH_4	17 940	19 467	-	22.00	22.00	0.00	0.06	0.00	0.00
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	N_2O	30	34	-	49.00	49.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources - Venting	CO_2	6 995	7 704	-	47.00	47.00	0.00	0.04	0.00	0.00
1.B.2.c	Fugitive Sources - Flaring	CO_2	4 490	4 630	-	7.00	7.00	0.00	0.01	0.00	0.00
1.B.2.c	Fugitive Sources - Venting & Flaring	CH_4	16 401	23 587	-	13.00	13.00	0.00	0.09	0.00	0.00
1.B.2.c	Fugitive Sources - Venting & Flaring	N_2O	3	7	-	24.00	24.00	0.00	0.00	0.00	0.00
1.C	CO_2 Transport and Storage	CO_2	-	0	2.00	100.00	100.00	0.00	0.00	0.00	0.00
2.A.1	IPPU - Cement Production	CO_2	5 756	6 263	-	12.00	12.00	0.00	0.01	-	-
2.A.2	IPPU - Lime Production	CO_2	1 759	1 339	5.00	2.00	8.20	0.00	0.01	-	0.00
2.A.3	IPPU - Glass Production	CO_2	191	56	-	10.00	10.00	0.00	0.00	0.00	0.00
2.A.4.b	IPPU - Other Uses of Soda Ash	CO_2	126	63	-	6.10	6.10	0.00	0.00	-	-
2.A.4.c	IPPU - Other (Magnesite Use)	CO_2	147	111	7.80	2.10	8.10	0.00	0.00	0.00	0.00
2.A.4.d	IPPU - Other (Limestone and Dolomite Use)	CO_2	449	204	-	34.00	34.00	0.00	0.02	-	-
2.B.1	IPPU - Ammonia Production	CO_2	2 774	2 851	-	8.40	8.40	0.00	0.01	-	-
2.B.2	IPPU - Nitric Acid Production	N_2O	973	1 111	-	2.20	2.20	0.00	0.00	-	-
2.B.3	IPPU - Adipic Acid Production	N_2O	10 303	-	-	11.00	11.00	0.00	0.23	-	-
2.B.7	IPPU - Soda Ash Production	CO_2	-	-	-	14.00	14.00	0.00	0.00	0.00	0.00
2.B.8	IPPU - Petrochemical and Carbon Black Production	CO_2	3 125	2 459	-	3.90	3.90	0.00	0.00	0.00	0.00
2.B.8	IPPU - Petrochemical and Carbon Black Production	CH_4	121	73	-	18.00	18.00	0.00	0.00	-	-
2.B.8	IPPU - Petrochemical and Carbon Black Production	N_2O	15	12	-	9.80	9.80	0.00	0.09	-	-
2.B.9	IPPU - Fluorochemical Production	HFCs	971	-	-	50.00	50.00	0.00	0.04	-	-
2.C.1	IPPU - Iron and Steel Production	CO_2	10 477	7 992	-	5.80	5.80	0.00	0.00	-	-

Table A2–1 Uncertainty Assessment Level and Trend without LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2015 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2015 TOTAL	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
2.C.1	IPPU - Iron and Steel Production	CH_4	2	2	1.00	410.00	410.00	0.00	0.02	-	0.00
2.C.3	IPPU - Aluminium Production	CO_2	2 715	5 052	-	7.10	7.10	0.00	0.12	-	-
2.C.3	IPPU - Aluminium Production	PFCs	7 558	954	-	9.10	9.10	0.00	0.00	-	-
2.C.3	IPPU - Aluminium Production	SF_6	56	10	-	3.30	3.30	0.00	0.02	-	-
2.C.4	IPPU - Magnesium Production	SF_6	2 738	-	-	4.00	4.00	0.00	0.00	-	-
2.C.7	IPPU - Other (Magnesium Casting)	SF_6	225	221	-	4.00	4.00	0.00	0.16	-	-
2.D.1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	5 015	10 798	-	20.00	20.00	0.00	0.00	-	-
2.E.1	IPPU - Integrated Circuit or Semiconductor	PFCs	0	2	-	23.00	23.00	0.00	0.00	-	-
2.E.1	IPPU - Integrated Circuit or Semiconductor	SF_6	4	1	-	45.00	45.00	0.00	0.00	-	-
2.E.1	IPPU - Integrated Circuit or Semiconductor	NF_3	0	0	-	300.00	300.00	0.00	0.00	-	-
2.E.5	IPPU - Other	PFCs	-	-	-	23.00	23.00	0.00	0.65	-	-
2.F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	11 011	-	36.00	36.00	0.00	0.00	-	-
2.F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	PFCs	-	2	-	23.00	23.00	0.00	0.00	-	-
2.G.1	IPPU - Electrical Equipment	SF_6	202	192	-	30.00	30.00	0.00	0.00	-	-
2.G.2	IPPU - SF_6 and PFCs from Other Product Use	PFCs	-	11	-	23.00	23.00	0.00	0.00	-	-
2.G.3.a	IPPU - Other (Medical Applications of N_2O)	N_2O	146	214	-	23.00	23.00	0.00	0.00	-	-
2.G.3.b	IPPU - Other (Uses of N_2O for Propellant)	N_2O	26	39	-	22.00	22.00	0.00	0.00	-	-
2.G.4	IPPU - Other (Use of Urea in SCR Vehicles)	CO_2	-	25	-	50.00	50.00	0.00	0.08	-	-
3.A	Agriculture - Enteric Fermentation	CH_4	22 815	25 005	1.40	21.00	22.00	0.01	0.07	0.00	0.00
3.B.1	Agriculture - Manure Management	CH_4	3 491	3 753	1.40	32.00	32.00	0.00	0.02	0.00	0.00
3.B.2	Agriculture - Manure Management Direct Emissions	N_2O	3 075	3 623	1.40	44.00	51.00	0.00	0.00	0.00	0.00
3.B.2	Agriculture - Manure Management Indirect Emissions	N_2O	985	1 141	1.40	100.00	100.00	0.00	0.00	0.00	0.00
3.D.1	Agriculture - Direct Agriculture Soils	N_2O	14 011	18 727	7.90	27.00	34.00	0.01	0.10	0.00	0.00
3.D.2	Agriculture - Indirect Agrictulure Soils	N_2O	2 718	3 982	7.90	75.00	100.00	0.00	0.09	0.00	0.00
3.F	Agriculture - Field Burning of Agricultural Residues	CH_4	177	42	50.00	40.00	64.00	0.00	0.01	0.00	0.00
3.F	Agriculture - Field Burning of Agricultural Residues	N_2O	55	13	50.00	48.00	69.00	0.00	0.00	0.00	0.00
	Agriculture - Total CO_2	CO_2	1 191	2 676	4.10	40.00	42.00	0.00	0.08	0.00	0.00
5.A.1	Solid Waste Disposal - Managed Waste Disposal Sites	CH_4	17 673	18 522	-	40.00	40.00	0.01	0.15	-	-
5.A.3	Solid Waste Disposal - Uncategorized Waste Disposal Sites - Wood Waste Landfills	CH_4	3 847	3 625	-	190.00	190.00	0.01	0.29	-	-
5.B.1	Biological Treatment of Solid Waste - Composting	CH_4	419	547	110.00	110.00	170.00	0.00	0.01	0.00	0.00

Table A2–1 Uncertainty Assessment Level and Trend without LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2015 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2015 TOTAL	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
5.B.1	Biological Treatment of Solid Waste - Composting	N_2O	299	391	110.00	110.00	170.00	0.00	0.01	0.00	0.00
5.C.1.1.b.iii	Incineration and Open Burning of Waste - Waste Incineration - Biogenic - Sewage Sludge	CH_4	66	6	-	60.00	60.00	0.00	0.01	-	-
5.C.1.1.b.iii	Incineration and Open Burning of Waste - Waste Incineration - Biogenic - Sewage Sludge	N_2O	65	6	5.00	110.00	110.00	0.00	0.01	0.00	0.00
5.C.1.2.a	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Municipal Solid Waste	CO_2	343	263	-	85.00	85.00	0.00	0.02	-	-
5.C.1.2.a	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Municipal Solid Waste	N_2O	54	41	-	85.00	85.00	0.00	0.00	-	-
5.C.1.2.b.ii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Hazardous Waste	CO_2	166	148	5.00	94.00	94.00	0.00	0.01	-	-
5.C.1.2.b.ii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Hazardous Waste	CH_4	0	0	5.00	110.00	110.00	0.00	0.00	0.00	0.00
5.C.1.2.b.ii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Hazardous Waste	N_2O	95	84	5.00	110.00	110.00	0.00	0.00	0.00	0.00
5.C.1.2.b.iii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Clinical Waste	CO_2	2	3	5.00	30.00	30.00	0.00	0.00	0.00	0.00
5.C.1.2.b.iii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Clinical Waste	CH_4	0	0	5.00	110.00	110.00	0.00	0.00	0.00	0.00
5.C.1.2.b.iii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Clinical Waste	N_2O	0	0	5.00	110.00	110.00	0.00	0.00	0.00	0.00
5.D	Wastewater Treatment and Discharge	CH_4	376	394	-	45.00	45.00	0.00	0.00	-	-
5.D	Wastewater Treatment and Discharge	N_2O	494	667	-	65.00	65.00	0.00	0.01	-	-

Note:
1. For categories where individual values are not given for emission factor and activity data uncertainty, combined uncertainty estimates are based on sectoral Monte Carlo analyses. For further information on sources of uncertainty data and calculation methods – as related to categories in the Energy, Industrial Processes and Product Use, and Waste sectors - the reader is referred to uncertainty sections in respective NIR chapters. In the case of Agriculture, emission factor uncertainty was back calculated from combined uncertainty from monte carlo analysis carried out for N_2O and CH_4 seperately and total contribution to uncertainty is the summation of uncertainty from monte carlo analysis of N2O and CH4, combined with error propagation calculations for CO_2.

Table A2–2 Uncertainty Assessment Level and Trend with LULUCF

	IPCC Source Category	Gas	Base Year Emissions	2015 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2015 TOTAL	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
	TOTALS		**511 725**	**688 255**	**0.55**	**2.3**	**12**	**12.23**	*Assumption: Emission factors are fully correlated between years*	*Assumption: Activity data is fully correlated between years*	**15.35**
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CO_2	93 720	83 042	0.55	4.1	4.1	0.00	0.34	0.01	0.00
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CH_4	45	137	0.59	24	24	0.00	0.00	0.00	0.00
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	N_2O	515	523	0.5	140	140	0.00	0.05	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	CO_2	17 301	17 300	1.2	11	11	0.00	0.13	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	CH_4	11	8	0.95	180	180	0.00	0.00	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	N_2O	52	33	0.59	260	260	0.00	0.02	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO_2	32 176	47 632	0.96	5.4	5.4	0.00	0.05	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 856	2 148	1.3	150	150	0.00	0.10	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	N_2O	234	306	0.95	460	460	0.00	0.01	0.00	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CO_2	64 258	98 592	2.6	3.6	3.9	0.00	0.09	0.01	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CH_4	60	86	2.9	21	21	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	N_2O	572	876	2.7	42	42	0.00	0.01	0.00	0.00
1.A.3.a	Fuel Combustion - Domestic Aviation	CO_2	7 093	7 225	-	0.6	0.6	0.00	0.00	-	-
1.A.3.a	Fuel Combustion - Domestic Aviation	CH_4	11	8	-	59	59	0.00	0.00	-	-
1.A.3.a	Fuel Combustion - Domestic Aviation	N_2O	66	63	-	540	540	0.00	0.03	-	-
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CO_2	88 446	141 381	-	0.5	0.5	0.00	0.02	-	-
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CH_4	338	229	-	72	72	0.00	0.03	-	-
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	N_2O	3 253	2 478	-	29	29	0.00	0.11	-	-
1.A.3.c	Fuel Combustion - Railways	CO_2	6 222	6 642	-	1.7	1.7	0.00	0.01	-	-

Table A2–2 Uncertainty Assessment Level and Trend with LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2015 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2015 TOTAL	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
1.A.3.c	Fuel Combustion - Railways	CH_4	9	10	3	150	150	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion - Railways	N_2O	718	780	3	200	200	0.00	0.07	0.00	0.00
1.A.3.d	Fuel Combustion - Domestic Navigation	CO_2	4 741	4 299	-	2.9	2.9	0.00	0.01	-	-
1.A.3.d	Fuel Combustion - Domestic Navigation	CH_4	11	10	3	50	50	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion - Domestic Navigation	N_2O	37	33	3	140	140	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	CO_2	27 808	27 982	-	1	1	0.00	0.02	-	-
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	CH_4	228	182	2.5	740	200	0.00	0.18	0.00	0.00
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	N_2O	2 437	2 762	3	200	27	0.00	0.20	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	CO_2	6 685	7 892	1	0.96	1.4	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	CH_4	167	198	1	15	15	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	N_2O	54	63	0.99	490	490	0.00	0.01	0.00	0.00
1.A.4	Fuel Combustion - Other Sectors	CO_2	69 204	73 152	2	1.7	2.3	0.00	0.07	0.01	0.00
1.A.4	Fuel Combustion - Other Sectors	CH_4	4 644	3 223	5.7	16	16	0.00	0.09	0.00	0.00
1.A.4	Fuel Combustion - Other Sectors	N_2O	932	891	4.9	28	28	0.00	0.02	0.00	0.00
1.B.1.a	Fugitive Sources - Coal Mining and Handling	CH_4	2 824	1 139	-	57	57	0.00	0.30	-	-
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	CO_2	121	318	-	12	12	0.00	0.00	-	-
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	CH_4	17 940	19 467	-	22	22	0.00	0.20	-	-
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	N_2O	30	34	-	49	49	0.00	0.00	-	-
1.B.2.c	Fugitive Sources - Venting	CO_2	6 995	7 704	-	47	47	0.00	0.16	-	-
1.B.2.c	Fugitive Sources - Flaring	CO_2	4 490	4 630	-	7	7	0.00	0.02	-	-
1.B.2.c	Fugitive Sources - Venting & Flaring	CH_4	16 401	23 587	-	13	13	0.00	0.04	-	-
1.B.2.c	Fugitive Sources - Venting & Flaring	N_2O	3	7	-	24	24	0.00	0.00	-	-
1.C	CO_2 Transport and Storage	CO_2	N/A	0	2	100	100	0.00	0.00	0.00	0.00
2.A.1	IPPU - Cement Production	CO_2	5 756	6 263	-	12	12	0.00	0.04	-	-
2.A.2	IPPU - Lime Production	CO_2	1 759	1 339	5	2	8.2	0.00	0.00	0.00	0.00
2.A.3	IPPU - Glass Production	CO_2	191	56	0	10	10	0.00	0.00	0.00	0.00
2.A.4.b	IPPU - Other Uses of Soda Ash	CO_2	126	63	-	6.1	6.1	0.00	0.00	0.00	0.00
2.A.4.c	IPPU - Other (Magnesite Use)	CO_2	147	111	7.8	2.1	8.1	0.00	0.00	0.00	0.00
2.A.4.d	IPPU - Other (Limestone and Dolomite Use)	CO_2	449	204	-	34	34	0.00	0.03	-	-
2.B.1	IPPU - Ammonia Production	CO_2	2 774	2 851	-	8.4	8.4	0.00	0.01	-	-
2.B.2	IPPU - Nitric Acid Production	N_2O	973	1 111	-	2.2	2.2	0.00	0.00	-	-

Table A2–2 Uncertainty Assessment Level and Trend with LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2015 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2015 TOTAL	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
2.B.3	IPPU - Adipic Acid Production	N_2O	10 303	-	-	11	11	0.00	0.31	-	-
2.B.7	IPPU - Soda Ash Production	CO_2	0	-	-	14	14	0.00	0.00	0.00	0.00
2.B.8	IPPU - Petrochemical and Carbon Black Production	CO_2	3 125	2 459	-	3.9	3.9	0.00	0.00	0.00	0.00
2.B.8	IPPU - Petrochemical and Carbon Black Production	CH_4	121	73	-	18	18	0.00	0.00	0.00	0.00
2.B.8	IPPU - Petrochemical and Carbon Black Production	N_2O	15	12	-	9.8	9.8	0.00	0.00	0.00	0.00
2.B.9	IPPU - Fluorochemical Production	HFCs	971	-	-	50	50	0.00	0.13	0.00	0.00
2.C.1	IPPU - Iron and Steel Production	CO_2	10 477	7 992	-	5.8	5.8	0.00	0.07	0.00	0.00
2.C.1	IPPU - Iron and Steel Production	CH_4	2	2	1	410	410	0.00	0.00	0.00	0.00
2.C.3	IPPU - Aluminium Production	CO_2	2 715	5 052	-	7.1	7.1	0.00	0.02	0.00	0.00
2.C.3	IPPU - Aluminium Production	PFCs	7 558	954	-	9.1	9.1	0.00	0.16	0.00	0.00
2.C.3	IPPU - Aluminium Production	SF_6	56	10	-	3.3	3.3	0.00	0.00	0.00	0.00
2.C.4	IPPU - Magnesium Production	SF_6	2 738	-	-	4	4	0.00	0.03	0.00	0.00
2.C.7	IPPU - Other (Magnesium Casting)	SF_6	225	221	-	4	4	0.00	0.00	0.00	0.00
2.D.1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	5 015	10 798	-	20	20	0.00	0.16	0.00	0.00
2.E.1	IPPU - Integrated Circuit or Semiconductor	PFCs	0	2	-	23	23	0.00	0.00	0.00	0.00
2.E.1	IPPU - Integrated Circuit or Semiconductor	SF_6	4	1	-	45	45	0.00	0.00	0.00	0.00
2.E.1	IPPU - Integrated Circuit or Semiconductor	NF_3	0	0	0	300	300	0.00	0.00	0.00	0.00
2.E.5	IPPU - Other	PFCs	-	-	-	23	23	0.00	0.00	0.00	0.00
2.F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	11 011	-	36	36	0.00	0.77	0.00	0.01
2.F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	PFCs	-	2	-	23	23	0.00	0.00	0.00	0.00
2.G.1	IPPU - Electrical Equipment	SF_6	202	192	-	30	30	0.00	0.00	0.00	0.00
2.G.2	IPPU - SF_6 and PFCs from Other Product Use	PFCs	-	11	-	23	23	0.00	0.00	0.00	0.00
2.G.3.a	IPPU - Other (Medical Applications of N_2O)	N_2O	146	214	-	23	23	0.00	0.00	0.00	0.00
2.G.3.b	IPPU - Other (Uses of N_2O for Propellant)	N_2O	26	39	-	22	22	0.00	0.00	0.00	0.00
2.G.4	IPPU - Other (Use of Urea in SCR Vehicles)	CO_2	-	25	-	50	50	0.00	0.00	0.00	0.00
3.A	Agriculture - Enteric Fermentation	CH_4	22 815	25 005	1.4	21	22	0.01	0.24	0.00	0.00

Table A2–2 Uncertainty Assessment Level and Trend with LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2015 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2015 TOTAL	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
3.B.1	Agriculture - Manure Management	CH_4	3 491	3 753	1.4	32	32	0.00	0.06	0.00	0.00
3.B.2	Agriculture - Manure Management Direct Emissions	N_2O	3 075	3 623	1.4	44	51	0.01	0.03	0.00	0.00
3.B.2	Agriculture - Manure Management Indirect Emissions	N_2O	985	1 141	1.4	100	100	0.00	0.04	0.00	0.00
3.D.1	Agriculture - Direct N_2O Emissions from Managed Soils	N_2O	14 011	18 727	7.9	27	34	0.00	0.04	0.00	0.00
3.D.2	Agriculture - Indirect N_2O Emissions from Managed Soils	N_2O	2 718	3 982	7.9	75	100	0.01	0.01	0.00	0.00
3.F	Agriculture - Field Burning of Agricultural Residues	N_2O	177	42	50	40	64	0.00	0.05	0.00	0.00
3.F	Agriculture - Field Burning of Agricultural Residues	N_2O	55	13	50	48	69	0.00	0.02	0.00	0.00
	Agriculture - Total CO_2	CO_2	1 191	2 676	4.1	40	42	0.00	0.01	0.00	0.00
4.A.2	LULUCF - Forest Land Remaining Forest Land	CO_2	(251 669)	(164 379)	-	44	44	1.10	15.04	0.00	2.26
4.A	LULUCF - Forest Land Remaining Forest Land	CH_4	312	259	-	120	120	0.00	0.04	0.00	0.00
4.A	LULUCF - Forest Land Remaining Forest Land	N_2O	144	127	-	130	130	0.00	0.02	0.00	0.00
4.A	LULUCF - Land Converted to Forest Land	CO_2	(1 076)	(506)	-	200	200	0.00	0.37	0.00	0.00
4.B	LULUCF - Cropland	CO_2	(791)	(15 323)	-	23	23	0.00	0.64	0.00	0.00
4.B	LULUCF - Cropland	N_2O	14	1	-	40	40	0.00	0.00	0.00	0.00
4.C	LULUCF - Grasslands	CH_4	492	520	-	64	64	0.00	0.02	0.00	0.00
4.C	LULUCF - Grasslands	N_2O	152	161	-	69	69	0.00	0.01	0.00	0.00
4.D	LULUCF - Wetlands	CO_2	2 498	1 615	-	0	0	0.00	0.00	0.00	0.00
4.D	LULUCF - Wetlands	CH_4	6	13	-	0	0	0.00	0.00	0.00	0.00
4.D	LULUCF - Wetlands	N_2O	4	9	-	0	0	0.00	0.00	0.00	0.00
4.E	LULUCF - Settlements	CO_2	(2 245)	(2 257)	-	22	22	0.00	0.03	0.00	0.00
	LULUCF - Conversion of Forest Land	CO_2	17 700	11 027	-	20	20	0.00	0.50	0.00	0.00
	LULUCF - Conversion of Forest Land	CH_4	455	206	-	23	23	0.00	0.02	0.00	0.00
	LULUCF - Conversion of Forest Land	N_2O	226	107	-	23	23	0.00	0.01	0.00	0.00
4.G.	LULUCF - Harvested Wood Products (HWP)	CO_2	134 503	134 877	-	29	29	0.32	2.58	0.00	0.07
5.A.1	Solid Waste Disposal - Managed Waste Disposal Sites	CH_4	17 673	18 522	-	40	40	0.01	0.41	0.00	0.00

Table A2–2 Uncertainty Assessment Level and Trend with LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2015 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2015 TOTAL	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
5.A.3	Solid Waste Disposal - Uncategorized Waste Disposal Sites - Wood Waste Landfills	CH_4	3 847	3 625	-	190	190	0.01	0.58	0.00	0.00
5.B.1	Biological Treatment of Solid Waste - Composting	CH_4	419	547	110	110	170	0.00	0.00	0.00	0.00
5.B.1	Biological Treatment of Solid Waste - Composting	N_2O	299	391	110	110	170	0.00	0.00	0.00	0.00
5.C.1.1.b.iii	Incineration and Open Burning of Waste - Waste Incineration - Biogenic - Sewage Sludge	CH_4	66	6	-	60	60	0.00	0.01	0.00	0.00
5.C.1.1.b.iii	Incineration and Open Burning of Waste - Waste Incineration - Biogenic - Sewage Sludge	N_2O	65	6	5	110	110	0.00	0.02	0.00	0.00
5.C.1.2.a	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Municipal Solid Waste	CO_2	343	263	-	85	85	0.00	0.03	0.00	0.00
5.C.1.2.a	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Municipal Solid Waste	N_2O	54	41	-	85	85	0.00	0.01	0.00	0.00
5.C.1.2.b.ii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Hazardous Waste	CO_2	166	148	5	94	94	0.00	0.01	0.00	0.00
5.C.1.2.b.ii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Hazardous Waste	CH_4	0	0	5	110	110	0.00	0.00	0.00	0.00
5.C.1.2.b.ii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Hazardous Waste	N_2O	95	84	5	110	110	0.00	0.01	0.00	0.00
5.C.1.2.b.iii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Clinical Waste	CO_2	2	3	5	30	30	0.00	0.00	0.00	0.00
5.C.1.2.b.iii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Clinical Waste	CH_4	0	0	5	110	110	0.00	0.00	0.00	0.00
5.C.1.2.b.iii	Incineration and Open Burning of Waste - Waste Incineration - Non-Biogenic - Other - Clinical Waste	N_2O	0	0	5	110	110	0.00	0.00	0.00	0.00

Table A2–1 Uncertainty Assessment Level and Trend without LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2015 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2015 TOTAL	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			kt CO_2 eq	kt CO_2 eq	%	%	%	%	%	%	%
5.D	Wastewater Treatment and Discharge	CH_4	376	394	-	45	45	0.00	0.01	0.00	0.00
5.D	Wastewater Treatment and Discharge	N_2O	494	667	-	65	65	0.00	0.00	0.00	0.00

Note:

1. For categories where individual values are not given for emission factor and activity data uncertainty, combined uncertainty estimates are based on sectoral Monte Carlo analyses. For further information on sources of uncertainty data and calculation methods – as related to categories in the Energy, Industrial Processes and Product Use, and Waste sectors - the reader is referred to uncertainty sections in respective NIR chapters. In the case of Agriculture, emission factor uncertainty was back calculated from combined uncertainty from monte carlo analysis carried out for N_2O and CH_4 seperately and total contribution to uncertainty is the summation of uncertainty from monte carlo analysis of N_2O and CH_4, combined with error propagation calculations for CO_2.

2. The uncertainty in LULUCF as reported is driven by the results of a Monte Carlo analysis of Forest Land uncertainty. These results were highly skewed (+44% to -24%) and the Tier 1 analysis uses the largest tail of the uncertainty estimate (44%). The high uncertainty and strong trend in Forest Land removals subsequently has a large impact on national level and trend uncertainty.

Annex 3

A3.1. Methodology and Data for Estimating Emissions from Fossil Fuel Combustion

The following presents an overview of the methodology, activity data and emission factors used to estimate CO_2, CH_4 and N_2O emissions from fuel combustion sources for the Energy Sector. Additional methodological details and refinements to the general approach are presented in sections A3.1.4.1 for stationary combustion sources and A3.1.4.2 for transport sources.

A3.1.1. Methodology

In general, a top-down method following the Tier 3 and Tier 2 sectoral approach from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) is used to estimate greenhouse gas (GHG) emissions from fuel combustion based on country-specific emission factors and on the quantity of fuel consumed at the source category level. As illustrated by Equation A3–1, for each source category, the quantity of fuel at the national and/or provincial level of detail is multiplied by a specific emission factor. Further refinements and deviations from the general approach to estimating combustion emissions are discussed in the stationary combustion and transport sections of this annex (sections A3.1.4.1 and A3.1.4.2, respectively). The purpose of these refinements is to increase the accuracy and allocation of the emissions associated with each source category when additional details or parameters are available. Specific methodological issues are presented in the Energy chapter (Chapter 3) of this report.

Equation A3–1: for general fuel combustion:

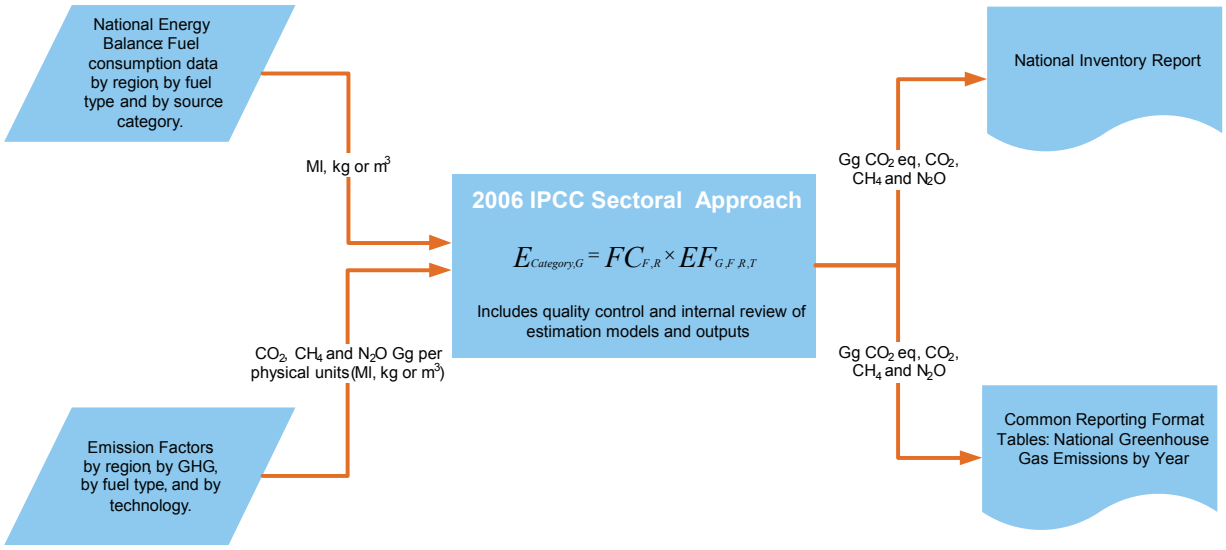
$$E_{Category,G} = FC_{F,R} * EF_{G,F,R,T}$$

where:

- $E_{Category,G}$ = GHG emissions by source category and by GHG (CO_2, CH_4 or N_2O)
- $FC_{F,R}$ = Quantity of fuel consumed (in physical units, such as kg, L, or m^3) by fuel type (i.e. natural gas, sub-bituminous coal, kerosene, etc.) and by region
- $EF_{G,F,R,T}$ = Country-specific emission factor (in physical units) by GHG, by fuel type, by region (where available) and by technology (for non-CO_2 factors)

Relational databases are primarily used in stationary combustion and transport models to process activity data and emission factors at national and provincial levels of detail for use in estimating GHG emissions (Figure A3–1). The national energy balance is prepared by Statistics Canada using data reported in physical units by the producing and consuming sectors. For this reason, the physical units reported by Statistics Canada have been judged the most accurate for generating emissions estimates. Country-specific emission factors, as applied, are in physical units to minimize the number of additional conversion factors and thus limit the uncertainty associated with estimates. When higher resolution emission factors at the regional level are available, regional information is applied rather than national values to further reduce the uncertainty of these estimates (e.g. coal and natural gas emission factors account for the variation in carbon content across various regions). Combustion technology differences are addressed by non-CO_2 emission factors.

Figure A3–1 GHG Estimation Process Flow



A3.1.2. Activity Data from Statistics Canada

The principal source of fuel and energy data used to estimate combustion emissions is the annual *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada 57-003-X). The RESD uses both top down and bottom-up approaches to estimate the supply of, and demand for, energy in Canada. The production of fuels in Canada is balanced with the use of fuels in broad categories such as import/export, producer consumption, residential and industry. Industrial energy-use data are divided into sectors based on the North American Industrial Classification System (NAICS). Currently, the energy data used to generate electricity or steam by industry (auto producers) is captured by the RESD in two separate lines (one for electricity and one for steam) without any further disaggregation by industrial subcategories. Prior to 2003, these summary lines were fractionally allocated to appropriate sectors based on the quantities reported by sector in the *Industrial Consumption of Energy Survey* (ICE) (Statistics Canada 2013). After 2003, the electricity line (from auto producers) is reallocated directly to the appropriate sector based on the quantities reported by sector in the *Electric Power Thermal Generating Station Fuel Consumption Survey* (EPTGS) (Statistics Canada 2013). This reflects a change in the RESD Electricity by Industry line, which from 2003 on was replaced directly with data from the EPTGS. This improvement was implemented by Statistics Canada to increase the transparency and accuracy of subsector information, since the fuel used to generate electricity is more complete and of higher quality. The steam line continues to be allocated using the fractional method and ICE data.

While the RESD provides fuel-use data at a provincial level, in general, the accuracy of these data is not as high as that of the national data. Statistics Canada generally collects the fuel data for the RESD through a number of specific surveys directed at suppliers of energy, provincial energy ministries and some users of energy. The accuracy of the sectoral end-use data is less than that of the total energy supply data. As a result, the total emission estimates for Canada are known with more certainty than the emissions from specific

categories. Since 1995, Statistics Canada has been collecting energy-use statistics from end users through the annual *Industrial Consumption of Energy Survey* (ICE). This bottom-up approach to estimating fuel use by industry provides more accurate information at the sectoral level. Refer to Annex 4, National Energy Balance, for additional discussion on the development of the RESD and the ICE data set, including a discussion of Statistics Canada's quality assurance / quality control activities. Sector-specific surveys, like the EPTGS, are also used to verify sector trends and emissions allocation.

The combustion and transport models apply the quantity of fossil fuel consumed in physical units rather than in energy units, since this is how the information is reported to Statistics Canada by reporting facilities under the *Statistics Act*. The quantities of fossil fuel consumed are also available in gross calorific units; however, this is assumed to be less accurate, since Statistics Canada applies constant energy conversion factors (a factor for 1990 to 1997 and another factor for 1998 onward) to each fuel type without taking into account year-to-year changes, especially for variable fuels such as coal and refinery fuel gas (still gas), except for natural gas. These energy conversion factors are applied for the reporting of fuel quantities in the CRF tables, and nationally weighted values were determined for reference approach calculation (refer to Table A4-2 for details). One exception involves waste fuels, for which the data are only available in energy units from the Cement Association of Canada. Statistics Canada and Environment and Climate Change Canada have initiated a multi-year work program to better track and update energy conversion factors; refer to the Planned Improvement section of Chapter 3 for additional detail.

Additional non-Statistics Canada activity data sources used by the combustion and transport models, such as landfill gas quantities, waste fuel consumption and vehicle fleet information, are included in the specific methodological discussions (sections A3.1.3.1 and A3.1.4.2).

A3.1.3. Fuel Combustion Emission and Oxidation Factors

A description of emission factors employed in estimating the emissions for the current fossil fuel combustion models can be found in Annex 6. The following is generally true:

Natural Gas: The emission factors for CO_2 vary depending on the source of natural gas and whether the product is marketable or non-marketable (raw natural gas for on-site consumption by natural gas producers). Therefore, emission factors are assigned for different provinces based on the origin and quality of the natural gas. The emission factors for CH_4 and N_2O vary with the combustion technology.

Refined Petroleum Products (RPP): The emission factors vary with fuel type and/or combustion technology (for CH_4 and N_2O).

Coal: The CO_2 emission factors vary by the coal properties, province of use and coal origin, whether domestic or foreign. The emission factors for CH_4 and N_2O vary by the combustion technology.

IPCC default oxidation values are used for all fuels, except coal for which country-specific oxidation factors have been applied at the provincial level. Refer to the Recalculation section of Chapter 3 and Annex 6 for more detail on coal oxidation factors.

A3.1.3.1. CO_2 Emission Factors

CO_2 emissions from fuel combustion activities depend on the amount of fuel consumed, the carbon content of the fuel and the applied oxidation factor. The derivation of CO_2 emission

factors is discussed in Annex 6, in *Fossil Fuel and Derivative Factors* (McCann 2000) and in *Updated Coal Emission, Energy Conversion and Oxidation Factors* (ECCC 2016). Fuel properties, such as carbon content, density and heating value, were determined using accepted industrial testing standards from the American Society for Testing and Materials (ASTM) and the Canadian General Standards Board (CGSB). The hydrocarbons and particulates formed during combustion are both accounted for to some extent, but emissions of CO are included in the estimates of CO_2 emissions. It is assumed that CO in the atmosphere undergoes complete oxidation to CO_2 shortly after combustion (within 5 to 20 weeks of its release).

The waste fuel factor is based on energy content since data reported by the Cement Association of Canada (CAC) are in energy units. The emission factors employed to estimate emissions are subdivided by the type of fuel used and, in the case of N_2O and CH_4 emissions, the combustion technology employed.

A3.1.3.2. Non-CO_2 Emission Factors

Emission factors for all non-CO_2 GHGs from combustion activities vary to a lesser or greater degree with:

- fuel type;
- technology;
- operating conditions; and
- maintenance and vintage of technology.

During the combustion of carbon-based fuels, a small portion of the fuel remains unoxidized as CH_4. Additional research is necessary to better establish CH_4 emission factors for many combustion processes. Overall factors are developed for sectors based on typical technology splits and available emission factors for the sector.

During combustion, some of the nitrogen in the fuel and air is converted to N_2O. The production of N_2O is dependent on the combustion temperature and the emission control technology employed. Additional research is necessary to better establish N_2O emission factors for many combustion processes. Overall factors are developed for sectors based on typical technologies and available emission factors for the sector. Non-CO_2 emission factors in this inventory are listed in Annex 6.

A3.1.3.3. Biomass

For reporting under the United Nations Framework Convention on Climate Change (UNFCCC), CO_2 emissions from biomass fuels (including landfill gas) are not to be included in the Energy Sector total. CO_2 emissions from biomass fuel combustion are accounted for in the Land Use, Land-use Change and Forestry (LULUCF) Sector as a loss of biomass (forest) stocks. CO_2 from biomass combustion for energy purposes is reported as a memo item of the UNFCCC's Common Reporting Format (CRF) tables for information only. CH_4 and N_2O emissions from biomass fuel combustion are reported in the Energy Sector in the appropriate subcategories and included in inventory totals.

A3.1.4. Methodology for Stationary Combustion and Transport

A3.1.4.1. Stationary Combustion

The methodology used to estimate GHG emissions from stationary fuel combustion is consistent with the IPCC Tier 2 sectoral approach, along with country-specific emission factors as outlined in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). The methodology for SF_6 emissions from electrical transmission systems is presented in the Industrial Processes and Product Use Sector (Annex 3.3).

Table A3–1 Activity Data Model References

Statistics Canada – Manufacturing, Construction and Energy Division; *Report on Energy Supply Demand in Canada* (RESD). Annual Report, Catalogue No. #57-003-X.
Waste fuel data - Based on CIEEDAC (2013). CIEEDAC Database on Energy, Production and Intensity Indicators for Canadian Industry. NAICS 327310 Cement Manufacturing. Canadian Industrial Energy End-use Data Analysis Centre. Also based on data collected by the Cement Association of Canada under WBCSD (2005). Cement Sustainability Initiative CO_2 Emissions Inventory Protocol. v.2.0.
Residential fuelwood consumption – Environment Canada. 2014. Residential Fuelwood Consumption in Canada. Unpublished report. Prepared by K. Tracey, Polllutant Inventories and Reporting Division, Environment Canada.
Landfill Gas Utilization – Environment and Climate Change Canada National Inventory Report (NIR). Section A3.6: Methodology for Waste Sector.

The emissions are calculated based on nationally reported activity data, except when emission factors are available at the provincial/territorial level. In these instances, the provincial/territorial emissions are aggregated to a national total.

Emission estimates are calculated using Equation A3–1 exclusively.

Activity data sources are presented in Table A3–1 for reference in the stationary combustion model methodology. The data are made available to Environment and Climate Change Canada in electronic format and may differ slightly when compared with Statistics Canada's rounded, published values.

Much of the stationary combustion model's complexity lies in the reallocation of data presented in the RESD in order to comply with the requirements of IPCC categories and UNFCCC CRF reporting tables. In addition, in keeping with 2006 IPCC Guidelines, all fuel types have been allocated based on the CRF fuel grouping of solid, liquid, gaseous, biomass and others (see Table A4-2 of Annex 4).

Combined Heat and Power Allocation

Activity data, in the form of fuel used by utilities, are currently aggregated to two summary lines in the RESD (Electricity by Utilities and Steam Generation lines), representing electricity generation and combined heat and power facilities. In addition, solid wood waste and spent pulping liquor used by utilities are allocated to Table 10 - Solid Wood Waste and Spent Pulping Liquor.

Since the Electricity by Utilities line (RESD Line 10) is populated with EPTGS survey data, the reallocation was completed using fractions developed based on the quantities reported by the Electricity Generation subcategory in the EPTGS survey. For each fuel and each province, the fuel use data reported in the EPTGS, along with a listing of facilities that are combined heat and power facilities (generated by Environment Canada), are used to develop the combined heat and power fraction of the total fuel use. The fractions are then used with RESD Line 10 to determine what portion of that line should be reallocated to combined heat and power. The remainder is allocated to electricity generation.

The solid wood waste and spent pulping liquor allocation are discussed below.

Electricity by Industry Allocation

Activity data, in the form of fuel used by industry (including Petroleum Refining) to generate electricity or steam, are currently aggregated to two summary lines in the RESD (Electricity by Industry and Steam Generation lines). In addition, solid wood waste and spent pulping liquor used by industry are allocated to Table 10 - Solid wood waste and spent pulping liquor.

Since the Electricity by Industry line (RESD Line 11) is populated with EPTGS survey data:

- the reallocation of RESD Line 11 values from 1998 to present was completed using fractions developed based on the quantities reported by the Electricity Generation subcategory in the EPTGS survey. For each fuel and each province, the fuel use data reported by industry in the EPTGS for electricity generation are used to develop each industry's fraction of the total fuel use. The fractions are then used with Line 11 from the RESD to determine what portion of that line should be reallocated

to a particular industry. This portion is added to the activity data already reported for that industry.

- the reallocation of RESD Line 11 values between 1990 and 1997 was completed using fractions developed based on the quantities reported by the Electricity Generation subcategory in the ICE survey, since EPTGS data are not available prior to 1998. For each fuel and each province, the fuel use data reported by industry in ICE for electricity generation are used to develop each industry's fraction of the total fuel use. The fractions are then used with Line 11 from the RESD to determine what portion of that line should be reallocated to a particular industry. This portion is added to the activity data already reported for that industry. Since ICE data did not exist prior to 1995, for years between 1990 and 1995, the 1995 fractions were used.

Since the Steam Generation line (RESD Line 14) is populated with ICE data, the procedure used to reallocate the RESD Line 11 values between 1990 and 1997 is also applied to the RESD Line 14 values (for all years) using corresponding ICE data representing steam generation by facilities falling under the Electricity Generation subcategory.

The solid wood waste and spent pulping liquor allocation is discussed below.

Solid Wood Waste Allocation

Activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor).

The Solid Wood Waste and Spent Pulping Liquor table (RESD Table 10) is populated with ICE data. The procedure used to reallocate the RESD Line 11 values between 1990 and 1997 is also applied to the Table 10 values (for all years) using corres pon- ding ICE data representing solid wood waste and spent pulping liquor consumption by facilities falling under the Electricity Generation subcategory.

A3.1.4.1.1. Public Electricity and Heat Production

(CRF Category 1.A.1.a)

The Public Electricity and Heat Production subcategory includes 1.A.1.a.i – Electricity Generation, 1.A.1.a.ii – Combined Heat and Power Generation, and 1.A.1.a.iii – Heat Plants. This subcategory should include all emissions from main activity producers (previously known as public utilities) of electricity generation, combined heat and power generation, and heat plants. Emissions from auto producers are allocated to their respective industrial subcategories.

Activity data from this subcategory are captured in two lines in the RESD (one for electricity and one for steam); however, they are summary lines and are not divided into electricity generation, combined heat and power, and heat plants. In addition, activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated data needs to be reallocated to the appropriate subcategory where the fuel is used. This is completed using the methods discussed in detail in section A3.1.4.1.

CO_2, CH_4 and N_2O emissions are estimated by applying Equation A3–1 to activity data and emission factors for each specific fuel. As previously discussed, in order to obtain higher accuracy in GHG emissions, regional emission factors are applied to provincial/territorial data where available. For this sector, there are regional emission factors for coal and natural gas. For the remaining fuels, the emission factors are applied to the nationally reported data.

Table A3–2 provides a summary of the methodology for the public electricity and heat production CRF category.

Table A3–2 Emission Estimation Methodology for Public Electricity and Heat Production

CRF Source Category[1]	Fuel Type[2]	Data Source			Provincial Aggregation[3]	
		Publication[2]	Table	Line	Fuel	Gas
1.A.1.a.i Electricity Generation	Solid Fuels	RESD	1 - Primary and Secondary Energy	Electricity by utilities[4] Steam generation[4]	COAL	CO_2
			Coal Details (unpublished)			
	Liquid Fuels	RESD	3 - Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 - Primary and Secondary Energy		NG	CO_2
			6 - Details of Natural Gas Liquids			
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[4]		NA	NA
1.A.1.a.ii Combined Heat and Power Generation	Solid Fuels	RESD	1 - Primary and Secondary Energy	Electricity by utilities[4] Steam generation[4]	COAL	CO_2
			Coal Details (unpublished)			
	Liquid Fuels	RESD	3 - Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 - Primary and Secondary Energy		NG	CO_2
			6 - Details of Natural Gas Liquids			
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[4]		NA	NA
1.A.1.a.iii Heat Plants	NO					

Notes:

1. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
2. Publication references are provided in Table A.3-1.
3. National activity data and emission factors are used except for fuels and gases specified here.
4. A portion of this data source is allocated to this CRF source category prior to calculating emissions.

NA - Not applicable. National aggregation only.
NG - Natural gas
NO - Not Occurring

A3.1.4.1.2. Petroleum Refining (CRF Category 1.A.1.b) and Manufacture of Solid Fuels and Other Energy Industries (CRF Category 1.A.1.c)

To meet the UNFCCC reporting requirements, activity data from Manufacture of Solid Fuels and Other Energy Industries were reallocated into two separate IPCC subcategories, both of which comprise the emissions associated with the combustion of fuels produced at the facilities (e.g. combustion of coal at a coal mine or natural gas at an oil and gas facility). Combustion emissions that support coal production are allocated to 1.A.1.c.i – Manufacture of Solid Fuels, while combustion emissions that support crude oil and natural gas production and upgrading of oil sands bitumen are allocated to 1.A.1.c.ii – Oil and Gas Extraction.

The methodology for estimating emissions from these subcategories involves applying Equation A3–1 on a national basis and subtracting emissions associated with flaring from the total GHG emissions for Petroleum Refining and Oil and Gas Extraction. The fuel-use data reported in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the Fugitive category. The fuel use, energy-content and emission data associated with flaring are subtracted to avoid double counting and emissions are reallocated to the Fugitive category 1.B.2.

To determine the activity data associated with the Petroleum Refining subcategory, some data reported in the RESD must be reallocated. All refined petroleum products reported as Producer Consumption are allocated to the Petroleum Refining subcategory, except in provinces where no refinery exists and these producer-consumed RPPs are assigned to Oil and Gas Extraction. Physical quantities of liquefied petroleum gases (LPGs) reported in the RESD as producer consump-

tion are divided between propane and butane, using energy data reported in the RESD.

Calculating the emissions associated with the fuels listed below involves summing the activity data reported under the RESD's Petroleum Refining and Producer Consumption lines and applying Equation A3–1 to:

- petroleum coke;
- still gas;
- kerosene;
- light fuel oil;
- heavy fuel oil;
- butane; and
- propane.

In addition, activity data, in the form of fuel used by industry to generate electricity or steam, are currently aggregated to two summary lines in the RESD (Line 11 – Electricity by Industry and Line 14 – Steam Generation). The aggregated data needs to be reallocated to the appropriate industry where the fuel is used. This is completed using one of two methods, which are discussed in detail in section A3.1.4.1.

Due to a lack of resolution in the RESD's Producer Consumption line, by specific industry, the Manufacture of Solid Fuels and Other Energy Industries subcategory does not include emissions associated with the transportation fuels listed below; these emissions are reported in the Petroleum Refining subcategory. In general, the combustion emissions for the Petroleum Refining subcategory from transportation fuels are calculated using activity data reported in the RESD under Producer Consumption and Equation A3–1:

- gasoline; and
- diesel fuel.

Table A3–3 Estimation Methodology for Petroleum Refining, Manufacture of Solid Fuels and Oil and Gas Extraction

CRF Source Category[1]	Fuel Type	Data Source			Provincial Aggregation[3]	
		Publication[2]	Table	Line	Fuel	Gas
1.A.1.b Petroleum Refining	Solid Fuels	NA				
	Liquid Fuels	RESD	3 - Refined Petroleum Products	Electricity by Industry[4] Steam Generation[4]	NA	NA
			11 - Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	NA		
	Gaseous Fuels	RESD	1 - Primary and Secondary Energy 6 - Details of Natural Gas Liquids	Electricity by Industry[4] Steam Generation[4] Petroleum Refining	NG	CO_2
	Biomass	NA				
1.A.1.c.i Manufacture of Solid Fuels	Solid Fuels	RESD	1 - Primary and Secondary Energy Coal Details (unpublished)	Producer Consumption	COAL	CO_2
	Liquid Fuels	NA				
	Gaseous Fuels	NA				
	Biomass	NA				
1.A.1.c.ii Oil and Gas Extraction	Solid Fuels	NA				
	Liquid Fuels	RESD	1 - Refined Petroleum Products 6 - Details of Natural Gas Liquids	Electricity by Industry[4] Producer Consumption	NA	NA
			11 - Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	NA		
	Gaseous Fuels	RESD	1 - Primary and Secondary Energy	Electricity by Industry[4] Producer Consumption	NG	CO_2
	Biomass	NA				

Notes:
1. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
2. Publication references are provided in Table A3-1.
3. National activity data and emission factors are used except for fuels and gases specified here.
4. A portion of this data source is allocated to this CRF source category prior to calculating emissions.

NA - Not applicable. National aggregation only.
NG - Natural gas

The IPCC default emission factors for N_2O are used to estimate emissions for petroleum coke and motor gasoline, and are based on the calorific value of the fuel. The gross calorific value (GCV) for petroleum coke is reported in the RESD and can change annually. As such, the emission factor for petroleum coke for both crude bitumen upgrading and crude oil refining changes on an annual basis. The conversion between the GCV and the net calorific value (NCV), a necessary part of generating annual emission factors, is based on data reported to and published by the Canadian Industrial Energy End-use Data Analysis Centre (CIEEDAC 2012).

To calculate GHG emissions from the Manufacture of Solid Fuels and Other Energy Industries subcategory, activity data for the following fuels reported as Producer Consumption in the RESD are used in Equation A3–1:

- natural gas;
- coal;
- propane; and
- butane.

The producer consumption line in the RESD includes petroleum coke, still gas and diesel used by refineries and by the crude bitumen upgrading industry. Information on the proportion of fuel consumed by the crude bitumen upgrading industry is provided in Table 11, Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil, of the RESD. This information is used to reallocate the relevant quantities of petroleum coke and still gas to the Oil and Gas Extraction subcategory (CRF category 1.A.1.c.ii). Diesel reported as producer consumption is used in oil sands mining trucks and is reallocated to Off-road Transportation (see section A3.1.4.2.1).

As previously mentioned in Section A3.1.4.1.1, emissions from combusted coal are estimated at a provincial/territorial level and aggregated to a national level.

To avoid double counting, the emissions associated with flaring are subtracted from the total for this subcategory and reallocated to the relevant fugitive tables (1.B.2). Flaring emissions from the fugitive Petroleum Refining model are subtracted from Petroleum Refining (1.A.1.b), while all other flaring emissions from the fugitive model are subtracted from Oil and Gas Extraction (1.A.1.c.ii) and reallocated to the relevant Fugitive category under 1.B.2.

Table A3–3 provides a summary of the methodology for this CRF category.

A3.1.4.1.3. Manufacturing Industries and Construction

(CRF Category 1.A.2)

The Manufacturing Industries and Construction category include a number of industrial categories. Activity data in the RESD are reported for the main economic and fuel-consuming industrial categories; however, this does not include fuel used to generate electricity or steam by industry. This energy is captured in the RESD in two separate summary lines (one for electricity and one for steam), which are not broken down by industrial categories. In addition, activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated data needs to be reallocated to the appropriate industry where the fuel is used. This reallocation is completed using the methods discussed in detail in section A3.1.4.1.

Emissions are calculated for the following categories:

- Mining;
- Iron and Steel;
- Non-ferrous Metals;
- Chemicals;
- Pulp, Paper and Print;
- Non-metallic Minerals;

- Construction; and
- Other Manufacturing (includes Food Processing, Beverages and Tobacco).

GHG emissions associated with the Manufacturing Industries and Construction category are calculated by applying Equation A3–1 to activity data reported in the RESD and emission factors for specific fuels on a national basis. Coal emissions are handled as described in Section A3.1.4.1.1. Emissions resulting from fuels used as feedstocks are reported under the Industrial Processes Sector, whereas emissions generated from the use of transportation fuels (e.g. diesel and gasoline) are allocated under the Transport category.

All emissions associated with the use of metallurgical coke in the iron and steel industry for the reduction of iron ore in blast furnaces have been allocated to the Industrial Processes Sector.

CO_2 emissions associated with biomass combustion are reported but not included in the national totals, whereas CH_4 and N_2O emissions are reported and included in the totals. Industrial consumption of biomass and spent pulping liquor is reported in the RESD; however, some of the data are limited. The RESD data for Newfoundland and Nova Scotia are combined. Facility-level data is used to re-allocate this consumption to Nova Scotia. In 2010, Environment Canada conducted a review of available wood waste moisture content data and concluded that for the purposes of the National Inventory Report (NIR), solid wood waste activity data are reported on a wet-weight basis and that the average moisture content is 50%.

CO_2 emissions from the combustion of waste fuels in the cement industry are calculated based on data provided by the Cement Association of Canada and reported by CIEEDAC (2013) on an energy basis.

Table A3–4 provides a summary of the methodology for this CRF category.

A3.1.4.1.4. Other Sectors

(CRF Category 1.A.4)

The Other Sectors category consists of three subcategories: Commercial/Institutional, Residential and Agriculture/Forestry/Fishing. GHG emissions associated with the Other Sectors category (with the exception of emissions from the combustion of residential firewood) are calculated by applying Equation A3–1 to activity data reported in the RESD and emission factors for specific fuels on a national basis.

The activity data used in the calculation of GHG emissions from the combustion of residential firewood are based on estimated fuel use, as determined from Environment Canada's study Residential Fuelwood Consumption in Canada (Environment Canada 2014). Firewood consumption data were collected through a survey of residential wood use for the years 1996, 2006 and 2012 (Canadian Facts 1997; TNS 2006; TNS 2012). These data were collected by province and grouped into six major appliance-type categories:

1. Fireplaces
2. Fireplace Inserts
3. Wood Stoves
4. Wood Furnaces
5. Pellet Stoves
6. Other Equipment

Some of these appliance types were further broken down into either advanced technology (catalytic or non-catalytic) or conventional (with or without glass doors, air-tight or not-air tight).

The surveys also collected data on the type of wood used by province. Since the firewood consumption data was collected on a volume basis, an average density value was determined by province, based on the proportion of the different type of wood used and the corresponding wood densities. The wood densities were taken from various Canadian wood density studies (Alemdag 1984; Gonzalez 1990; Jessome 2000).

Table A3–4 Estimation Methodology for Manufacturing and Construction

CRF Source Category[1]	Fuel Type	Data Source			Provincial Aggregation[3]	
		Publication[2]	Table	Line	Fuel	Gas
1.A.2.a. Iron and Steel	Solid Fuels	RESD	1 - Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[4] Steam Generation[4] Iron and steel manufacturing	COAL	CO_2
	Liquid Fuels	RESD	3 - Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids		NG	CO_2
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[4]		NA	NA
1.A.2.b. Non-Ferrous Metals	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[4] Steam Generation[4] Aluminum and non-ferrous metal manufacturing	COAL	CO_2
	Liquid Fuels	RESD	3 – Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids		NG	CO_2
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[4]		NA	NA
1.A.2.c. Chemicals	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[4] Steam Generation[4] Chemicals and fertilizer manufacturing	COAL	CO_2
	Liquid Fuels	RESD	3 – Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids		NG	CO_2
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[4]		NA	NA
1.A.2.d. Pulp, Paper and Print	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[4] Steam Generation[4] Pulp and paper manufacturing	COAL	CO_2
	Liquid Fuels	RESD	3 – Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids		NG	CO_2
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[4]		NA	NA
1.A.2.e. Food Processing, Beverages and Tobacco	Emissions for this subcategory are included in 1.A.2.f.iv. – Other Manufacturing.					
1.A.2.f. Non-Metallic Minerals	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[4] Steam Generation[4] Cement	COAL	CO_2
			Waste fuel data from the Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC).		NA	NA
	Liquid Fuels	RESD	3 – Refined Petroleum Products	Electricity – By industry[4] Steam Generation[4] Cement	NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids		NG	CO_2
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[4]		NA	NA
1.A.2.g.iii Mining	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity – By industry[4] Steam Generation[4] Total mining & oil & gas extraction	COAL	CO_2
	Liquid Fuels	RESD	3 – Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids		NG	CO_2
	Biomass	RESD	NA		NA	NA
1.A.2.g.v Construction	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Construction	COAL	CO_2
	Liquid Fuels	RESD	3 – Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids		NG	CO_2
	Biomass	RESD	NA		NA	NA
1.A.2.g.viii.1 Other Manufacturing	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity – By industry[4] Steam Generation[4] Other Manufacturing	COAL	CO_2
	Liquid Fuels	RESD	3 – Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids		NG	CO_2
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[4]		NA	NA

Notes:
1. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
2. Publication references are provided in Table A3-1.
3. National activity data and emission factors are used except for fuels and gases specified here.
4. A portion of this data source is allocated to this CRF source category prior to calculating emissions.

NA - Not applicable. National aggregation only.
NG - Natural gas

Table A3–5 Estimation Methodology for Other Sectors

CRF Source Category[1]	Fuel Type	Data Source			Provincial Aggregation[3]	
		Publication[4]	Table	Line	Fuel	Gas
1.A.4.a.i Commercial / Institutional – Stationary Combustion	Solid Fuels	RESD	1 - Primary and Secondary Energy Coal Details (unpublished)	Electricity – by industry[4] Commercial and other institutional Public administration	COAL	CO_2
	Liquid Fuels	RESD	3 - Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids		NG	CO_2
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[4]		NA	NA
		NIR	Table A3-68: Estimated MSW CH_4 Generated, Captured, Flared and Emitted			
1.A.4.b.i Residential – Stationary Combustion	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Residential	COAL	CO_2
	Liquid Fuels	RESD	3 – Refined Petroleum Products	Residential	NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	Residential	NG	CO_2
	Biomass	Estimated using Environment Canada residential fuelwood consumption model.			NA	NA
1.A.4.c.i Agriculture/ Forestry/ Fishing – Stationary Combustion	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity – by industry[4] Steam Generation[4] Forestry and logging and support activities for forestry Agriculture	COAL	CO_2
	Liquid Fuels	RESD	3 – Refined Petroleum Products		NA	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids		NG	CO_2
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption		NA	NA

Notes:
1. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
2. Publication references are provided in Table A.3-1.
3. National activity da¼ta and emission factors are used except for fuels and gases specified here.
4. A portion of this data source is allocated to this CRF source category prior to calculating emissions.

NA - Not applicable. National aggregation only.

The mass of firewood consumed for the other years was extrapolated based on the number of houses in each province using wood as a principal or supplementary heat source (Statistics Canada 1997, 2009) in relation to the survey years. GHG emissions were calculated by multiplying the amount of wood burned in each appliance by the emission factors.

CO_2 emissions associated with biomass combustion in the Residential category are reported but not included in the national total; however, CH_4 and N_2O emissions are included.

The Commercial category includes GHG emissions associated with the combustion of landfill gas. As landfill gas is considered a biofuel, CO_2 emissions associated with combustion are reported but not included in the national total; however, CH_4 and N_2O emissions are included.

In addition, activity data, in the form of fuel used by industry (including Commercial/Institutional subcategory) to generate electricity are currently aggregated to a summary line in the RESD (Line 11 – Electricity by Industry). Activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated data needs to be reallocated to the appropriate subcategory where the fuel is used. This is completed using the methods discussed in detail in section A3.1.4.1.

The Agriculture/Forestry/Fishing category (CRF Category 1.A.4.c) includes emissions from stationary fuel combustion only from the agricultural and forestry industries. Emissions are from on-site machinery operation and from space heating and are estimated based on fuel use data for agriculture and forestry as reported in the RESD. Fishery emissions are reported under either the Transport or Other Manufacturing (i.e. food processing) category. Mobile emissions associated with this category are not disaggregated and

are all included as off-road or marine emissions reported under Transport.

Table A3–5 provides a summary of the methodology for this CRF category.

A3.1.4.2. Transport

(CRF Category 1.A.3)

GHG emissions from the Transport subsector are divided into six categories:

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

Emission estimates are developed at the provincial/territorial level and aggregated to the national level. Fuel combustion emissions associated with the Transport subsector are calculated using various adaptations of Equation A3–1.

CO_2 emissions are predominantly dependent on the type and characteristics of fuel being combusted, whereas N_2O and CH_4 emissions are dependent on both the fuel combusted and emission control technologies present. Annex 6 provides a complete listing of transportation-related emission factors and their specific references.

New for this submission, Canada's Mobile Greenhouse Gas Emission Model (MGEM) is replaced with the Motor Vehicle Emissions Simulator (MOVES) model, version MOVES2014, developed by the U.S. EPA. In addition, a modified version of the U.S. EPA's NONROAD model (NONROAD2012c) has been implemented for Other Transportation (Off-road). The primary reasons for these updates are to remain current with regulatory changes in the Canadian vehicle fleet, which are harmonized with the United States; to align GHG estimates with those published in the *Air Pollutant Emissions Inventory* and *Canada's Black Carbon Inventory*; and to create a bottom-up inventory for off-road emissions by making use of equipment and operational data. Use of the NONROAD model also has the added benefit of allocation to additional economic subsectors on an equipment basis. The Aviation Greenhouse Gas Emission Model (AGEM) is used to calculate aviation emissions. Railway and navigation emissions are based on fuel reported in the RESD. Combustion emissions associated with pipeline transport are estimated separately.

A3.1.4.2.1. Road Transportation (CRF Category 1.A.3.b.i-v) and Other Transportation (Off-road) (CRF Category 1.A.3.e.ii)

The methodology used to estimate Road Transportation and Other Transportation (Off-road) GHG emissions follows a detailed IPCC Tier 3 approach. Since these two subcategories are collectively normalized to fuel available as reported in the RESD, a combined methodology for the two subcategories is outlined below.

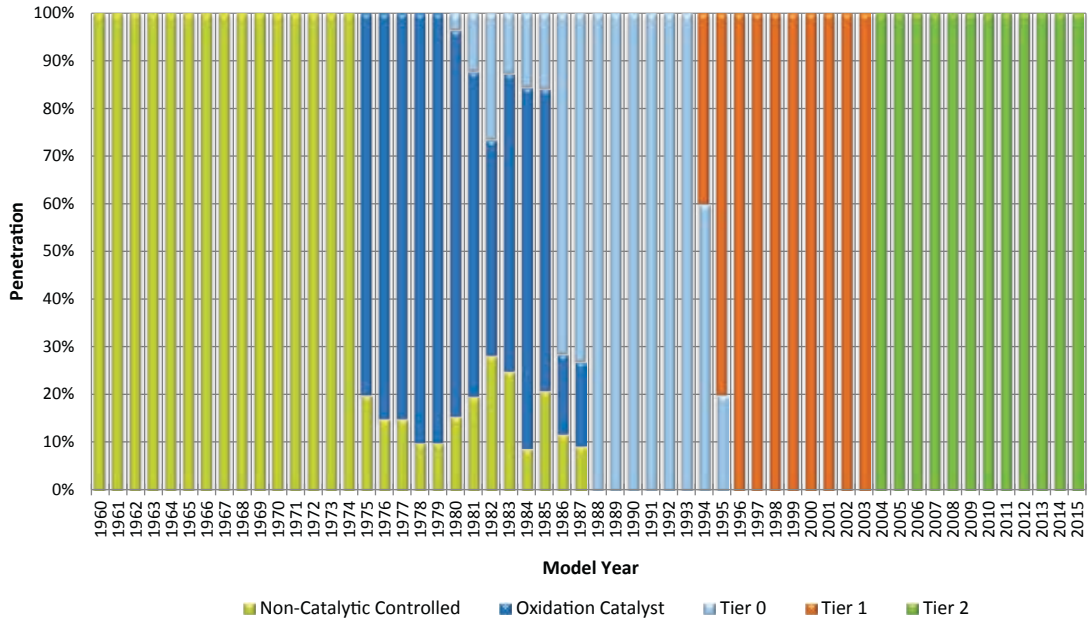
Step 1: On-road Activity Data – Vehicle Populations, Technology Penetration, Catalyst Survival Rate, Kilometre Accumulation Rates, Fuel Consumption Rates and Biofuels

Vehicle Populations

Vehicles are separated into different classes depending on their fuel type, body configuration (car versus truck) and gross vehicle weight rating (GVWR). GVWR is the maximum allowable weight of a fully loaded road vehicle, including the weight of the vehicle, fuel, passengers, cargo and other miscellaneous items, including optional accessories.

Two distinct data sets are used to develop a complete vehicle population profile. Light-duty

Figure A3–2 Technology Penetration for Light-duty Gasoline Vehicles and Trucks



vehicle and truck populations for 1990–2002 and 2005–2013 were obtained from the *Canadian Vehicles in Operation Census*, which is maintained by DesRosiers Automotive Consultants Inc. Light-duty vehicle and truck populations for 2003–2004 were derived from Statistics Canada's Canadian Vehicle Survey (CVS). Heavy-duty vehicle populations were obtained from R.L. Polk & Co. for 1994–2002 and 2005–2013. Heavy-duty vehicle populations for 2003–2004 were derived from Statistics Canada's *Canadian Vehicle Survey*, while populations for 1990–1993 were estimated based on historical population trends. The 2014 and 2015 populations were estimated based on scrappage and growth rates.[1] Light-duty vehicles (cars) and light-duty trucks (pickups, minivans, SUVs, etc.) are those with a GVWR of less than or equal to 3900 kg, whereas heavy duty classes have a GVWR above 3900 kg.[2]

Motorcycle populations for 1990–2013 were based on road motor vehicle annual registrations from Statistics Canada (CANSIM, Tables 405-0001 and Table 405-0004). The annual motorcycle counts were then stratified into model year bins with the aid of published age distributions found in the Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. EPA, 2015). The 2014 and 2015 population was estimated based on a scrappage and growth rate.

Technology Penetration

To account for the effects of emission control technologies on emission rates of CH_4 and N_2O,

1 Scrappage rates for all vehicle classes (including motorcycles) were developed based on historical population trends. The growth rates for light-duty vehicles and motorcycles are from the U.S. EPA Motor Vehicle Emission Simulator (MOVES2014, 2014). For all other classes, DesRosiers Automotive Consultants Inc. provided growth rates.

2 The 2005–2013 light- and heavy-duty populations received from DesRosiers and Polk were in a new format when compared with previously received data sets and were also the result of updated vehicle identification algorithms. As a result, when the 1990–2004 data set was merged with the 2005–2013 data set, there were step changes in some classes between 2004 and 2005. The classes affected were light-duty trucks (GVWR less than or equal to 3900 kg) and heavy-duty vehicle 2b and 3 classes (GVWR between 3901 kg and 6351 kg). Since the newer data set with updated algorithms is believed to be more representative, the class ratios between light-duty trucks and heavy-duty vehicle 2b and 3 classes from the newer data were applied to the older data set while maintaining the overall population of the older data set.

Table A3–6 Technology Penetration for HDGVs, HDDVs, LDDVs, LDDTs and MCs

Control Technology	Model Years
Heavy-duty Gasoline Vehicles (HDGVs)	
Uncontrolled	1960–1984
Non-catalytic Controlled	1985–1995
Three-way Catalyst	1996–2015
Heavy-duty Diesel Vehicles (HDDVs)	
Uncontrolled	1960–1982
Moderate Controls	1983–1995
Advanced Controls	1996–2015
Light-duty Diesel Vehicles and Trucks (LDDVs and LDDTs)	
Uncontrolled	1960–1982
Moderate Controls	1983–1995
Advanced Controls	1996–2003
Tier 2	2004–2015
Motorcycles (MCs)	
Uncontrolled	1960–1995
Non-catalytic Controlled	1996–2015

Note: extrapolated to the 2015 calendar year for the 2017 submission

estimates of the number of vehicles on the road equipped with catalytic converters and other control technologies were developed. Figure A3–2 illustrates the varying penetration percentages of evolving technologies into new light-duty gasoline vehicles (LDGVs) and light-duty gasoline trucks (LDGTs) in successive model years. Technology penetration for heavy-duty gasoline vehicles (HDGVs), heavy-duty diesel vehicles (HDDVs), light-duty diesel vehicles (LDDVs), light-duty diesel trucks (LDDTs) and motorcycles (MCs) are detailed in Table A3–6 (U.S. EPA 2014).

Catalyst Survival Rate

With use, catalytic converters deteriorate, affecting tailpipe emission rates. Based on information from industry experts, a technology-specific deterioration rate is applied to LDGVs and LDGTs with catalytic controlled technologies. To model the deterioration effect, the vehicles with deteriorated catalysts are assigned to the non catalytic controlled technology. For provinces with inspection and maintenance (I/M) programs (Ontario and British Columbia), the catalyst survival rate is not applied to Tier 0, Tier 1 or Tier 2 technologies, as these emission control technologies are inspected and replaced or repaired as necessary.

Fuel Consumption Rates (FCR)

With the adoption of MOVES2014, fuel consumption rates are now embedded within the model in the form of energy rates in kJ/s. The rates vary, taking into account a range of default parameters or user inputs, such as vehicle type, model year, speed, road type and operating mode. As the Canadian and U.S. vehicle markets are made virtually identical through regulation, it is believed that the MOVES energy rates are representative of fuel consumption for Canadian vehicles. MOVES also factors in more current fuel efficiency regulations, such as the *On-Road Vehicle and Engine Emission Regulations* for light-duty vehicles and the *Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations* for heavy-duty vehicles. Further documentation on MOVES energy rates for both light- and heavy-duty vehicles can be found on the U.S. EPA website at https://www3.epa.gov/otaq/models/moves/moves-reports.htm.

For this submission, Canada only uses MOVES' energy allocation capability. MOVES output is on an energy basis and Canada's current emissions factors are developed on a fuel volume basis. The energy output from MOVES is therefore converted to fuel volumes using energy conversion factors as reported by Statistics Canada, taking into consideration the use of biofuels (see below). MOVES reports energy output on a lower heating value basis. Canada plans to review the GHG emission factors within MOVES for their potential use in a future submission.

Kilometre Accumulation Rates

Kilometre accumulation rates (KARs) are a measure of the average annual kilometres travelled by a single vehicle of a given age in a specific vehicle class. Light-duty car and truck KARs are estimated from the results reported in a study that examined observed differences in a vehicle odometer reading

recorded between successive inspection and maintenance (I/M) tests from Ontario and British Columbia (Stewart Brown Associates 2013). Due to the absence of I/M programs in other jurisdictions, the Ontario KAR estimates are adopted in all other provinces and territories excluding British Columbia, where the B.C. KAR estimates are directly applied.

Biofuels

Under the previous method, quantities of ethanol and biodiesel were accounted for on a volume basis using data supplied from Natural Resources Canada. In contrast, MOVES requires biofuel content on a relative content basis (i.e., percent) as an input, as well as a range of other fuel characteristics, such as vapour pressure, sulphur content, and benzene content. These parameters were derived by Environment and Climate Change Canada using information collected under the *Renewable Fuels Regulations, Sulphur in Liquid Fuels* reports and related sources. However, volumes of biofuels are recalculated as outputs such that emissions can be estimated on the basis of Equation A3–1 and the use of appropriate emission factors in Table A6-12.

Step 2: On-road Fuel Calculation

Using the inputs from Step 1, on-road fuel consumption is estimated by MOVES2014 in litres. This calculation represents the initial "bottom-up" fuel calculation for consideration in the fuel normalization process described below. On-road vehicles are grouped into eight major vehicle classes:

- Light-duty gasoline vehicles (LDGV)
- Light-duty gasoline trucks (LDGT)
- Heavy-duty gasoline vehicles (HDGV)
- Motorcycles (MC)
- Light-duty diesel vehicles (LDDV)
- Light-duty diesel trucks (LDDT)
- Heavy-duty diesel trucks (HDDV)
- Propane and natural gas vehicles.

Step 3: Other Transportation (Off-road)

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

GHG emissions for off-road transportation are calculated using NONROAD2012c, a Canadianized update to NONROAD2008 developed by the U.S. EPA. Key inputs to the model are equipment population, average rated power, load factor and activity (in hours/year). Further, the Canadian modifications to NONROAD include a user-defined age distribution of equipment that is not part of the U.S. model, as well as a unique coding for oil sands equipment and additional renewable fuels capabilities. NONROAD outputs are expressed on a fuel volume basis, to which Equation A3–1 is applied using the emissions factors in Table A6.12.

Activity data used in the model are largely derived from Power Systems Research (PSR) data. PSR is an independent supplier of data which maintains PartsLink, a comprehensive database that includes off-road equipment used in Canada. A significant study conducted by PSR in 2011 forms the basis of activity input, which includes parameters such as engine populations, age distribution, engine load size, factor and hours of use for the years 1990 to 2015. NONROAD default parameters used include deterioration and other factors. Updates to the 2011 data set were performed in 2012 and 2013. Unlike MOVES, which outputs on an energy basis, NONROAD calculates fuel use on a volume basis, which is later scaled upwards or downwards in the fuel normalization step (Step 4) once biofuels are taken into account.

A great advantage of NONROAD is its capability to allocate emissions to distinct sectors on an equipment basis. Primary sectors from NONROAD include agriculture, airport (equipment), commercial, construction and mining, industrial, residential, forestry, railway (equipment) and recreational equipment. Where applicable, emissions from these sectors are reported under the appropriate CRF sector.

Step 4: Normalization

In an effort to mitigate some of the uncertainties associated with separate bottom-up calculations for on- and off-road estimates, the fuel consumption estimates from these two subsectors are combined and balanced against top-down fuel availability information. The source of top-down fuel availability data to be considered against the bottom-up fuel consumption estimate is the RESD (Statistics Canada #57-003).

Statistics Canada has stated that the volumes of gasoline reported in the RESD include ethanol. Therefore, the estimated volume of ethanol fuel is removed from the volume of gasoline reported. As a result, when comparing total volumes of gasoline in the RESD with that of the CRF, one should be cognizant that the CRF gasoline volume must be added to the CRF ethanol volume in order to equate to the RESD gasoline volume. For diesel fuel, the opposite is true: given that the RESD does not report biodiesel, diesel fuel volumes in the CRF will equate to the diesel fuel volumes in the RESD.

In Step 4, bottom-up estimates of fuel consumption from on- and off-road sources are pooled together on a fuel basis at the provincial/territorial level, and the total volume of fuel is scaled to match the fuel available as reported in the RESD. At a provincial level, top-down and bottom-up gasoline consumption estimates differ slightly; however, at a national level, there is a high degree of correlation between the two estimates. Please refer to Table A3–7 and Table A3–8 for the normalization factors calculated on a national basis, for gasoline and diesel fuel respectively.

Table A3–7 Gasoline Normalization Values, Selected Years

		1990	2005	2010	2011	2012	2013	2014	2015
Raw	Bottom-up On-Road Fuel Consumption Estimate (ML)	37 121	40 674	46 620	46 288	46 926	48 332	49 052	49 436
	Bottom-up Off-Road Fuel Consumption Estimate (ML)	6 659	2 508	2 865	2 395	2 270	2 303	2 557	2 596
	Total Bottom-Up Fuel Consumption Estimate (ML)	43 780	43 182	49 485	48 682	49 196	50 635	51 610	52 032
	Bottom-up On-Road Portion (%)	84.8%	94.2%	94.2%	95.1%	95.4%	95.5%	95.0%	95.0%
	Bottom-up Off-Road Portion (%)	15.2%	5.8%	5.8%	4.9%	4.6%	4.5%	5.0%	5.0%
Target	Total Top-down Fuel Available (ML)	33 943	40 816	43 357	42 924	43 032	44 219	43 464	43 959
	Scale Factor	78%	95%	88%	88%	87%	87%	84%	84%
Scaled	Final On-Road Fuel Estimate (ML)	28 780	38 445	40 847	40 813	41 046	42 208	41 311	41 766
	Final Off-Road Fuel Estimate (ML)	5 163	2 371	2 510	2 112	1 986	2 011	2 154	2 193
	Sum of Final On and Off-Road Fuel (ML)	33 943	40 816	43 357	42 924	43 032	44 219	43 464	43 959

Table A3–8 Diesel Fuel Normalization Values, Selected Years

		1 990	2 005	2 010	2 011	2 012	2 013	2014	2 015
Raw	Bottom-up On-Road Fuel Consumption Estimate (ML)	5 327	14 677	18 321	17 799	18 854	19 039	18 981	19 103
	Bottom-up Off-Road Fuel Consumption Estimate (ML)	9 416	10 277	10 555	9 573	9 000	8 904	8 890	9 460
	Total Bottom-Up Fuel Consumption Estimate (ML)	14 743	24 955	28 876	27 372	27 854	27 943	27 871	28 562
	Bottom-up On-Road Portion (%)	36%	59%	63%	65%	68%	68%	68%	67%
	Bottom-up Off-Road Portion (%)	64%	41%	37%	35%	32%	32%	32%	33%
Target	Total Top-down Fuel Available (ML)	13 028	22 601	25 696	26 949	26 576	27 275	26 734	26 636
	Scale Factor	88%	91%	89%	98%	95%	98%	96%	93%
Scaled	Final On-Road Fuel Estimate (ML)	5 317	13 807	16 610	17 914	18 276	18 785	18 347	18 015
	Final Off-Road Fuel Estimate (ML)	7 711	8 794	9 087	9 035	8 300	8 491	8 387	8 621
	Sum of Final On and Off-Road Fuel (ML)	13 028	22 601	25 696	26 949	26 576	27 275	26 734	26 636

Step 5: Emission Calculation

Once a final allocation of fuel is complete for all vehicle and equipment types, emissions are calculated using Equation A3–1 with the emission factors in Table A6-12.

A3.1.4.2.2. Domestic Aviation

(CRF Category 1.A.3.a)

The methodology used to estimate GHG emissions from the Domestic Aviation category employs a modified IPCC Tier 3 approach. The Aviation model has been named AGEM as an acronym for Aviation Greenhouse Gas Emission Model.

This category includes all emissions from domestic air transport (commercial, private, agricultural, etc.). In accordance with the 2006 IPCC Guidelines, and because of the Tier 3 approach, military air transportation emissions are reported in the Other — Mobile category (CRF Category 1.A.5.b). Excluded are emissions from fuel used at airports for ground transport (reported under Other Transportation (Off-road) and fuel used in stationary combustion applications at airports. Emissions from international flights are designated as "bunker" emissions and are not included in national totals but are estimated and reported separately under International Bunkers.

Careful consideration should be paid when comparing emission estimates in this category against those reported to other institutions, such as the International Energy Agency (IEA). The IEA estimates are, in particular, quite different from those reported in the CRF when comparing domestic and international (bunker) emissions from aviation turbo fuel. The Tier 3 method employed by AGEM in the NIR allows detailed flight-by-flight distinction between domestic and international movements based on a flight's origin and destination. The fuel consumption values (disaggregated into domestic and international sectors) reported to the IEA by Canada assume that all fuel sold to Canadian carriers is domestic and that all fuel sold to foreign carriers is international, which greatly underestimates the amount of emissions identified as aviation bunkers, given that many movements by Canadian carriers are international in nature. Because the reporting requirements for these two separate reports (UNFCCC, IEA) do not align, the reported values will not align either.

Step 1: Activity Data: Aircraft Movements, Flight Path Length, Airport Coordinates, Aircraft Fuel Use Characteristics, Representative Aircraft Mapping, Aircraft Emission Performance

Aircraft Movements

The aircraft movement data (AMS 2015) used in AGEM are flight-by-flight tower data collected by NAV Canada (Canada's civil air navigation services provider) starting in November 1996 and by Transport Canada before November 1996. Both data streams are processed by Statistics Canada and redistributed to NAV Canada and Transport Canada. Environment Canada receives the information directly from Statistics Canada, including small airport movements that Statistics Canada collects directly and appends to the tower data from NAV Canada.

The data identify, among other things, the origin, destination and aircraft type for any given movement occurring in Canada. Statistics Canada's processing of the data includes adding information based on other raw data fields provided to them as well as validation of airports, aircraft types and various data fields that are not crucial to modelling fuel use.

Military emissions are estimated based on the movement data, as they are labelled as military by Statistics Canada.

Flight Path Length

The flight path length is the true distance travelled between two airports. The movement data used for modelling are not radar data and thus do not track the exact path travelled by each individual movement. AGEM estimates the flight path length based on additional information obtained from the Federal Aviation Administration (FAA). The FAA operates an aviation model titled Aviation Environmental Design Tool (AEDT) (formely System for assessing Aviation's Global Emissions (SAGE)) that is based on true radar data. The FAA provided Environment Canada with an extract from their model for calendar year 2005 involving Canadian airports and included the statistical measures (maximum, minimum, average, standard deviation) for the radar distance travelled between any Canadian origin and final destination for a given aircraft type (Fleming 2008a). The average distance from these combinations was then used as the distance flown when the same combination appeared in AGEM's movement data (regardless of the calendar year of the movement). There are cases, however, when a combination in AGEM exists without a corresponding average distance. In these cases, another method needed to be developed.

An adjusted great circle distance (GCD3[3]) is used when the average radar distance is unknown. A factor applied to the GCD was developed by comparing GCD to radar distance for a given origin/destination/aircraft type. Graphing the known radar lengths against their corresponding GCDs leads to an equation that can be used for adjusting all raw GCD distances. Therefore, all GCDs are adjusted by a factor to approximate the flight path length with the factors decreasing in magnitude as the GCD increases.

3 Great circle distance is the shortest distance between two points on a sphere; with respect to aviation, it is the shortest possible flight path length between the origin and destination of a flight movement.

Airport Coordinates

All possible airport entries within the AGEM movement data were extracted and defined. Information on the airports such as latitude, longitude, name, elevation, etc. were compiled from various sources including Transport Canada (Cadieux 2006), the Canada Flight Supplement (NAV Canada 2009), SAGE (Fleming 2008b), the Modeling and Database Task Force (MODTF) (Fleming 2008c), the FAA (FAA 2009) and previous departmental work (Manning 2007). The main information required is the geographical coordinates so that a GCD can be calculated and used to determine the flight path length.

Aircraft Fuel Use Characteristics

Once the flight path length is determined, the fuel consumed by the aircraft for that movement can be calculated knowing the fuel characteristics of that aircraft. The fuel characteristics of various representative aircraft are drawn from the Base of Aircraft Data (BADA) (BADA 2009), the International Civil Aviation Organization (ICAO) via their engine emissions databank (ICAO 2009), the Swedish Defence Research Agency (FOI) via their turbo prop engine emissions databank (Hagstrom 2010) and the Federal Office of Civil Aviation (FOCA) in Switzerland (FOCA 2007).

For aviation turbo fuel aircraft, the information in BADA is used for estimating fuel use from just after takeoff to landing. The ICAO information is used for defining the remaining portions of the landing and takeoff cycle (LTO), which are taxi and takeoff (explained in more detail in Step 2). Finally, the FOI serves the same purpose as the ICAO but covers the smaller turbo prop type aircraft not available in the ICAO data.

For aviation gasoline aircraft, the information in FOCA is used predominately for the LTO cycle. However, BADA is used when applicable for the LTO cycle and is always used for the cruise portion of flight (above 3000 ft).

Representative Aircraft Mapping

All possible aircraft type entries within the AGEM movement data were extracted and defined. Once defined, each aircraft was mapped to a representative aircraft with known fuel-use characteristics so that fuel consumption could be calculated for all aircraft in AGEM. The mapping was done using published mapping guides whenever possible (BADA 2009, IPCC 2006, ICAO 2008, EMEP/CORINAIR 2006) and matching aircraft characteristics (MTOW,[4] number of engines, engine type, etc.) when there was no published mapping for a given aircraft.

Aircraft Emission Performance

In an attempt to better estimate CH_4 emissions from aviation turbo fuel, aircraft-specific emission factors are used within AGEM for the LTO cycle. The factors are taken from Table 3.6.9 in the 2006 IPCC Guidelines, in the form of total emissions per LTO cycle. These factors are then adjusted by a ratio based on the total LTO fuel difference between that published in the table and that calculated in AGEM. It is recognized that a one to one adjustment of CH_4 emissions based on fuel ratio differences may not be entirely correct; however, lacking any additional information, this modification was made recognizing that the default values from Table 3.6.9 do not truthfully reflect AGEM's methodology. For the cruise portion, CH_4 emissions are assumed to be zero (Wiesen et al. 1994). For ease of use by the general public, the published CH_4 emission factor will be a fleet average across the entire time series and based on total fuel consumed (LTO and cruise).

Table 3.6.9 in the 2006 IPCC Guidelines also has N_2O aircraft-specific aviation turbo fuel emission factors on a total LTO cycle basis; however, they are calculated using a Tier 1 fuel-based emission factor and therefore the Tier 1 factor is used directly since the amount of fuel consumed during the LTO cycle is calculated by AGEM.

Country-specific emission factors on a g/L basis are used for CO_2 emissions from aviation turbo fuel aircraft and for CO_2, CH_4 and N_2O emissions from aviation gasoline aircraft.

Step 2: Aircraft Fuel Calculation

Fuel consumed by each individual movement is estimated using the following equation.

Equation A3–2:

$$FuelConsumption_{FlightTotal} = FuelConsumption_{LTO} + FuelConsumption_{Cruise}$$

where:

$FuelConsumption_{FlightTotal}$	=	total fuel consumed on a per flight basis
$FuelConsumptionL_{TO}$	=	fuel consumption during landing and takeoff phase (3,000 ft and below)
$FuelConsumption_{Cruise}$	=	fuel consumption during the cruise phase (over 3,000 ft)

The LTO phase of flight (3000 ft and below) consists of takeoff (accelerating down the runway until liftoff), climb out (from liftoff to 3000 ft), approach (3000 ft to landing) and taxi in/out (manoeuvring from the airport runway to/from the gate). The various LTO phases of flight are quantified by using either standard time-in-modes for that phase multiplied by the fuel consumption rate for that phase (drawn from ICAO, FOI or FOCA) or BADA fuel use characteristics for the aircraft as applicable (only available for the climb-out and approach phases).

The cruise phase of flight (above 3000 ft) is calculated based on the BADA fuel-use characteristics of the aircraft and the flight path length of the movement. The cruise phase is broken up into three parts, consisting of climb (3000 ft to cruise altitude), steady-state cruise (constant cruise altitude reached after completion of climb) and descent (from cruise altitude to 3000 ft). The

4 Maximum takeoff weight.

distance it takes to reach and descend from the steady-state cruise altitude (including the LTO portions of climb out and approach) is subtracted from the flight path length when determining the distance travelled at the steady-state cruise altitude.

The LTO and cruise phases of flight for any given movement are estimated by first using the representative aircraft mapping information, which relates the aircraft identified in the movement data to a representative aircraft with known performance characteristics. For the fuel rates of the representative aircraft that are distance-based, the flight path length for the movement is drawn from either the list of radar movement data provided by the FAA or calculated by quantifying the GCD and multiplying by an adjustment factor as explained above. The fuel rates that are time-based in the LTO cycle already have the time-in-mode defined. With the known fuel characteristics of the aircraft, the time-in-mode and flight path length, the LTO and cruise fuel estimates can be computed.

Step 3: Normalization

All aviation turbo fuel and aviation gasoline apparently consumed in Canada is reported in the RESD (Statistics Canada 57-003-X). The fuel consumed, as estimated by the bottom-up approach of AGEM, is adjusted to match that of the RESD at a national level. The adjustment to LTO and cruise fuel estimates takes place at the individual movement level, across all movements.

Step 4: Emission Calculation

Emission estimates are generated at the individual movement level based on the normalized total fuel consumed and the appropriate emission factor as outlined in Equation A3–1 (as mentioned previously, for aviation turbo fuel, the CH_4 LTO emission estimate at the movement level is not fuel dependent). The individual emission estimates are then summed to generate the national emission estimate.

A3.1.4.2.3. Domestic Navigation

(CRF Category 1.A.3.d)

The emission calculation methodology is considered to be an IPCC Tier 2 method for CO_2 emissions and an IPCC Tier 1 for CH_4, and N_2O emissions. Domestic marine fuel consumption reported in the RESD (Statistics Canada 57 003-X) is multiplied by fuel-specific emission factors (see Annex 6). Fuel sold to foreign marine vessels is assumed to be used only for international travel and therefore emissions are reported under International Navigation (Marine Bunkers).

Some Canadian vessels are engaged in international marine travel. Comprehensive data that would allow an accurate disaggregation of domestic and international shipping activities by Canadian vessels are currently unavailable.

A3.1.4.2.4. Railways

(CRF Category 1.A.3.c)

The methodology is considered to be an IPCC Tier 2 method for CO_2 emissions and an IPCC Tier 1 for CH_4, and N_2O emissions. Railway fuel consumption reported in the RESD (Statistics Canada 57-003-X) is multiplied by fuel-specific emission factors (see Annex 6).

In Canada, locomotives are powered primarily by diesel fuel. A review of emissions attributable to steam train operations in Canada have determined that emissions associated with steam trains are insignificant. Electrically driven locomotives are accounted for under electricity production.

A3.1.4.2.5. Biomass (CRF Category 1.D.3)

The methodology used to estimate emissions from the consumption of biogenic transport fuels (ethanol and biodiesel) follows a modified IPCC Tier 1 method for gasoline and diesel fuel on-road

transportation and an IPCC Tier 1 method for off-road transportation, railways and domestic marine. The volume of biofuels apparently consumed for Transportation is proportionally reallocated back into the respective diesel fuel and gasoline emission technology classes based on those classes' initial consumption volumes.

The volumes of biofuels used for on- and off-road are described in Section A3.1.4.2.1. The volumes of biofuels used for the rail and marine categories are based on the following sources: for 1990–1996, volumes were obtained from a 2011 report examining biofuel production and consumption in Canada (TFIS Inc. 2011), while for 1997–2015, national consumption values are based on information obtained from Natural Resources Canada (NRCan, 2015).

Often, these biofuel volumes are reported directly to NRCan from the provinces. If not, and a given province has a regional mandate, that mandated percentage is applied to the volumes of fossil-based fuels available in that region in order to estimate the volume of biofuel available. Where no provincial mandate existed, the federal mandate percentage was applied.

In lieu of developing specific CH_4 and N_2O emission factors for biofuels, the gasoline and diesel fuel emission factors from the equivalent emission technology classes are applied. CO_2 emission factors are developed according to the chemical properties of the fuel.

A3.1.4.2.6. Pipeline Transport

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

Pipelines represent fossil fuel combustion engines used to power motive compressors to transport oil and natural gas products. The fuel used is primarily natural gas, but some refined petroleum, such as diesel fuel, is also used. Oil pipelines tend to use electric motors to operate pumping equipment.

Combustion-related GHG emissions associated with this equipment are calculated by applying Equation A3–1 to activity data and emission factors for specific fuels on a provincial (for natural gas) and national basis.

A3.2. Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution

Detailed methodologies for estimating fugitive emissions from solid fuel production and the oil and gas industry are covered in this annex.

As the primary source of fugitive emissions, Canada's large oil and gas industry consists of a mix of production types, including natural gas production and processing; light, medium and heavy crude oil production; oil sands mining and extraction; and synthetic crude oil production. Refer to Chapter 3 of this report for a detailed description of sources of fugitive emissions.

All GHG emissions from fuel combustion activities associated with fossil fuel exploration, production, processing, transmission and distribution are reported under the Energy Industries (Section 3.2.4) and Transport (Section 3.2.6) sections of Chapter 3, and their respective methodologies can be found in Annex 3.1 (sections A3.1.4.1 and A3.1.4.2.

A3.2.1. Solid Fuels

A3.2.1.1. Coal Mining

Canada Specific Coal Mining Studies

Canada's fugitive emission estimates are largely based on three studies: *Methane Emissions from Canadian Coal Operations: A Quantitative Estimate*, prepared by B. Hollingshead in 1990 for the Transalta Utilities Corp. (Hollingshead 1990); *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options*, prepared by B. King in 1994 for Neill and Gunter Ltd (King 1994); and *Compilation of a National Inventory of Greenhouse Gas and Fugitive VOC Emissions by the Canadian Coal Mining Industry*, prepared by Cheminfo Services Inc. and Clearstone Engineering Ltd (Cheminfo/Clearstone 2014) for Environment and Climate Change Canada (ECCC).

The Hollingshead study was commissioned by Transalta Utilities Corp., with the goal of estimating methane emissions from coal mines and coal combustion in Canada. The study developed, for the year 1989, estimates of fugitive emissions from underground and surface mines and combustion emissions from all coal use in Canada. As such, the emphasis of this study was not on developing emission factors that would be usable on a yearly basis, but rather on providing a snapshot of all emissions from coal for a particular year. However, in the process of estimating these total emissions, a large amount of useful data was collected pertaining to the methane composition of coal mined in Canada.

Canada has both underground and surface coal mines, and the method developed by King (1994) produced CH_4 emission factors (EFs) for all coal types and all individual coal mines. Where possible, King employed the Canada-specific data included in the Hollingshead study, while clearly identifying and explaining this data source. King's method is a modified version of a process developed for the International Energy Agency by the Coal Industry Advisory Board (CIAB). Further discussion of these modifications can be found in the section below on surface mines. Prior to the 2016 submission, the EFs for CH_4 determined in the King (1994) study were used to estimate the CH_4 fugitive emissions from all 23 operational mines and from all mines abandoned after 1990 in Canada.

In 2014, ECCC awarded a contract to Cheminfo Canada and Clearstone Engineering to update the EFs for coal mines in western Canada. The study produced new emission factors for seven of the 21 active surface mines using field tests from two sub-bituminous coal mines in central Alberta, one bituminous coal mine in northeast British Columbia and one bituminous coal mine in northwest Alberta. Results from the four tested mines were applied to three nearby mines that exploited the same coal seams and had similar geography. The mobile plume transect system (MPTS) that was employed develops a two-dimensional y-z plot of the pollutant concentration and wind profile downwind of the target source(s). The measurement system comprised: (1) a cavity ring-down spectrometer; (2) an 8-channel multi-plexer sampling system; (3) an ultrasonic 3-D wind anemometer; (4) a GPS and inertial system; (5) a vehicle (SUV) equipped with a vertical sampling mast; and (6) a computer and software.

The emissions model is a hybrid of IPCC Tier 3 and Tier 2 methodologies that depends on the availability of mine-specific data. Gross production provided by Statistics Canada, before cleaning and prep work, is used to calculate fugitive emissions for all mine types. The associated post-mining activity emissions are accounted for in the underground and surface mining EFs. Additional details of the methodologies used to estimate the emissions from underground and surface mines are provided below.

The emission factors vary for each coal field, region and mine type, whether above or below ground.

Underground Mines

King (1994) estimated emissions for underground mines on a mine-specific basis by summing emissions from the ventilation system, degasification systems and post-mining activities. In the absence of measured data, emissions from the mine shaft ventilation system were estimated using Equation A3–3.

Equation A3–3:

$$Y = 4.1 + (0.023 \times X)$$

where:

Y	=	emissions of CH_4 per gross tonne of coal mined, m^3 CH_4/t coal
X	=	depth of mine, m

Emissions from post-mining activities were estimated by assuming that 60% of the remaining coal CH_4 (after removal from the mine) is emitted to the atmosphere before combustion. If the CH_4 content of the mined coal was unknown, then 1.5 m^3/t, the global average for coals (King 1994) was assumed. All underground mines in Canada are drift mines and have an effective depth of zero metres. Emissions from post-mining activities are included in the coal production emission factors, after all quantities are converted to mass units, using a standard conversion of .67 kg/m^3 CH_4.

Between the years 1992 and 1999, all underground mining ceased in eastern Canada. The remaining underground mines are located in Alberta and British Columbia and are less gassy than mines in eastern Canada. Despite the closing of east coast mines, production increases at less gassy surface mines in Alberta and British Columbia have sustained Canada's total annual coal production. The net effect is that, while production has stayed steady, total fugitive emissions associated with coal mining have declined significantly since 1990.

Surface Mines

The CIAB methodology was modified using Canada- or United-States-specific data for the three coal types mined in-country. King developed emission factors by region, by mine and by coal types; the average CH_4 content of bituminous or sub-bituminous coal was 0.4 m^3/t (based on tests at 50 mines in the United States, obtained by King) and the Canada-specific methane content for lignite was 0.05 m^3/t (Hollingshead 1990), with the assumption that 60% of the gas is released before combustion. The EFs in Table A3–9 incorporate these data and assumptions.

Surrounding unmined strata are a significant source of emissions from surface mines. Using Canadian mine-specific data from the Hollingshead study, King applied a high-wall adjustment to the surrounding unmined strata, to a depth of 50 m below the mining surface. Base EFs for surface mining were increased by 50% (King 1994) to account for this out-gassing adjustment and are reflected in the emission factors in Table A3–9.

To obtain the emissions from coal mining, Equation A3–4 is used.

Equation A3–4:

$$Provincial\ Emissions = \sum \left(EF_{i,j,k,l} \times Coal_{i,j,k,l} \right)$$

where:

$EF_{i,j,k,l}$	=	the emission factor from the King (1994) or Cheminfo/Clearstone (2014) studies for province i, coal type j, mine k and coal field l
$Coal_{i,j,k,l}$	=	the gross production of coal for province i, coal type j, mine k and coal field l

Emissions are calculated for each province and then summed to determine the emission estimate for Canada.

Activity Data

The model requires the gross mine output data for each type of coal mined in each province. Until 2002, the data were obtained from Statistics Canada's *Coal and Coke Statistics* publication (Cat. No. 45-002-X, Table 2). In 2002, the publication was discontinued, and Statistics Canada now provides this data directly to Environment and Climate Change Canada via a memorandum of understanding.

Emission Factors

Emission factors were developed by coal type, coal mine type and coal field. Because of confidentiality requirements, factors can only be reported at the provincial level. Therefore, weighted emission factors were developed at the provincial level.

The weighted emission factors, by mine and coal type, developed using the King (1994) and Cheminfo/Clearstone (2014) studies, are listed in Table A3–9.

A3.2.1.2. Abandoned Underground Coal Mines

Coal mine methane (CMM) and other gases naturally exist within coal seams and are released to the atmosphere under suitable conditions. Of these emissions, methane is the gas of greatest concern, while releases of other gases, such as CO_2, are small and are not estimated (IPCC 2006).

As noted in A3.2.1.1, structural disturbance exposes the coal to lower atmospheric pressures, allowing the release of fugitive emissions during mining and post-mining operations, including handling, crushing and transportation. Once an underground mine closes and active venting stops, emissions may continue for decades. After production ceases, all subsequent emissions are estimated using the model described in this section.

Methodology

Coal mine methane is influenced by many factors, including geological seam structure, coal rank and characteristics, mining activities, pressure gradients, mine flooding and post-mining venting and capping. There is no Canadian data available on post-mining venting and capping.

The IPCC Tier 2 equation for abandoned mines takes the general form in Equation A3–5:

Equation A3–5: IPCC Tier 2

$$CH_4 \text{ Emissions} = \text{Unflooded Mines} \times \text{Fraction Gassy} \times \text{Average Emission Rate} \times EF \times \text{Conversion Factor}$$

where:

CH_4 Emissions	=	yearly emissions (Gg/year)
Unflooded Mines	=	number of unflooded mines
Fraction Gassy	=	% of mines defined as gassy
Average Emission Rate	=	(m^3/year)
EF	=	emission factor, dimensionless, of the form $(1+aT)^b$
Conversion Factor	=	converts CH_4 volume to mass - (0.67 kg/m^3, at 20°C and 1 atmosphere pressure)

The IPCC Tier 3 equation for abandoned mines takes the general form in Equation A3–6:

Equation A3–6: IPCC Tier 3

$$CH_4 \text{ Emissions} = (\text{Emission rate at closure} \times EF \times \text{Conversion Factor})$$

where:

CH_4 Emissions	=	yearly emissions (Gg/year)
Emission rate at closure	=	known emission rate for specific mine (m^3/year)
EF	=	emission factor, dimensionless, of the form (1+aT)b
Conversion Factor	=	converts CH_4 volume to mass - (0.67 kg/m^3, at 20°C and 1 atmosphere pressure)

Detailed data on mine CH_4 emission rates during production years were only available for five mines in Nova Scotia (King 1994). This data allowed the use of Equation A3–6: IPCC Tier 3

Table A3–9 Fugitive Emissions Factors for Coal Mining

Area	Coal Type	Mine Type	Emission Factor	Units
Nova Scotia	Bituminous	Surface	0.07	t CH_4/kt coal mined
Nova Scotia	Bituminous	Underground	14.49	t CH_4/kt coal mined
New Brunswick	Bituminous	Surface	0.07	t CH_4/kt coal mined
Saskatchewan	Lignite	Surface	0.07	t CH_4/kt coal mined
Alberta	Bituminous	Surface	0.46	t CH_4/kt coal mined
Alberta	Bituminous	Underground	1.69	t CH_4/kt coal mined
Alberta	Sub-bituminous	Surface	0.22	t CH_4/kt coal mined
British Columbia	Bituminous	Surface	0.83	t CH_4/kt coal mined
British Columbia	Bituminous	Underground	2.78	t CH_4/kt coal mined

Source: Adapted from King (1994) and Cheminfo et al. (2014).

following the IPCC Tier 3 approach, for estimating abandoned mine emissions in this region. For all other regions of Canada, known production data for abandoned mines was averaged over the life of the mines, and the EFs in Table A3–9: Fugitive Emission Factors for Coal Mining were used to estimate emissions in the final year of production. On the basis of this estimate, Equation A3–5: IPCC Tier 2 was used to calculate emissions. Calculations were done using five time intervals, which can be seen in Table A3–12 following the Tier 2 approach for the determination of percent gassy mines per time interval. Mines abandoned before 1900 are assumed to be non-emitting (IPCC 2006).

Following the end of mining activities, methane emissions have been shown empirically to drop off following a hyperbolic decline curve. This is modeled using the IPCC Tier 2/3 emission factor equation (1+aT)b, where a and b are mine- or basin-specific constants and T is the time since abandonment (IPCC 2006). See Table A3–10 for a list of constants applied to Canadian data. This IPCC EF formula was used for all provincial estimates.

Table A3–10 Tier 2/3 – Emission Factor Coefficients

Coefficients for Tier 2/3 Emission Factor		
Coal Rank	**a**	**b**
Anthracite	1.72	-0.58
Bituminous	3.72	-0.42
Sub-bituminous	0.27	-1.00

Methane emissions from flooding mines decrease dramatically once active pumping ceases. Water pressure inhibits methane from being emitted due to reduced relative permeability. U.S. EPA empirical studies (U.S. EPA 2004) based on U.S. mines indicate that mine flooding occurs within eight years. The 2006 IPCC Guidelines (IPCC 2006) indicate that fully flooded mines be assigned zero emissions but be explicitly listed.

For the purposes of calculating emissions, mines are assumed unflooded unless specific data exists. Provincial experts in Alberta indicated that most mines are flooded, but had knowledge of flooding at only the Bellevue Mine Museum. Therefore, only the 12 abandoned mines in the near vicinity of the Bellevue Mine Museum—that closed over 20 years ago—were assumed flooded. For Nova Scotia, provincial experts at Nova Scotia Environment confirmed that underground mines started flooding immediately after pumps were turned off and that all mines were flooded by end of summer, 2013.[5] Table A3–11 characterizes the condition of abandoned mines by flooded and non-flooded, for all regions of Canada that have underground coal mines.

5 Nova Scotia Environment. 2015. Personal communication (email from Miller M, Policy Analyst, Nova Scotia Environment to Baker W, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada, dated November 16, 2015).

Table A3–11 Tier 2/3 - Abandoned Underground Coal Mines, 2015

Region	Number of Abandoned coal mines[a]	Number of abandoned mines flooded[b]
Nova Scotia[c]	282	282
Saskatchewan[d]	245	0
Alberta	854	13
British Columbia	50	0
CANADA	**1431**	**295**

a. Only mines that produced more than 0.5 kilotonnes are included.
b. When no data is available, mines are assumed to be non-flooded.
c. Tier 2 & 3 estimates used for Nova Scotia.
d. Saskatchewan lignite mine estimate uses IPCC Tier 2 sub-bituminous emissions factor calculated for each time band (see IPCC 2006 p 4.27, Equation 4.1.12).

Nova Scotia Environment. 2015. Personal communication (email from Miller M, Policy Analyst, Nova Scotia Environment to Baker W, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada, dated November 16, 2015).

The IPCC defaults in Table A3–12 were used to estimate the percentage of gassy mines in each region and time interval. For all regions of Canada, with the exception of Saskatchewan, the default high values for gassiness were assumed

The lower IPCC default percentage of gassy mines was chosen for Saskatchewan mines based on time since abandonment, lignite rank, small mine size and shallow depth—often dug from a riverbed into a slight hill. Additionally, during a public safety review, all mine entrances were either capped or sealed. The non-gassy nature of these mines was previously reported in Hollingshead 1990.

Activity Data

This model uses data obtained from industry and from provincial and federal government sources. The general lack of detailed data sources affected the choice of estimation methods, preventing the incorporation of likely but unconfirmed flooding and mine-specific emissions measurements. Conservative assumptions were made when accurate data were unavailable for mine gassiness, flooded status and emission factors. This may produce some overestimation of emissions in all regions.

Emissions

The results of emission calculations for select years can be seen in Chapter 3.3.1 of the NIR. Abandoned mines in Nova Scotia have historically contributed the largest proportion of emissions; the two emission peaks at years 1993 and 2000 correspond to closures of large mines in that province. There have been no recent mine abandonments and the effect of the models decline curves are visible after the year 2002.

A3.2.2. Oil and Natural Gas

A3.2.2.1. Upstream Oil and Natural Gas Production

Fugitive emissions from the upstream oil and gas (UOG) industry are based on two separate studies: a study titled *A National Inventory of Greenhouse Gas* (GHG), *Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emissions by the Upstream Oil and Gas Industry* (CAPP 2005a), prepared by Clearstone Engineering Ltd. for the Canadian Association of Petroleum Producers (CAPP) and referred to hereafter as the CAPP study, and an update to the inventory that was completed in 2014 for Environment Canada by Clearstone Engineering Ltd. and referred to hereafter as the UOG study (Environment Canada 2014). Both inventories used an IPCC Tier 3 bottom-up assessment to estimate all GHG emissions from the UOG sector, with the exclusion of oil sands mining, extraction and upgrading. The CAPP study provided a detailed emission inventory for the year 2000, while the UOG study produced inventories for the years 2005 and 2011.

Table A3–13 lists the sectors and sources that were estimated in the CAPP and UOG studies (CAPP 2005a; Environment Canada 2014) and the

Table A3–12 Tier 2 – IPCC Default - % Gassy Mines per Time Interval

Time Interval	Low	High
1900-1925	0%	10%
1925-1950	3%	50%
1951-1975	5%	75%
1976 - 2000	8%	100%
2001 - present	9%	100%

allocation of these emissions according to the Common Reporting Format (CRF) categories.

In general, the emission inventories for the years 2000, 2005 and 2011 were used directly, except for a few special cases. If a specific source did not exist in one of the inventory years (e.g. the 2000 inventory) due to insufficient data but did exist in another inventory year (e.g. the 2005 inventory), then emissions for that particular source were extrapolated from the known year and included in the inventory that was missing data to ensure completeness. A brief description of the methodology used in the CAPP and UOG studies is presented below, along with the methodology used to estimate the emissions for 1990–1999, 2001–2004, 2006–2010 and from 2012 onwards.

Methodology for the 2000, 2005 and 2011 Estimates

The emission estimates contained in the CAPP and UOG studies were developed using a bottom-up approach, beginning at the individual facility and process unit level and aggregating the results to provide emission estimates by facility and geographic area. The Canadian UOG sector's assets and operations are vast: the 2011 inventory included over 300 000 capable oil and gas wells, 14 100 batteries producing gas into more than 5000 gathering systems delivering to almost 750 gas plants, and 24 000 oil batteries delivering to 150 tank terminals, all of which are interconnected by tens of thousands of kilometres of pipeline carrying hydrocarbons from wells to batteries to plants and finally to markets.

Emissions from flaring, venting, equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses and accidental releases were estimated. The basic methods used to estimate GHG emissions were:

- emission monitoring results;
- emission source simulation results;
- emission factors; and
- destruction and removal efficiencies.

In order to estimate emissions, large amounts of data were collected including:

- measured volumes of natural gas taken from the process;
- vented and flared waste gas volumes;
- fuel purchases (propane, diesel fuel, etc.);
- fuel analyses;
- emission monitoring results;
- process operating conditions that may be used to infer the work being done by combustion devices (gas compositions, temperatures, pressures and flows, etc.); and
- spill and inspection reports.

Other required data included the following:

- types of processes being used;
- equipment inventories;
- emission source control features;
- sulphur content of the fuels consumed and waste gas flared; and
- composition of the inlet and outlet streams.

Refer to the CAPP study (CAPP 2005a) and UOG study (Environment Canada 2014) for further details.

Methodology for Extrapolating Emission Estimates

The method for extrapolating emissions from a known inventoried year to other non-inventoried years was developed by Clearstone Engineering Ltd. (CAPP 2005b). This method was used to backcast the 2000 emission estimates for the 1990–1999 time period, to extrapolate the 2011 inventory for 2012 onwards and, in conjunction with other

Table A3–13 Allocation of UOG Inventory Emissions to CRF Fugitive Categories

CRF Fugitive Category	Emission Sector Categories	Emission Source Categories
1.B.2.a.ii Oil—Production	Light/Medium Crude Oil Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Heavy Crude Oil Cold Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Well Servicing	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Heavy Crude Oil Thermal Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Well Testing	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Disposal and Waste Treatment	Fugitive Equipment Leaks
1.B.2.a.3 Oil—Transport	Petroleum Liquids Transportation	Fugitive Equipment Leaks; Storage Losses
1.B.2.b.2 Natural Gas—Production	Natural Gas Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
1.B.2.b.3 Natural Gas—Processing	Natural Gas Processing	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
1.B.2.b.4 Natural Gas—Transmission and Storage	Gas Transmission; Gas Storage	Fugitive Equipment Leaks; Spills/Pipeline Ruptures
1.B.2.b.5 Natural Gas—Distribution	Gas Distribution	Fugitive Equipment Leaks; Spills/Pipeline Ruptures
1.B.2.b.6.1 Natural Gas—Other—Accidents and Equipment Failures	Accidents and Equipment Failures	Surface Casing Vent Flow/Gas Migration; Spills/Pipeline Ruptures
1.B.2.c.1.i Venting—Oil	Light/Medium Crude Oil Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Heavy Crude Oil Cold Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Heavy Crude Oil Thermal Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Petroleum Liquids Transportation	Reported Venting; Unreported Venting
1.B.2.c.1.ii Venting—Natural Gas	Natural Gas Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Natural Gas Processing	Glycol Dehydrator Off-Gas; Formation CO_2; Reported Venting; Unreported Venting
	Gas Transmission	Reported Venting
	Gas Distribution	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Gas Storage	Reported Venting; Unreported Venting
1.B.2.c.1.iii Venting—Combined	Well Drilling; Well Servicing	Reported Venting
	Well Testing	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Disposal and Waste Treatment	Unreported Venting
1.B.2.c.2.i Flaring—Oil	Light/Medium Crude Oil Production; Heavy Crude Oil Production; Heavy Crude Oil Thermal Production; Petroleum Liquids Transportation	Flaring
1.B.2.c.2.ii Flaring—Natural Gas	Natural Gas Production; Natural Gas Processing; Gas Transmission; Gas Storage; Gas Distribution	Flaring
1.B.2.c.2.iii Flaring—Combined	Well Drilling; Well Servicing; Well Testing; Disposal and Waste Treatment	Flaring

curve fitting methods, to interpolate the 2001–2004 and 2006–2010 time periods.

Equation A3–7 is used to estimate emissions for non-inventoried years by multiplying base year emissions data for a given source and sector by the ratio of activity data for the non-inventoried year to that of the base year. Twelve activity parameters for each province/territory and year were used:

- raw gas production;
- light/medium crude oil production (CO);
- heavy crude oil production (HO);
- crude bitumen production (CB);
- fuel gas volume;
- flared gas volume;
- number of wells drilled;
- number of spills, ruptures and blowouts;

- total capable oil and gas wells;
- CO + HO + CB;
- HO + CB; and
- shrinkage.

The publicly available activity data listed in Table A3–14 are used to calculate the 12 activity parameters given above.

Equation A3–7:

$$ER_{i,j}^{k} = ER_{i,j}^{baseYr} \times \left(\frac{AF_{j}^{k}}{AF_{j}^{baseYr}} \right)$$

where:

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k, t/year
$ER_{i,j}^{baseYr}$	=	base year (e.g. 2011) emission rate for compound i and source j, t/year
AF_{j}^{k}	=	activity factor for source j and year k
AF_{j}^{baseYr}	=	base year (e.g. 2011) activity factor for source j

Table A3–15 contains a list of the activity factors used to estimate emissions and the dependent source category.

The emissions for 1990–1999 were backcast by sector and source at the provincial level based on the year 2000 emission estimates from the CAPP study (CAPP 2005a). The only exception to this was the province of Nova Scotia, which from 1992 to 1999 was an oil-only producing province. In 2000, it switched to a gas-only producing province. As such, the year 2000 data could not be used to estimate emissions for the 1990–1999 time period, and Nova Scotia's fugitive emissions were extrapolated based on CAPP's 1995 UOG study data (CAPP 1999). Refer to the UOG study (CAPP 2005a) for further details.

The emissions from 2012 onwards were extrapolated using emissions by sector and source at the provincial/territorial level based on the year 2011 emission estimates from the UOG study (Environment Canada 2014).

Methodology for 2001–2004 and 2006–2010

In order to estimate emissions for the 2001–2004 and 2006–2010 time periods, all three base year inventories (2000, 2005 and 2011) were extrapolated for the 2000–2011 time period using the method described above. This resulted in three curves which were used to interpolate the intermediate years by using either a "wedging" or "proportional adjustment" method, depending on the circumstance. The "wedging" method was used unless it resulted in negative emission estimates for any year in the time period. Less than 0.3% of cases required the use of the "proportional adjustment" method.

Wedging

The "wedging" method evenly distributes the difference in emissions for a given source and sector in a given province between an inventoried year and an extrapolated year to maintain the emissions trend using Equation A3–8.

Equation A3–8:

$$ER_{i,j}^{k} = ER_{i,j}^{k,k1\_exp} \quad \frac{\left(ER_{i,j}^{k2\_inv} - ER_{i,j}^{k2,k1\_exp}\right)}{(k2-k1)} \times (k-k1)$$

where:

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k
$ER_{i,j}^{k,k1\_exp}$	=	emission rate of compound i and source j from extrapolated year k1 data
$ER_{i,j}^{k2\_inv}$	=	emission rate of compound i and source j from inventoried year k2 data
$ER_{i\,j}^{k2,k1\_exp}$	=	emission rate of compound i, source j and year k2 from extrapolated year k1 data
k	=	year between k1 and k2
$k1$	=	base year 1 (e.g. 2000 or 2005)
$k2$	=	base year 2 (e.g. 2005 or 2011)

If k1 is equal to 2005, k2 is equal to 2011, and k is equal to k1, then the result of Equation A3–9 is the emission rate from the 2005 inventoried year. This occurs since the 2005 extrapolated data uses the 2005 inventoried year as is for the year 2005. If k is equal to k2, then the result is the emission rate from the 2011 inventoried year. This shows that this

Table A3–14 Required Activity Data and their Source

Publisher	Publication	Activity Data
Statistics Canada	CANSIM Table 131-0001 Supply and disposition of natural gas, monthly (Statistics Canada 2016a)	Less field flared and waste Field disposition and usage Gathering system disposal and use Plant uses Shrinkage
	CANSIM Table 126-0001 Supply and disposition of crude oil and equivalent, monthly (Statistics Canada 2016b)	Gross new production Heavy crude oil Light and medium crude oil Synthetic crude oil Crude bitumen
Saskatchewan Ministry of Economy	2015 Crude Oil Volume and Value Summary (SK MOE 2016a)	Light and medium crude oil production Heavy crude oil production
	Petroleum and Natural Gas Spill Report Directory (SK MOE 2016b)	Sum of spills
Canadian Association of Petroleum Producers (CAPP)	*Statistical Handbook for Canada's Upstream Petroleum Industry (CAPP 2016)*	Total wells drilled (including dry and service) (Tables 1.2b - 1.2f) Sum of Operated Oil Wells (Table 3.17a) and Operated Gas Wells (Table 3.18a)
Alberta Energy Regulator (AER)	AER Compliance Dashboard (2016a)	Number of incidents
British Columbia Oil and Gas Commission	Drilling Kicks and Blowouts by Area (BCOGC 2016)	Sum of kicks and blowouts
Canada–Newfoundland and Labrador Offshore Petroleum Board (CNLOPB)	Development Wells – Hibernia (CNLOPB 2016a) Development Wells – Terra Nova (CNLOPB 2016b) Development Wells – White Rose (CNLOPB 2016c) Development Wells – North Amethyst (CNLOPB 2016d) Environment Statistics - Spill Frequency and Volume Annual Summary (CNLOPB 2016e)	Number of capable wells Number of capable wells Number of capable wells Number of capable wells Number of spills

method will maintain the emission estimates for the inventoried years, while interpolating the intermediate years and maintaining the emissions trend.

Figure A3–3 shows the results of the "wedging" method in graphical form. In general, the 2000 and 2005 inventory years are used to interpolate emissions by sector, source and province/territory for the 2001–2004 time period, while the 2005 and 2011 inventory years are used to interpolate emissions for the 2006–2010 time period. However, there are a few special cases where the 2000 and 2011 inventory years are used to interpolate emissions for the 2001–2010 time period. This occurs when data were missing or incomplete for the 2005 data year and, as a result, specific sector, source and province/territory combinations were not able to be estimated for the 2005 inventory. In addition, on the basis of conversations with the contractor and the province of Saskatchewan, the Saskatchewan venting emissions for the cold production heavy crude oil sector in the 2005 inventory were determined to be unreliable. As a result, emissions for this source and sector were interpolated using the 2000 and 2011 data as end points with the 2005 data point being omitted.

Finally, if any specific source and sector in a given province/territory only existed in one of the inventoried years, then the inventoried data were extrapolated for the entire time series. All of this was done to ensure time-series consistency.

Proportional Adjustment

As stated previously, if the "wedging" method resulted in negative emissions in any year of the interpolation time period, then the method was abandoned for that given sector, source and province/territory and the "proportional adjustment" method was used, as shown in Equation A3–9.

Table A3–15 Activity Data Used to Extrapolate Emission Sectors and Sources

Emission Sector Category	Emission Source Category	Activity Factors
Accidents and Equipment Failures	Spills/Pipeline Ruptures	Total number of spills, ruptures and blowouts
Accidents and Equipment Failures	Surface Casing Vent Flow/Gas Migration	Total number of capable oil and gas wells
Disposal and Waste Treatment, Heavy Crude Oil Cold Production, Heavy Crude Oil Thermal Production, Light/Medium Crude Oil Production, Natural Gas Production, Natural Gas Processing, Petroleum Liquids Transportation	Flaring	Flared gas volume
Light/Medium Crude Oil Production	Fugitive Equipment Leaks, Glycol Dehydrator Off-gas, Loading/Unloading, Reported Venting, Storage Losses, Unreported Venting	Light/medium crude oil production
Heavy Crude Oil Cold Production	Fugitive Equipment Leaks, Glycol Dehydrator Off-gas, Loading/Unloading, Reported Venting, Storage Losses, Unreported Venting	Heavy crude oil production
Heavy Crude Oil Thermal Production	Fugitive Equipment Leaks, Glycol Dehydrator Off-gas, Loading/Unloading, Reported Venting, Storage Losses, Unreported Venting	Heavy crude oil + crude bitumen production
Natural Gas Production, Natural Gas Processing	Fugitive Equipment Leaks, Glycol Dehydrator Off-gas, Loading/Unloading, Reported Venting, Storage Losses, Unreported Venting	Raw gas production
Natural Gas Processing	Formation CO_2	Shrinkage
Disposal and Waste Treatment, Petroleum Liquids Transportation	Fugitive Equipment Leaks, Storage Losses, Unreported Venting	Light/medium crude oil + heavy crude oil + crude bitumen production
Petroleum Liquids Transportation	Reported Venting	Light/medium crude oil + heavy crude oil + crude bitumen production
Well Drilling, Well Testing, Well Servicing	Flaring, Reported Venting	Number of wells drilled
Well Servicing, Well Testing	Fugitive Equipment Leaks, Storage Losses, Loading/Unloading	Number of wells drilled
Well Testing	Unreported Venting, Glycol Dehydrator Off-gas	Number of wells drilled
Gas Transmission, Gas Storage, Gas Distribution	Flaring, Fugitive Equipment Leaks, Glycol Dehydrator Off-gas, Reported Venting, Unreported Venting	Kilometers of pipeline

Equation A3–9:

$$ER_{i,j}^{k} = ER_{i,j}^{k,k1\_exp} \times \frac{\left(ER_{i,j}^{k2\_inv}\right)}{\left(ER_{i,j}^{k2,k1\_exp}\right)}$$

where:

$ER_{i,j}^{k}$ = emission rate of compound i, source j, and year k

$ER_{i,j}^{k,k1\_exp}$ = emission rate of compound i and source j from extrapolated year k1 data

$ER_{i,j}^{k2\_inv}$ = emission rate of compound i and source j from inventoried year k2 data

$ER_{i,j}^{k2,k1\_exp}$ = emission rate of compound i, source j and year k2 from extrapolated year k1 data

k = year between k1+1 and k2

$k1$ = base year 1 (e.g. 2000 or 2005)

$k2$ = base year 2 (e.g. 2005 or 2011)

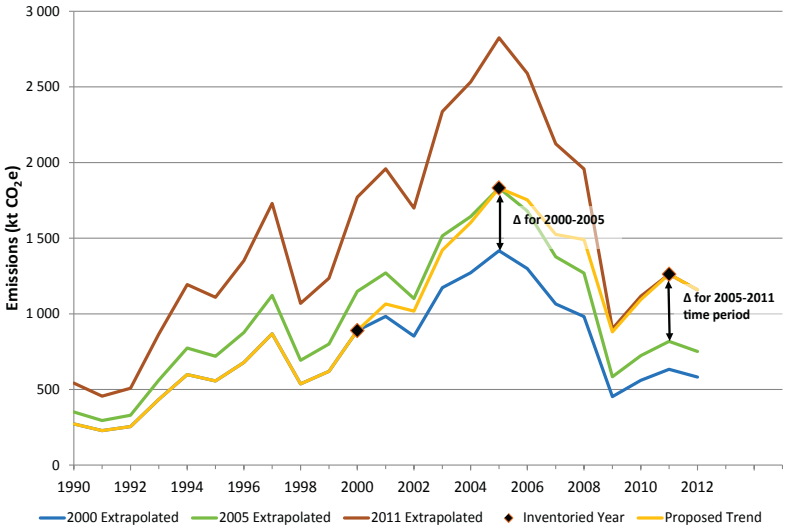
If k1 is equal to 2005, k2 is equal to 2011 and k is equal to k2, then the result of Equation A3–9 is the emission rate of the inventoried year for 2011. Otherwise, the emission rate of the extrapolated data is modified by the same percentage for each year in the interpolated time period. This method was required in less than 0.3% of all cases and was generally only required for sources with very low emissions.

A3.2.2.2. Natural Gas Transmission

Methodology

Virtually all of the natural gas produced in Canada is transported from the processing plants to the gate of the local distribution systems by high-pressure pipelines. The majority of emissions are from equipment leaks and process vents along these pipelines.

Figure A3–3 Graphical Representation of the "Wedging" Method



Fugitive emissions for natural gas transmission are based on several documents. The first, *CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP 1999), was prepared by Clearstone Engineering Ltd. for CAPP in July 1999. The second source is ancillary tables provided by Brian Ross of Clearstone Engineering Ltd. that describe the CO_2 emissions. There are no N_2O fugitive emissions from natural gas transmission. The CO_2 and CH_4 emissions for 1990–1996 are taken directly from the two sources. The CO_2 and CH_4 emissions for 1997–1999 were estimated based on province/territory natural gas transmission pipeline length and leakage rates, which were developed based on the 1996 emissions from CAPP (1999) and pipeline lengths from Statistics Canada.

For the years 2005 and 2011, emissions are taken from the UOG study (Environment Canada 2014), which followed 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 were compiled by ORTECH Consulting Inc. (2013) for the Canadian Energy Partnership for Environmental Innovation (CEPEI). Data for the years 2000–2004, 2006–2010 and 2012–2014 were provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2015 were extrapolated from 2014 data using the same extrapolation method as described for the UOG sector (see Equation A3–7), with the length of natural gas transmission pipeline used as the activity factor.

The emissions are calculated per province/territory and then summed to obtain the total CO_2 and CH_4 emissions for Canada. Newfoundland and Labrador, Prince Edward Island, Yukon, and Nunavut do not have natural gas transmission pipelines. However, there are natural gas gathering lines in Yukon, and fugitive emissions from those lines are accounted for in the 1.B.2.b.2 – Natural Gas – Production category of the CRF table.

No natural gas transmission pipelines were operating in Nova Scotia, New Brunswick or the Northwest Territories until 1999.

Activity Data

The activity data required to estimate the fugitive emissions for 1997–1999 and 2015 are the length of the natural gas pipeline used for natural gas transmission each year. Transmission pipeline lengths were published annually in *Natural Gas*

Transportation and Distribution (Statistics Canada 57-205-XIB). Statistics Canada has discontinued this publication but still collects the data and releases it to Environment and Climate Change Canada (ECCC). However, pipeline length data were only available up to and including 2014; pipeline lengths for 2015 were therefore estimated. For Quebec, Ontario, Manitoba, Saskatchewan, Alberta, British Columbia and the Northwest Territories, the 2015 pipeline lengths were estimated based on the average annual change in length between 2000 and 2014. The 2015 values were assumed to be the same as 2014 for New Brunswick and Nova Scotia since the natural gas transmission pipeline lengths have not changed since 2003 and 2002, respectively. Improvements to the model are being investigated.

A3.2.2.3. Petroleum Refining

The refinery model is based on the study *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI 2004), prepared for the Canadian Petroleum Products Institute (CPPI), Natural Resources Canada (NRCan), Environment Canada and Industry Canada in 2004 by Levelton Consultants Ltd. The study surveyed the refining industry and used these data, along with data collected by the Canadian Industrial Energy End-Use Data and Analysis Centre, to develop GHG emission estimates for 1990 and 1994–2002.

There are three sections in the refinery methodology: fugitive (unintentional releases), process venting and flaring. The combustion methodology for petroleum refining is discussed in Annex 3.1 of the National Inventory Report.

Methodology

Fugitive Emissions

The CO_2 and CH_4 emission factors were developed by Levelton Consultants Ltd. and were presented in the refinery study (CPPI 2004). These emission factors are used to estimate the fugitive emissions for the years not included in the study, i.e. 1991–1993 and 2003 onwards.

The fugitive emissions are generated using Equation A3–10.

Equation A3–10:

$$FugitiveGHGEmissions(t) = EmissionFactor(t/GJ) \times RefineryAnnualEnergyConsumption(GJ)$$

The refinery annual energy consumption (in GJ) is the sum of the energy of all fuels consumed by refineries in the Report on *Energy Supply and Demand in Canada* (Statistics Canada 2003–#57-003-XIB), including fuels listed under producer consumption from the refined petroleum products table. The energy consumption value is the same as that in the stationary combustion model for 1.A.1.b Petroleum Refining of the CRF table.

The emission factors are 2.78 t CO_2/GJ for CO_2 and 11.89 t CH_4/GJ for CH_4.

The refinery study has listed fugitive N_2O emissions for 1990 and 1994–2002 as a constant 100 t N_2O/year; however, there were not enough data to develop an emission factor for them. The N_2O emissions were kept constant at 100 t N_2O/year for the years 1991–1993 and 2003 onwards. It is assumed that the reported N_2O emissions from the refinery study are a residual from combustion sources and that the majority of N_2O emissions associated with petroleum refining are correctly reported in the stationary combustion section of the inventory.

Process Emissions (Venting)

Process emissions are mainly associated with the venting of CO_2 from the production of hydrogen using natural gas. This hydrogen is used as an input in the production of refined petroleum products (RPPs). Using data provided from the refinery study

Table A3–16 Required Refinery Activity Data and Their Source

Publisher	Publication	Activity Data
Statistics Canada	*Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada 57-003-XIB)	Refinery and producer consumption (by refineries) annual energy consumption. Refinery RPP production
Canadian Petroleum Products Institute (CPPI)	*Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* by Levelton Consultants Ltd. (CPPI 2004)	Fugitive Emissions Table 3-2 CPPI Regional GHG Inventory—Detailed (kilotonnes)
		Process Emissions Table 3-2 CPPI Regional GHG Inventory—Detailed (kilotonnes)
		Flaring Emissions Appendix E— Flare Gas

for the years 1990, 1994–1998 and 2000–2002, CO_2 emissions from the production of hydrogen were correlated to refinery annual RPP production. These results were used to estimate CO_2 emissions for the years 1991–1993, 1999 and 2003 onwards.

Flaring Emissions

Flaring emissions have been determined for CO_2, CH_4 and N_2O using the estimates from the refinery study and RPP production by Canadian refineries. The study provided emissions for the years 1990, 1994–1998 and 2000–2002, and these emissions were correlated to refinery annual RPP production. Flaring emissions for the years 1991–1993, 1999 and 2003 onwards were estimated based on this correlation and known RPP production data.

Activity Data

The activity data required to estimate the fugitive emissions from refineries are listed in Table A3–16.

A3.2.2.4. Natural Gas Distribution

Methodology

Fugitive emissions for the 1990–1999 time period from natural gas distribution are based on the Canadian Gas Association (CGA) report titled *1995 Air Inventory of the Canadian Natural Gas Industry* (CGA 1997) and the Gas Research Institute (GRI) report titled *Vented Emissions from Maintenance at Natural Gas Distribution Stations in Canada* (GRI 2000). The CGA study estimated emissions from the Canadian gas pipeline industry for the years 1990 and 1995 using an IPCC Tier 3 approach. Emissions were calculated based on emission factors from the U.S. EPA, other published sources and engineering estimates. The activity data were obtained from published sources and specialized surveys of gas distribution system companies. The surveys contained information on equipment schedules, operating parameters of equipment, pipeline lengths used in the Canadian distribution system, etc. The GRI (2000) report is an update to the CGA (1997) study with more accurate and better substantiated data for station vents. An emission factor was developed for the distribution system based on the study data (CGA 1997; GRI 2000) and on gas distribution pipeline distances by province provided by Statistics Canada, which were then used to estimate emissions for the 1990–1999 time period.

For the year 2000 onwards, emissions are based on data from the UOG study (Environment Canada 2014), following an IPCC Tier 3 approach that rolled up the reported GHG emissions from individual natural gas companies for 2005 and 2011. Input data for the natural gas distribution industry was compiled by ORTECH Consulting Inc. (2013) for CEPEI. Data for the years 2000–2004, 2006–2010 and 2012–2014 were provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2015 were estimated using length of natural gas distribution pipeline, using the approach governed by Equation A3–7.

The fugitive emissions for natural gas distribution are estimated for each province and then summed to obtain the overall emissions for Canada. At present, no natural gas distribution pipelines exist in the following provinces and territories: Newfoundland and Labrador, Prince Edward Island, Nunavut, Yukon, and Nunavut.

Activity Data

The required activity data are the length of natural gas distribution pipeline per province, which was historically published in *Natural Gas Transportation and Distribution* (Statistics Canada 57-205-XIB). Statistics Canada discontinued this publication in 2003 but still collects the data and releases it to ECCC. However, pipeline length data were only available up to and including 2014; pipeline lengths for 2015 were therefore estimated for all provinces based on the change in length between 2013 and 2014.

For New Brunswick and Nova Scotia, pipeline lengths for 2000–2006 were provided by Enbridge Gas New Brunswick[6] and Heritage Gas,[7] respectively. In the Northwest Territories, the Ikhil Pipeline began providing Inuvik with natural gas in 1999 (Quenneville 2009). Distribution lengths for 1999–2006 were backcast based on the change in distribution length between 2007 and 2008.

The 2007 pipeline length for British Columbia provided by Statistics Canada was twice the 2006 value. Statistics Canada confirmed that the data for 2006 and previous years were incorrect but was unable to provide corrected distribution lengths. It was assumed that the 1999 value was correct, and a linear trend was used to fill in the 2000–2006 data.

6 Enbridge Gas New Brunswick. 2010. Personal communication (email from Nicholson L, Communications Coordinator, Enbridge Gas New Brunswick, to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated December 7, 2010).

7 Heritage Gas. 2010. Personal communication (email from Bracken J, President, Heritage Gas to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated December 7, 2010).

A3.2.2.5. Oil Sands and Heavy Oil Upgrading Industry

The oil sands and heavy oil upgrading (OS/HOU) industry produces synthetic crude oil and other products from bitumen. Bitumen is a naturally occurring viscous mixture consisting of hydrocarbons heavier than pentane and other contaminants (e.g. sulphur compounds); in its natural state, it will not flow under reservoir conditions or on the surface. Bitumen occupies the lower end of the range of heavy crude oils and is sometimes referred to as ultra-heavy crude oil. "Oil sands" is a term applied by the Government of Alberta to a particular geographical area of the province of Alberta that contains concentrations of bituminous sands as well as deposits of other heavy crude oil. Bituminous sands are an unconsolidated mixture of sand, clay, water and bitumen.

In this area, bitumen is extracted from open-pit mined oil sands or from in situ bitumen operations using thermal extraction techniques. The emissions from in situ bitumen extraction are included in the UOG study (CAPP 2005a). Emissions from the mining, processing and upgrading of bitumen and heavy oil are taken from the report *An Inventory of GHGs, CACs, and H_2S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP 2006), prepared by Clearstone Engineering Ltd. for CAPP.

The bitumen report (CAPP 2006) is the basis for the 1990–2003 fugitive emissions from oil sands mining and upgrading activities.

For 2004 onwards, emissions are estimated using the Bitumen-Oil Sands Extrapolation Model – Rev 3, created by Clearstone Engineering Ltd. for Environment Canada in 2007 (Environment Canada 2007) (hereafter referred to as the bitumen model). The bitumen model uses results from the bitumen report (CAPP 2006) as its basis,

along with annual production data as reported by the Alberta Energy Regulator (AER) and the National Energy Board (NEB). The methodology, model and data used are briefly discussed below. For more details, please refer to the bitumen report (CAPP 2006).

The major emission sources in the OS/HOU industry are the following:

- process emissions from the steam reforming of natural gas to produce hydrogen for upgraders;
- CH4 present in the oil sands deposits that is released during mining, mine dewatering and ore handling activities;
- volatilization of hydrocarbons from the exposed oil sands and during transport and handling of the oil sands;
- biogenic gas formation (primarily CH4) in some tailings ponds;
- volatilization and decomposition of residual bitumen and diluent, which carry through to the tailings ponds;
- fugitive equipment leaks, venting, flaring and storage losses at ore preparation, extraction and upgrader plants and their associated utility and cogeneration plants;
- spills and accidental releases; and
- secondary sources, such as sewage treatment facilities, landfills, onsite construction and fabrication activities, motor vehicle fleets, corporate aircraft, and boats and dredges used on the tailings ponds.

These emissions have been grouped in the source categories and process areas listed in Table A3–17.

Table A3–17 Emission Source Categories and Process Areasin the Bitumen Report (CAPP 2006)

Source Category	Process Area
Flaring	All
Fugitives	American Petroleum Institute (API) Separator
	Equipment Leaks
	Exposed Oil Sands
	Ponds
	Other
	Storage Tanks
Process Venting	Flue Gas Desulphurization (FGD)
	Formation CO_2 from Acid Gas
	Hydrogen Plant
	Non-Combustion Point Sources

Bitumen Report: 1990–2003 Emission Estimates

The bitumen report (CAPP 2006) is a compilation of the individual Tier 3 inventories of facilities involved in the OS/HOU industry: Syncrude Canada Ltd. (Mildred Lake mining, extraction and upgrading facility and Aurora North mining and extraction facility); Suncor Energy (mining, extraction and upgrading facility); Husky Energy (Lloydminster upgrader); Consumers' Co-operative Refineries Limited (Regina upgrader); Albian Sands Energy (Muskeg River mining and extraction facility); and Shell Canada Limited (Scotford upgrader). The facility boundaries were determined to ensure that all target emissions, including those from cogeneration facilities, were included.

Where available, the bitumen report (CAPP 2006) used the emissions from the individual facility reports. These emissions were verified against inventories and data reported to Alberta Environment. When this was not possible, emissions were estimated based on available activity data and emission factor data. There were two methods for estimating emissions. The first method—the emission factor method—uses specific activity data and standard emission factors. If there were no activity data available, the emission factor ratio technique was applied. Refer directly to the bitumen report (CAPP 2006) for specific methodological discussions.

The following sources were used to estimate emissions:

- facility operator information;
- energy statistics published by the AER;
- source emission monitoring results reported to Alberta Environment;
- data from company submissions to the Voluntary Challenge Registry;

- Environment and Climate Change Canada's National Pollutant Release Inventory (NPRI);
- environmental impact assessment files as part of recent energy development applications in the OS/HOU industry; and
- open literature.

Consult the bitumen report (CAPP 2006) for more details.

Bitumen Model: 2004 Onwards

The bitumen model estimates GHG emissions from thermal heavy oil production and oil sands mining, extraction and upgrading in Canada. The model was developed based on the results from the bitumen report (CAPP 2006) along with publicly available activity data and facility specific emission data to extrapolate emissions for 2004 onwards. It provides the same level of disaggregation of the emissions by source category as is reported in the base inventories.

In 2006, the Petro-Canada Fort Hills oil sands operations started reporting to the AER. It has yet to produce any product. In 2008, the CNRL Horizon mining, extraction and upgrading operation and OPTI-Nexen upgrader came online. Emissions from the CNRL Horizon mining, extraction and upgrading operations were estimated using various emission factors from Suncor, Syncrude and Albian's Muskeg River operations. Emissions from the OPTI-Nexen upgrader were estimated using emission factors from the Shell Scotford upgrader, except for CO_2 flaring. These approximations are problematic in that each facility has different processes with different emissions, especially when comparing the Nexen and Scotford upgraders. The Nexen upgrader is the only facility to employ gasification technology that transforms waste product (asphaltenes) into syngas used to create steam for in-situ extraction and hydrogen for upgrading (AER 2016). For CO_2 emissions from flaring, the emission factor was estimated using data reported to the Greenhouse Gas Reporting Program by OPTI-Nexen and publicly available activity data from the AER. This was done because use of the Scotford flaring emission factor resulted in hugely overestimated flaring emissions. All of these approximations will be addressed when a new bitumen study is conducted in the future. Refer directly to the report on the bitumen model (Environment Canada 2007) for specific methodological discussions.

In 2010, the Shell Jackpine oil sands mine started reporting to the AER. Emissions from the Jackpine mine were estimated using emission factors for the Albian Sand's Muskeg River operation. In 2013, the Imperial Oil Kearl Lake oil sands mine started production. Emissions from this facility were estimated using emission factors for the Albian Sand's Muskeg River operation.

Estimation Methodology

The bitumen model provides emission estimates for the OS/HOU industry for 2004 onwards by applying facility-specific emission factors and pro-rating factors derived from the facility base inventories (1990–2003) to appropriate publicly available activity data for the specific year. It uses Equation A3–11 to estimate emissions.

Equation A3–11:

$$ER_i = EF_i \times (A_1 + A_2)$$

where:

ER_i	=	emissions of substance i,
EF_i	=	emission factor for substance i
A_1, A_2	=	activity values applicable to the emission factor

Emission Factors

For the OS/HOU sector in Alberta and Saskatchewan, source-specific factors were developed for each facility by correlating the most recent three or four years of emission data for the facility, taken from the bitumen report (CAPP 2006), with available site-specific production accounting data. These

emission factors can be found in the bitumen model (Environment Canada 2007).

Activity Data

Two activity data sources are used to extrapolate emissions. Alberta facilities data are extracted from ST 39: *Alberta Mineable Oil Sands Plant Statistics, Monthly Supplement December 2015* (AER 2016c). Data for Saskatchewan are taken from the NEB's *2015 Estimated Production of Canadian Crude Oil and Equivalent* (NEB 2016) table. The required data are listed in Table A3–18.

A3.2.2.6. Flaring Special Case – Avoiding double counting

As defined in the *Report on Energy Supply and Demand in Canada* (Statistics Canada 2003–), producers' consumption "is the consumption by the producing industry of its own produced fuel—for example refined petroleum products consumed by the refined petroleum product industry, or natural gas used in the field, flared and waste,

Table A3–18 Activity Data Required for the Bitumen Model

Required data from AER ST-43		
Operator	**Site**	**Required Parameters**
Albian Sands	Muskeg River	Bitumen Production
		Oil Sands Mined
Imperial Oil	Kearl Lake	Bitumen Production
		Oil Sands Mined
Petro-Canada	Fort Hills	Bitumen Production
		Oil Sands Mined
Shell	Scotford Upgrader	Process Gas Flared/Wasted
		Synthetic Crude Production
		Synthetic Crude Deliveries
Shell	Jackpine	Bitumen Production
		Oil Sands Mined
Suncor	Tar Island	Diluent Naphtha Flared/Wasted
		Diluent Naphtha Further Processed
		Diluent Naphtha Production
		Sulphur Flared/Wasted
		Synthetic Crude Fuel/Used
		Synthetic Crude Production
		Oil Sands Mined
Syncrude	Mildred Lake	Bitumen Production
		Intermediate Hydrocarbon Production
		Oil Sands Mined
		Synthetic Crude Fuel/Used
		Synthetic Crude Production
	Aurora	Bitumen Production
		Oil Sands Mined
		Synthetic Crude Fuel/Used
CNRL	Horizon	Bitumen Production
		Oil Sands Mined
		Synthetic Crude Production
		Diluent Naphtha Further Processed
		Diluent Naphtha Production
		Sulphur Flared/Wasted
OPTI Canada Inc.	OPTI-Nexen Upgrader	Synthetic Crude Production
		Synthetic Crude Deliveries
		Process Gas Flared/Wasted
Williams Energy, Inc.	Tar Island - Williams Energy	Process Gas Flared/Wasted
		Diluent Naphtha Production
Aux Sable Canada Ltd.	Aux Sable Heartland Offgas Plant	Process Gas Flared/Wasted
Required data from the NEB for Saskatchewan emission estimates		
Crude Type	Crude Subcategory	Province
Heavy Crude	SK CONV	Saskatchewan

field uses, gathering uses, plant uses and metering adjustments."

Producer consumption volumes are collected by Statistics Canada through administrative agreements with most provinces. For example, the AER collects detailed production accounting data from all oil and gas production facilities in the province. This production accounting data includes the volumes of gas produced, flared, vented, etc. and is incorporated into the RESD by Statistics Canada.

Combustion emissions from the consumption of producer-consumed fuels are estimated using the full fuel volumes reported in the RESD (See Annex 3.1). Since flaring emissions are reported as fugitives, it is necessary to subtract the flaring emission estimates from the combustion estimates in order to avoid double counting as described in Section A3.1.4.1.2.

The provinces that report producer consumption of natural gas to Statistics Canada accounted for approximately 98% of all oil and gas production in Canada in 2013. Flaring emissions for those provinces are estimated using the amount of fuel flared as reported to Statistics Canada. Three provinces (Manitoba, Ontario and New Brunswick) accounted for the remaining 2% of oil and gas produced in 2013. Flaring emissions for these provinces are estimated using oil and gas production volumes, since the amount of fuel flared is not tracked by the respective provinces and therefore not reported to Statistics Canada.

In situations where flaring emissions are estimated for a particular province that has no producer consumption, the flaring emissions are not subtracted to ensure there is no underestimation of emissions. Additionally, checks are made to ensure that the volumes of flared gas subtracted do not exceed the volumes of producer consumption reported in each province.

Estimates for flaring emissions from Petroleum Refining are calculated using the refinery model (see A3.2.2.3). The volume of fuel flared is back-calculated from the flaring emissions and then subtracted from the producer consumption of still gas (also known as refinery fuel gas).

A3.3. Methodology for Industrial Processes and Product Use

The Industrial Processes and Product Use (IPPU) Sector covers greenhouse gas (GHG) emissions arising from non-energy-related industrial activities. Categories included in this sector are Mineral Industry, Chemical Industry, Metal Industry, Non-energy Products from Fuels and Solvent Use, Electronics Industry, Product Uses as Substitutes for Ozone Depleting Substances (ODS), and Other Product Manufacture and Use. Chapter 4 presents methodological issues for each of these categories. This section of Annex 3 provides additional details on the methodologies used to estimate emissions in the following IPPU categories:

- Chemical Industry – CO_2 emissions from Ammonia Production;
- Metal Industry – CO_2 emissions from Iron and Steel Production;
- CO_2 emissions from Non-energy Products from Fuels and Solvent Use;
- HFC emissions from Product Uses as Substitutes for ODS; and
- Other Product Manufacture and Use – SF_6 emissions from Electrical Equipment.

A3.3.1. CO_2 Emissions from Ammonia Production

Steam methane reforming (SMR), which generates hydrogen—the essential feed to the Haber-Bosch production process for ammonia—may use natural gas as the energy source to drive the process. Natural gas is also used as feedstock for the SMR process to provide a source for hydrogen. In both uses, the majority of carbon in natural gas ends up as CO_2 emissions. The source category 2.B.1, Ammonia Production, includes CO_2 emissions from the feedstock use of natural gas in the SMR process and the emissions recovered for urea production. The GHG emissions (CO_2, N_2O, and CH_4) from the energy use of natural gas in SMR process, and GHG emissions from fuels used in non-SMR ammonia production processes, are accounted for in the Energy Sector.

Facility-level data on the feedstock use of natural gas and the annual ammonia production were obtained as part of Environment Canada's voluntary data collection for the years 2005 through 2009. These data were then used to develop the facility-level ammonia-to-feed fuel (conversion) factors. These facility-level ammonia-to-feed fuel factors are considered confidential and therefore not publically available. However, based on the data collected, the average ammonia-to-feed fuel factor is 671 m3 of natural gas/tonne of NH_3 produced, and this average was used to estimate emissions from facilities that did not participate in the voluntary data collection.

The facility-level annual ammonia production data are then multiplied by the facility-specific (or average) ammonia to-feed fuel factors to determine the amount of natural gas used as feedstock for each facility. The feedstock uses of natural gas are then aggregated according to the province in which these facilities are located (Equation A3–12).

Equation A3–12:

$$NG_p = \sum_{i=1}^{n} P_{ammonia,i} \times FF_{ammonia,i}$$

where:

NG_p	=	natural gas consumed as feedstock in province p, m^3 natural gas
i	=	the SMR facility
n	=	the total number of SMR facilities in province p
p	=	a province of Canada containing one or more SMR ammonia-producing facilities
$P_{ammonia,i}$	=	the annual production of ammonia, in facility i, kt
$FF_{ammonia,i}$	=	the ammonia-to-feed fuel factor of facility i, m3 natural gas/ kt NH_3

The aggregated feedstock use (i.e. natural gas) for each province is then multiplied by the respective provincial natural gas carbon content found in Table A6-1 of Annex 6 (CO_2 emission factors for marketable natural gas) to determine the total carbon used. It is expected that all carbon present in the feedstock is transformed to CO_2 (IPCC 2006). Based on these factors, the (gross) generated process CO_2 emissions from ammonia production are calculated using Equation A3–13.

Equation A3–13:

$$Generated\ CO_2 = \sum_{p=1}^{m} NG_p \times CC_p \times COF$$

where:

Generated CO_2	=	CO_2 emissions generated, kt
NG_p	=	natural gas consumed as feedstock in province p, m^3 natural gas
p	=	a province of Canada containing one or more SMR ammonia producing facilities
m	=	the total number of provinces containing one or more SMR ammonia producing facilities
CC_p	=	carbon content factor of the fuel in province p, t CO_2/m^3 natural gas
COF		carbon oxidation factor = 1 (unitless)

The portion of emissions recovered for use in urea production is estimated using Equation A3–14, based on the assumption that urea production consumes a stoichiometric quantity of CO_2 and

that 0.005 tonnes of CO_2 are emitted per tonne of urea produced.

Equation A3–14:

$$Recovered\ CO_2 = \sum_{p=1}^{m}\left\{\sum_{i=1}^{n} P_{urea,i} \times R\right\}$$

where:

- p = a province of Canada containing one or more SMR ammonia producing facilities
- m = the total number of provinces containing one or more SMR ammonia producing facilities
- n = the total number of SMR facilities in province p
- i = the SMR facility
- $P_{urea,\ i}$ = annual urea production of facility i, t urea
- R = CO_2 emissions recovery factor per unit mass of urea production where R = [M – L] = 0.728 t CO_2/t urea
- M = stoichiometric mass ratio of CO_2 required for urea production, 44/60 or 0.733 t CO_2/t urea
- L = urea production process losses of CO_2, 0.005 t CO_2/t urea

The net CO_2 emissions from ammonia production, with CO_2 recovery for urea production, are then calculated by subtracting the CO_2 associated with recovery from the gross CO_2 emissions.

It should be noted that the quantity of natural gas feedstock used in the SMR process is subtracted from the overall non-energy use of natural gas—as reported by Statistics Canada—in order to estimate the residual (non-ammonia-related) process CO_2 emissions (refer to Section A3.3.3 Non-energy Products from Fuels and Solvent Use).

The annual facility-level ammonia production data for the years 1990 to 2015 were obtained from the following sources: 1990 to 2004 from the Cheminfo Services (2006) study; 2005 to 2009 from Environment Canada's voluntary data collection; and 2008 to 2015 from Statistics Canada's annual survey titled *Industrial Chemicals and Synthetic Resins* (Statistics Canada 46-002-X).

Facility-level urea production data for the years 2008 through 2015 were also obtained from Statistics *Canada's Industrial Chemicals and Synthetic Resins* survey. Facility-level urea production values for earlier years (1990 through 2007) were estimated using the six-year average ratio of urea to ammonia production for the data years 2008–2013.

A3.3.2. CO_2 Emissions from Iron and Steel Production

Canadian Iron and Steel Manufacturing Facilities

As of 1998, the Canadian steel sector consisted of 17 facilities, namely 5 integrated mills and 12 non-integrated mills (10 mini-mills and 2 specialty steel mills). Of the 17 facilities, 9 are located in Ontario (including 4 integrated mills), 4 in Quebec and 1 in each of Alberta, Saskatchewan, Manitoba and Nova Scotia. Table A3–19 provides a list of these facilities along with the type of manufacturing processes involved (Environment Canada 1998).

Canadian Iron and Steel Process Technologies

Steel is produced in Canada by two main steel-making processes (see Figure A3–4): basic oxygen furnaces (58.5% in 1998) and electric arc furnaces (41.5% in 1998) (Environment Canada 1998). The basic oxygen furnace (BOF) is used in integrated mills in conjunction with coke making, sintering, and blast furnace (BF) iron making operations. Integrated mills, which smelt iron ore and melt scrap, produce the greatest diversity of products, including bars, rods, structural shapes, plates, sheets, pipes and tubes, and wire rods. Although electric arc furnace (EAF) technology is gaining importance, it is usually used in non-integrated mills (mini-mills or specialty steel mills) fed by scrap or direct reduced iron (DRI) to produce a wide product range of carbon and alloy steels. ArcelorMittal Dofasco Inc. (formerly Dofasco Inc.) operates the only integrated steel plant in Canada that produces part of its steel by the electric arc furnace process. Ispat Sidbec Inc. operates the only Canadian steel mill that produces and uses DRI as part

Table A3–19 Canadian Iron and Steel Manufacturing Facilities and Processes

Plant Company/Name	Location	Manufacturing Process
AltaSteel Ltd.	Edmonton, AB	MM
IPSCO Inc.	Regina, SK	MM
Gerdau MRM Steel Inc.	Selkirk, MB	MM
Algoma Steel Inc.	Sault Ste. Marie, ON	IM
Dofasco Inc.	Hamilton, ON	IEM
Stelco Inc., Hilton Works	Hamilton, ON	IM
Lake Erie Steel Co. (Stelco)	Nanticoke, ON	IM
Slater Steels, Specialty Bar Division	Hamilton, ON	MM
Gerdau Courtice Steel Inc.	Cambridge, ON	MM
Atlas Specialty Steels	Welland, ON	SS
Co-Steel Lasco	Whitby, ON	MM
Ivaco Inc.	L'Orignal, ON	MM
Ispat Sidbec Inc.	Contrecoeur, QC	DRM
Stelco-McMaster Ltée	Contrecoeur, QC	MM
Atlas Stainless Steels	Tracy, QC	SS
QIT-Fer et Titane Inc.	Sorel, QC	IM
Sydney Steel Corporation	Sydney, NS	MM

Legend:
IM = Integrated Mills
IEM = Integrated and Electric Arc Furnace Mill
MM = Mini-Mill
DRM = Direct Reduction Mini-Mill
SS = Specialty Steel Mill

of its raw material feed. Ancillary or secondary steelmaking processes that are common to both integrated and non-integrated steelmaking include ladle metallurgy, continuous casting, hot forming, cold forming and finishing.

The following provides all process material and corresponding emission factors and carbon contents that are considered in the CO_2 emission estimates for CRF category 2.C.1, Iron and Steel Production.

Process materials:

- metallurgical coke (source: Statistics Canada 1990–2015)
- pig iron production (source: Statistics Canada 1990–2003, Statistics Canada 2004–2012, CSPA 2013–2015)
- pig iron charge to steel furnance (including direct reduced) (source: Statistics Canada 1990–2003, Statistics Canada 2004–2012, CSPA 2013–2015)
- scrap steel (own and purchased) (source: Statistics Canada 1990–2003, Statistics Canada 2004–2012, CSPA 2013–2015)
- limestone and dolomite use (source: NRCan 1990–2006, NRCan 2007–2015)

Emission factors:

- metallurgical coke = 3.27 to 3.38 kt CO_2/kt coke (these EFs are year-specific) (source: Cheminfo 2010)
- electrode consumption in EAF = 4.53 kg CO_2/t steel produced in EAF (source: CSPA 2009)
- electrode consumption in BOF = 0.23 kg CO_2/t steel produced in BOF (source: CSPA 2009)
- limestone use = 418 g CO_2/kg $CaCaO_3$ (source: AMEC 2006)
- dolomite use = 468 g CO_2/kg $MgCO_3$ (source: AMEC 2006)

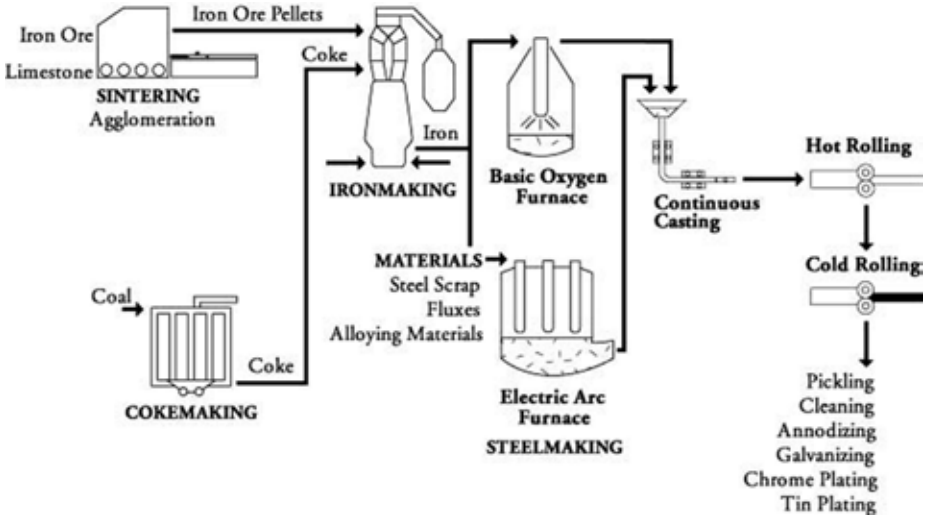
Carbon contents (source: CSPA 2009):

- pig iron (production of pig iron) from BFs and DRI plants = 4.41%
- pig iron (includes hot metal, cold iron, DRI and pig iron) for steel making: = 3.92%
- crude steel produced in BOF: 0.14%
- crude steel produced in EAF: 0.13%
- scrap steel (own): 0.10%
- scrap Steel (purchased): 0.11%

Note that due to the integrated nature of the iron and steel facilities manufacturing coal-based metallurgical coke in Canada, it is currently not possible to disaggregate the data submitted by this industry for energy use. All emissions related to the use of metallurgical coke as a reagent for reduction of iron ore in the production of pig iron are allocated in CRF category 2.C.1. As illustrated in Chapter 4 (Equation 4-7), emissions from pig iron production are estimated on the basis of various parameters, including the mass of metallurgical coke used as a reductant and its respective emission factor.

Also note that CO_2 emissions from CRF category 2.C.2, Ferroalloys Production, are included in CRF category 2.C.1.a, Steel Production, since production

Figure A3–4 Canadian Steelmaking Processes



of ferroalloys is a direct production of specialty steels from iron ore via the EAF process using reductants. However, disaggregation of the reductant portion (i.e., metallurgical coke) is not available and therefore these emissions are included in CRF category 2.C.1.b, Pig Iron Production.

A3.3.3. CO_2 Emissions from Non-Energy Products from Fuels and Solvent Use

Industrial activities in Canada that use fuel for non-energy purposes (e.g. feedstock material) include ammonia production, petrochemical production, non-ferrous mining and processing, iron and steel production, and other chemical industries.

CO_2 emissions from non-energy use of hydrocarbons—that are not reported elsewhere in the inventory—are reported under the category of Non-energy Products from Fuels and Solvent Use. The emission estimates are based on non-energy fossil fuel use data collected by Statistics Canada [*Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada 1990–2015)] and aggregated by fuel type (e.g. natural gas, coke, butane, ethane, etc.) at the provincial/territorial level. Statistics Canada does not disaggregate this fuel data by industry or industrial activity, which means that, without other supporting information, it is not possible to allocate this fuel data to a specific industry.

In some cases, Canada has obtained supporting information (e.g. through studies, surveys, other data sources, etc.) such that all or part of the non-energy fuel use data can be disaggregated and allocated to the appropriate source category. Allocation of non-energy fuel use data to specific source categories is possible for the following industrial activities:

- natural gas used to produce hydrogen for ammonia production;
- various fuels used as feedstock in the production of petrochemicals (methanol, ethylene and ethylene dichloride);
- carbon anodes used to electrically reduce alumina to aluminium in the aluminium production process; and
- coke used in iron and steel production.

For these industrial activities, known or estimated non-energy fuel types and quantities are used in estimating emissions. These known or estimated fuel quantities are then subtracted from the RESD non-energy fuel use data, and the remaining (residual) fuel quantities represent the non-energy fuel used by other industries. This avoids double counting of emissions and improves transparency in the inventory.

To estimate emissions, average national level CO_2 emission factors are available for each fuel type and are applied to the total non-energy fuel quantities (or residual quantities, if applicable) at the provincial/territorial level. Provincial/territorial estimates are then aggregated to provide a national total for CRF source category 2.D, Non-energy Products from Fuels and Solvent Use.

The following describes the methods used to estimate emissions for each category of non-energy use of fossil fuels (gaseous, solid and liquid fuels) and, where possible/applicable, how emissions are disaggregated and allocated to specific source categories (previously mentioned) in order to avoid double counting of emissions.

Gaseous Fuels

The only gaseous fuel considered in this category is natural gas. Natural gas can be used for methanol and thermal carbon black production; however, a large portion is used in the SMR process to manufacture ammonia.

CO_2 emissions from ammonia production and methanol production are estimated and reported in CRF source categories 2.B.1 and 2.B.8.a, respectively. The quantities of feedstock use of natural gas in ammonia and methanol manufacturing are subtracted from the RESD's overall non-energy natural gas to determine the remaining (residual) non-energy natural gas quantity.

Based on a study conducted in 2005 (Cheminfo Services 2005a), a CO_2 emission factor for the residual non-energy use of natural gas was developed (38 g CO_2/m3) and applied to the residual non-energy natural gas quantity to estimate emissions from this source.

Note that emissions arising from non-energy use of natural gas to produce hydrogen in the oil refining and bitumen industries are allocated to the Energy Sector of the inventory.

Solid Fuels

Solid fuels considered in the Non-energy Products from Fuels and Solvent Use category are:

- Canadian bituminous coal;
- sub-bituminous coal;
- foreign bituminous coal;
- lignite;
- anthracite;
- metallurgical coke; and
- petroleum coke.

CO_2 emissions from the non-energy use of these solid fuels are determined by applying the fuel-, province- and/or year specific emission factors presented in tables A6-5, A6-8 and A6-9 of Annex 6 for petroleum coke, coal and metallurgical coke (coke from coal), respectively, to the RESD data.

The emission factors used for estimating releases of CO_2 from the non-energy use of coal are the same as those for combustion; it is assumed that 100% of the carbon in these products will eventually be oxidized and emitted as CO_2.

CO_2 emissions resulting from the consumption of electrodes in the aluminium industry are reported in CRF source category 2.C.3, Aluminium Production. A key fuel used to make electrodes for the aluminium industry is petroleum coke. Non-energy coke is also used to make electrodes used in electric arc furnaces (EAFs) in the iron and steel industry (CRF source category 2.C.1, Iron and Steel Production). The quantities of petroleum coke used in the aluminium industry and iron and steel industry are subtracted from the RESD's

overall non-energy use of petroleum coke. The CO_2 emissions from the residual non-energy petroleum coke use are calculated by applying the emission factors provided in Table A6-5 of Annex 6.

Liquid Fuels

In addition to the emissions from gaseous and solid fuels, CO_2 emissions from the non-energy use of liquid fuels (natural gas liquids (NGLs), oil refinery petrochemical feedstocks and lubricants) are also reported in CRF category 2.D, Non-energy Products from Fuels and Solvent Use.

CO_2 emissions from the non-energy use (i.e. feedstock use) of liquid fuels in the production of petrochemicals are allocated to ethylene production (CRF category 2.B.8.b). Quantities of feedstock use of liquid fuels (specifically propane, butane, ethane, petrochemical feedstocks) in the production of petrochemicals are subtracted from the RESD's overall non-energy liquid fuels. The remaining quantities of non-energy liquid fuels are multiplied by the corresponding emission factors, as shown in Table A3–20 and Table A3–21 to estimate CO_2 emissions from this source.

It should also be noted that, owing to the way in which energy statistics are currently collected in Canada, a portion of non-energy use of liquid fuels has been reported under energy use, which is accounted for in the Energy Sector.

In the case of the residual non-energy use of NGLs—i.e. residual of petrochemical production use—the potential emission factors that occur when all the carbon is oxidized are provided in the McCann (2000) study. The residual non energy use emission factors of the three NGLs are presented in Table A3–20.

The residual and non-residual non-energy use of petroleum products coming out of the oil refineries (i.e. petrochemical feedstocks, naphthas, lubricants, greases and other petroleum products) also results in CO_2 emissions and is accounted for in the Non-energy Products from Fuels and Solvent Use Category. Derivations of the non-energy use emission factors are shown in Table A3–21. To estimate emissions at national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

Table A3–20 CO_2 Emission Factors for Residual Natural Gas Liquids

	Fraction of Carbon Stored in Products	Emission Factors (g CO_2/L)
Propane	0.8	303
Butane	0.8	349
Ethane	0.8	197

Data source: McCann (2000)

Table A3–21 CO_2 Emission Factors for Non-Energy Petroleum Products

Non-Energy Products	Carbon Factor (g C/L)[1]	Molecular Weight Ratio between CO_2 and Carbon	Fraction of Carbon Stored[2]	Resulting CO_2 Emission Factor (g CO_2/L)
	A	B	C	D = A × B × (1 – C)
Petrochemical Feedstocks	680	44/12	0.8	500
Naphthas	680	44/12	0.75	625
Lubricating Oils and Greases	770	44/12	0.5	1410
Petroleum Used for Other Products	790	44/12	0.5	1450

Notes:
1. Mass of carbon emitted per unit of fuel used; data source: Jaques 1992.
2. IPCC default values; data source: IPCC/OECD/IEA 1997.

A3.3.4. HFC Emissions from Product Uses as Substitutes for Ozone Depleting Substances (ODS)

A3.3.4.1. Activity Data

HFC emission estimates for 1995 were based on data gathered from an initial HFC survey conducted by Environment Canada in 1996.[8] The Department revised subsequent surveys to obtain more detailed activity data for later years. The 1998, 1999, 2001 and 2005 HFC surveys were the source of activity data for emission estimates for the years 1996–2000 and 2004 (2004–2006 emails from Y. Bovet and Y. Guilbault).[9] In some cases, one survey was done to collect data for two years. HFC sales data for 2001–2003 were also collected in 2005 from major HFC importers in Canada (Cheminfo Services 2005b). These data were provided by market segment, such that the total quantity used for each type of application could be determined. HFC import and sales data for 2005–2010[10] were collected by Environment Canada through a voluntary data submission process, whereby requests for data were sent to the main importers of bulk HFCs and to companies that import/export HFC-containing products. For 2009, the distribution list for data collection was expanded, as Environment Canada became aware of other importers/exporters in the market (either importers of bulk HFCs or importers/exporters of items with HFCs) by looking at HFC import data collected by the Canada Border Services Agency (CBSA).[11] Information on HFC-245fa received in these surveys has been incorporated for 2000 through 2007 and extrapolated to the current inventory year. In 2014, Environment Canada performed a mandatory survey of bulk importers for the data years 2008 to 2012, and the results of the survey and update (Environment Canada 2015a) were incorporated into the inventory. Where duplicate reporting occurred between the mandatory and voluntary surveys, the mandatory survey was chosen for the inventory due to the legal reporting requirements.

In 2016, Environment and Climate Change Canada (ECCC) performed mandatory surveys of bulk importers (ECCC 2016a, ECCC 2016b) for the data years 2013–2014 and 2015, which have been included in the inventory.

In terms of data on import/export of HFC-containing products, in cases where data were not available from companies, either the non-reported quantities were assumed to remain at the levels of the most recent years for which data were available or the data were linearly interpolated. For instance, 1995 data on the quantities of HFCs contained in imported and exported manufactured items (MIs), except imported and exported vehicles, were not available; therefore, the 1996 to 1998 results were used to linearly extrapolate back to 1995. For 1999–2003, these quantities were linearly interpolated from the data available in 1998 and 2004. Similar to the situation for data on bulk HFCs, the distribution list for HFC MI data collection has been expanded for 2009 data, and this list was used for the 2010 data collection.

Once the emission estimates at the national level were obtained, they were distributed by province/territory based on proxy variables, such as gross

8 Bovet Y, Guilbault Y. 2004–2006. Personal communications (emails received from Bovet Y and Guilbault Y to Au A, Greenhouse Gas Division, during the years 2004–2006). UPCIS.

9 Bovet Y, Guilbault Y. 2004–2006. Personal communications (emails received from Bovet Y and Guilbault Y to Au A, Greenhouse Gas Division, during the years 2004–2006). UPCIS.

10 Except for 2010, data collected by Environment Canada on bulk HFCs only covered sales. However, with no Canadian production existing for HFCs and an insignificant amount of exports, the import values should theoretically be close to the sales values. In fact, import values were added to the 2010 data collection in order to verify the sales values.

11 It should be noted that HFC data from the CBSA cannot be used for GHG inventory purposes, as they are collected and categorized only under three types: HFC-134a, HFC-152a and others. Also, the data are not presented by use type. However, company-specific data from the CBSA are a useful tool for data verification and for expanding the distribution list for the HFC data collection

output of accommodation and food services for commercial refrigeration, and number of households for residential refrigeration.

A3.3.4.2. Methodology

Preparation of Data for the Inventory

Canada uses a relatively detailed sector breakdown of HFC subcategories (refer to Table A3–22), requiring that the HFC use data be broken down at this level annually. To meet this requirement, missing data had to be filled in, and aggregated data had to be broken down by subcategory.

To fill in the data gaps from reporters to the voluntary surveys, a variety of techniques were used. When a company did not report in subsequent years, the data was held constant. Where data years were missing due to no surveys being performed (e.g. imports/exports of manufactured items from 1999 to 2003), linear interpolation was used to estimate the missing data.

To meet the requirements of a Tier 2 methodology, Environment and Climate Change Canada used two approaches to break down the 1995 to 2004 use data, which were sometimes aggregated, to the subcategory level. If a large proportion of the HFC emissions reported for a category had been reported at the subcategory levels, then the subcategory-level proportions were used to break down the aggregated category-level data. If sufficient breakdown was not available for the year and category level, the breakdown from the closest historical year for the same HFC and category level was used.

For the 2008 to 2012 mandatory reported bulk sales data, where aggregated HFC data were reported, the data were broken down by subcategory based on the 2004 breakdown. While these data are up to eight years older than the mandatory data, HFC had been used for almost 10 years by 2004. The 2004 data are currently the best information

Table A3–22 Canadian HFC Use Categories and Sub-Categories

Category/Sub-category Description
Aerosols
Personal care products
Pharmaceutical products
Medical products
Household products
Mining application products
Commercial / Industrial products
Blowing agent in foams
Cushioning - automobiles (seats, roof, etc.)
Cushioning - other (furniture, mattresses, etc.)
Thermal insulation - homes and buildings
Thermal insulation - pipes
Thermal insulation - refrigerators and freezers
Thermal insulation - other (specify)
Packaging - food (specify)
Packaging - non-food (specify
Other foam uses (specify)
Air conditioning (Original Equipment Manufacture)
Air conditioner units in motor vehicles
Chillers (specify centrifugal or reciprocating)
Residential (air conditioners, dehumidifiers, etc.)
Air conditioning (Service/Maintenance)
Air-conditioner units in motor vehicles
Chillers (specify centrifugal or reciprocating)
Residential (air conditioners, dehumidifiers, etc.)
Refrigeration (Original Equipment Manufacture)
Commercial transport
Commercial and institutional (retail foods, vending machines, etc.)
Industrial (warehouses, process equipment, etc.)
Residential (freezers, refrigerators)
Other equipment (specify)
Refrigeration (Service/Maintenance)
Commercial transport
Commercial and institutional (retail foods, vending machines, etc.)
Industrial (warehouses, processes, etc.)
Residential (refrigerators, freezers, etc.)
Other equipment (specify)
Solvent
Electronic industry
Metal cleaning/drying
Dry cleaning
Laboratory solvent
General cleaning (specify)
Fire suppression/extinguishing systems (Original Equipment Manufacture)
Portable (mobile) systems
Total flooding (fixed) systems
Fire suppression/extinguishing systems (Service/Maintenance)
Portable (mobile) systems
Total flooding (fixed) systems
Miscellaneous
Hospital/institutional sterilizing
Leak testing
Other (specify)

Table A3–23 Surrogates Used for HFC Trend Interpolation/ Extrapolation

Surrogate Description
Commercial Floor Space
Residential Households
Population
Gross Domestic Product
Gross Output for the following categories:
Computer and Electronic Products Manufacturing
Fabricated Metal Products
Food
Furniture and Related Products
Health Care & Social Assistance
Mining (excluding Oil, Gas and Coal)
Other Manufacturing
Other Services (excluding Public Administration)
Professional, Scientific and Technical Services
Transportation Equipment

available for this purpose. For the recent 2013 – 2014 and 2015 mandatory reported bulk sales data, where aggregated HFC data were reported, the data were broken down by subcategory based on the primarily on the 2012 breakdown and when sufficient information was not available the 2004 breakdown was used.

For the information on new HFCs received under the mandatory reporting program, existing breakdowns of a category to the subcategory level of other HFCs (generally HFC-134a) were used.

The bulk voluntary submission data for the intermediate 2005 to 2007 data years were considered incomplete and were therefore estimated using linear interpolation between the 2004 and 2008 data years.

To extrapolate beyond the latest data year, the data were reviewed with respect to time series consistency (IPCC 2006, Volume 1, Chapter 5, Section 5.3.3.4). The data were found to be inconsistent and some gaps were noted. Due to this trend, extrapolation using surrogates was applied to obtain data to the current inventory year as required. Figure A3–23 lists the various surrogate data applied for trend extrapolation.

A3.3.4.3. Emission Factors and Lifetimes

In 2013, Environment Canada conducted a survey of the air-conditioning and refrigeration categories to obtain information for developing emission factors.

The information on emission factors was reviewed (EHS 2013; Environment Canada 2015b), taking into account the IPCC Good Practice Guidance, specifically the chapter on quality control measures (IPCC 2000). The emission factors were also compared to values published in the 2006 IPCC Guidelines and most were found to be within the same range. Several emission factors did not meet the IPCC Good Practice Guidance for expert elicitation (generally the decommissioning); a value was therefore chosen within the range of emission factors established by the 2006 IPCC Guidelines, guided by other information such as the regulatory environment in Canada. These emission factors have been applied to the whole time series from 1995 onwards.

The emission factors for the subcategory of "Other equipment" under Refrigeration—a mix of specialty applications—were derived through a weighted average of the emission factors for the other specific refrigeration subcategories.

For the air conditioning and refrigeration categories, the expected lifetimes applied in the emission estimations were chosen based on the survey results and the information provided in the 2006 IPCC Guidelines.

For the remaining HFC categories, emission factors and lifetimes were chosen from the 2006 IPCC Guidelines.

Table A3–24 presents the emission factors used to estimate the HFC emissions.

Table A3–24 HFC Emission Factors (%)

Sub-category	Assembly	In-Service	End-of-Life	Life Time
Aerosols [1]	0	50% of orginal	-	2
Blowing agent in foams [1]				
Open-cell foam	100	-	-	-
Closed-cell foam	10	4.5	100	23
Air conditioning (Original Equipment Manufacture) [2]				
Air-conditioner units in motor vehicles	0.5	10	75	13
Chillers (specify centrifugal or reciprocating)	1	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	1	4	20	17
Air conditioning (Service/Maintenance) [2]				
Air-conditioner units in motor vehicles		10	75	13
Chillers (specify centrifugal or reciprocating)		4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)		4	20	17
Refrigeration (Original Equipment Manufacture) [2]				
Commercial transport	1	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	1	10	30	17
Industrial (warehouses, process equipment, etc.)	1	10	30	17
Residential (freezers, refrigerators)	0.6	0.5	30	15
Other equipment (specify)	1.0	10.8	30	15
Refrigeration (Service/Maintenance) [2]				
Commercial transport		15	30	13
Commercial and institutional (retail foods, vending machines, etc.)		10	30	17
Industrial (warehouses, processes, etc.)		10	30	17
Residential (refrigerators, freezers, etc.)		0.5	30	15
Other equipment (specify)		10.1	30	15
Solvent [1]	0	50% of orginal		2
Fire suppression/extinguishing systems (Original Equipment Manufacture) [1]				
Portable (mobile) systems	-	4	-	18
Total flooding (fixed) systems	-	2	-	18
Fire suppression/extinguishing systems (Service/Maintenance) [1]				
Portable (mobile) systems	-	4	-	18
Total flooding (fixed) systems	-	2	-	18
Miscellaneous [1]	-	50% of orginal	-	2
Other (specify) [1]	-	50% of orginal	-	2

Data sources:
1. IPCC 2006
2. Environment Canada 2015b.

A3.3.5. SF_6 Emissions from Electrical Equipment

A3.3.5.1. Methodology – Derivation of the Country-Specific Quantification Method

To quantify SF_6 emissions (for 2006–2015), the Canadian electricity industry uses a method derived from the basic Tier 3 IPCC 2006 life-cycle Equation 8.10 (Volume 3), as explained in the following sections.

A3.3.5.1.1. Equipment Manufacturing Emissions

According to some utilities, electrical equipment purchased by the Canadian electricity sector is manufactured in the United States, Europe or Asia and hence emissions associated with manufacturing would have occurred mainly outside of Canada.

A3.3.5.1.2. Equipment Installation Emissions

SF_6 equipment is delivered to utilities pre-charged with some SF_6 and charged to full capacity at the time of installation. In the Canadian electricity industry, the potential for SF_6 emissions during equipment installation is considered to be extremely rare. A vacuum hold check is typically performed prior to the installation of new equipment to ensure that the equipment is gas tight.

A3.3.5.1.3. Equipment Use Emissions

The primary source of SF_6 releases is associated with the cumulative minute releases that occur during normal equipment operation. Gas releases could potentially occur during gas handling and transfer operations, although such releases would be significantly smaller in magnitude than emissions that occur during normal operations.

Due to the SF_6 leakage that occurs during the above circumstances, utilities are required to "top-up" their equipment to keep their equipment properly charged and operational. By topping up equipment with SF_6 gas, utilities are able to replace the amount of gas that has escaped.

A3.3.5.1.4. Equipment Decommissioning and Failure Emissions

During the decommissioning of retired equipment, SF_6 gas must be recovered from the retired equipment prior to disposal. As SF_6 gas releases may occur as a result of the way in which the gas is transferred out of the equipment during gas recovery, decommissioning of retired equipment becomes a potential source of SF_6 releases.

When catastrophic failures of equipment occur, a significant amount of SF_6 leaks out of the equipment. Equipment damage is therefore a potential source of emissions.

Retired equipment and damaged equipment that cannot be repaired are sent off-site for disposal.

A3.3.5.1.5. Emissions from SF_6 Recycling

When SF_6 gas is recovered from equipment, it is filtered through a gas cart or other filtering equipment to remove moisture and impurities before it is reused. When SF_6 gas has been contaminated

with air and impurities and has a purity of less than a certain level (the acceptable level can vary between 95% and 99%, depending on utility practices), it cannot be reused and is sent for off-site purification in the United States. There are no facilities in Canada that perform SF_6 gas purification. One of the methods utilized to purify SF_6 gas is the use of a cryogenic process to separate and remove the air/nitrogen from the SF_6 gas. The purification of SF_6 gas does not produce SF_6 emissions. Hence, emissions from SF_6 recycling are eliminated from the calculation of total emissions.

Given the reasoning above, the Canadian electricity industry uses a modified, country-specific Tier 3 IPCC approach to estimate SF_6 releases. Only emissions from equipment use and equipment decommis-sioning and failure are calculated, as shown in Equation A3–15.

Equation A3–15:

$$\begin{aligned} &\textit{Total Utility } SF_6 \textit{ Emissions} \\ &= \sum \textit{Equipment Use Emissions} \\ &+ \sum \textit{Equipment Decommissioning and Failure Emissions} \end{aligned}$$

A3.3.5.2. Methodology – Quantifying Equipment Use Emissions

Emissions that occur during equipment use are a result of leakages during gas transfer and handling operations and during normal operation of the equipment. In order to keep equipment properly charged and operational, utilities must fill their equipment to replace the amount that has escaped. This amount is referred to as a "top-up."

Leakages of SF_6 are also seen during maintenance/repair activities. When equipment needs to be repaired or sent for maintenance, SF_6 gas is recovered from equipment and, once the equipment is repaired, it is refilled with the SF_6 gas that was recovered. There will be an additional amount needed to refill the equipment, since some gas may have escaped due to normal operations and during the transfer of the recovered gas from the equipment to gas carts (or storage cylinders) and back to the equipment. It is this additional/incremental amount of SF_6 gas that is referred to as the "top-up." Hence, an accurate estimate of the amount of SF_6 released is the amount used by utilities to top up their equipment during the equipment use stage.

A3.3.5.2.1. Options for Tracking SF_6 Consumed for Top-ups

The following is a list of options for Canadian electric utilities to track the amount of SF_6 that is used for top-up purposes in order to quantify emissions of SF_6 from the equipment use phase. These options are listed in order of most accurate to least accurate. The most accurate method involves directly measuring the amount of gas transferred during top-ups, and the less accurate methods involve utilities relying on inventory records or purchase receipts to obtain an estimate. Each utility will have discretion over which method to use. Canadian electric utilities may track the amount of SF_6 that is used annually for top-up purposes (i.e. the amount that has been emitted) by using mass flow meters, a mass balance, or counting the number of cylinders consumed.

For all of these tracking options, it is assumed that the quantities of SF_6 tracked do not include the gas used to pressurize the new switchgear to its full capacity at time of installation. Quantities of gas used for this pressurization are typically provided by the switchgear vendor at time of installation and hence do not come out of the utility inventory (see also A3.3.5.1.2, Equipment Installation Emissions).

Option 1: Mass Flow Meters

Mass flow meters provide the most accurate method for measuring the quantity of SF_6 consumed during each equipment top-up operation. The sum of all measured quantities during top-up operations will be used to determine the equipment use emissions.

Option 2: Mass Balance

Utilities may choose to weigh their SF_6 cylinders to determine the quantity of SF_6 consumed for top-up operations. The difference in mass of the cylinders can be determined every time there is an equipment top-up operation, or it can be determined on an inventory basis. Utilities must also account for any purchases or additions to the inventory, the weight of SF_6 cylinders returned to suppliers and the quantity of SF_6 sent off-site for recycling or destruction during the year. When using a mass balance, utilities should ensure that the accuracy of the weigh scale is compatible with the weight of the cylinders to be weighed. For example, utilities should use a scale accurate to ±1 kg, rather than ± 5 kg, to weigh a 50-kg cylinder.

Option 3: Cylinder Count

In the absence of mass flow meters or weigh scales, utilities may choose to rely on information from supplier or inventory records and from purchase receipts to obtain the number and weight of SF_6 cylinders purchased for top-up purposes. The mass of SF_6 consumed can be assumed to be equal to the amount of SF_6 purchased in a year or equal to the change in maintenance inventory.

The weight of SF_6 found in different types of cylinders should be known. Therefore, utilities can simply obtain the weight of SF_6 consumed for top-up purposes by performing a cylinder count. If more than one type of cylinder is used, utilities must ensure that the number of cylinders of each type is multiplied by the cylinder weight for that type. The products obtained for all cylinder types are then summed together to give the total SF_6 use.

A3.3.5.3. Methodology – Quantifying Equipment Disposal and Failure Emissions

Equipment disposal and failure emissions include emissions from decommissioning of retired equipment and emissions that result from the rare event of catastrophic equipment failures.

In the decommissioning of retired equipment, SF_6 losses occur as gas is being recovered from the retired equipment. Emissions can be estimated by taking the difference between the nameplate capacity of the equipment and the recovered amount of SF_6.

Equation A3–16:

$$\begin{aligned}\textit{Equipment decommisioning emissions} &= \textit{Nameplate capacity of retired equipment} \\ &- \textit{SF}_6\ \textit{amount recovered from retired equipment}\end{aligned}$$

The value of nameplate capacity (in mass units) can be obtained from equipment specifications provided by the equipment manufacturer or from sound engineering estimates. The amount of recovered SF_6 gas is weighed.

When equipment failure or damage occurs to the point where it they cannot be repaired, it is assumed that the nameplate capacity of the equipment is representative of the emissions that have taken place as a result of equipment failures.

The information provided in this section (A3.3.5) is extracted from the SF_6 Emission Estimation and Reporting Protocol for Electric Utilities (Environment Canada and Canadian Electricity Association 2008), available upon request at

http://www.publications.gc.ca/site/eng/454401/publication.html. For further details on data uncertainty, data quality control, data verification by third party, transfer of information and data to Environment Canada, documentation and archiving, new information or data updates, and protocol reviews and amendments, please refer to the Protocol.

A3.3.5.4. Data Sources

The SF_6 emissions by province for 2006-2015 were provided by the Canadian Electricity Association and Hydro Quebec.

A3.4. Methodology for the Agriculture Sector

This section of Annex 3 describes the estimation methodologies, equations, activity data, emission factors and parameters that are used to derive the greenhouse gas (GHG) estimates in the Agriculture Sector, namely:

- CH_4 emissions from enteric fermentation;
- CH_4 and N_2O emissions from manure management and field burning of agricultural residues;
- N_2O emissions from agricultural soils (direct emissions, indirect emissions and animal manure emissions on pasture, range and paddock); and
- CO_2 emissions from agricultural use of lime and urea.

The sources of animal population data required to calculate agricultural emissions of CH_4 and N_2O are presented in Section A3.4.1. The methods used to calculate agricultural GHG emissions are described in sections A3.4.2to A3.4.8. Note that agricultural soils also emit and sequester CO_2, but these sources/sinks are reported in the Land Use, Land-use Change and Forestry (LULUCF) Sector (see-- Annex 3.5).

A3.4.1. Animal Population Data Sources

Annual livestock population data at a provincial level were used to develop emission estimates. Livestock and poultry populations, by animal sub-category and by province, were obtained from Statistics Canada and other sources, as described in Table A3–25.

Annual cattle, sheep and swine populations are presented as the simple mean of semi annual or quarterly surveys. These smaller surveys are corrected by Statistics Canada to the accurate *Census of Agriculture* (COA) population estimates, which are collected every five years, to assure the accuracy of the estimates.

The populations of horses, goats, bison,[12] llamas and alpacas, deer and elk, wild boars, rabbits, and poultry are taken from the COA exclusively, and annual populations are developed by linear interpolation in order to avoid large changes in census years. Populations of deer and elk, considered new to Canadian livestock production and only reported in the COA for census years beginning in the reporting period, were extrapolated back to zero for the census year previous to their first appearance in the COA. Mule and ass populations were received via personal communication[13] and originate from recently compiled responses to the COA for the years 2001, 2006 and 2011. Mule and ass populations were not compiled prior to the 2001 census year and were assumed to be constant at the 2001 level from 1990 to 2000. Wild boar populations for census years 1991 and 1996 were received via personal communication[14] and were compiled from responses to the COA. Wild boar and buffalo populations were not collected

12 In the CRF tables, the IPCC animal category buffalo is used to report values for North American bison (Bison bison) raised for meat.

13 Laborde L. 2015. Personal communication (e-mail from Laborde L to Section Head, Agriculture, Forestry and Other Land Uses, dated September 2, 2015). Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

14 Laborde L. 2016. Personal communication (e-mail from Laborde L to Flemming C, Agriculture, Forestry and Other Land Uses, dated October 26, 2016). Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

in 1986; thus, the populations were set constant for 1990 at the 1991 level.

Breeding mink and fox populations were taken from an annual Statistics Canada survey titled *Supply and Disposition of Mink and Fox on Fur Farms*, which provides the number of fox and mink on farms for January 1 of the survey year. Rabbit populations were taken from responses to the COA as provided on the AAFC Red Meat Market website (see Table A3–25), but were modified based on expert opinion[15] using a correction factor in order to estimate the number of does, as opposed to total rabbits.

For beef and dairy cattle, the IPCC Tier 2 approach (IPCC 2006) was adopted to estimate CH_4 emission factors from enteric fermentation and manure management. The subcategories of provincial cattle populations collected by Statistics Canada

15 Tapscott B. 2015. Personal communication (e-mail from Tapscott B, OMAFRA, to Section Head, Agriculture, Forestry and Other Land Uses, dated September 16, 2015). Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

Table A3–25 Animal Categories and Sources of Population Data

Category	Sources/Notes
Cattle	Statistics Canada. Table 003-0032 - Number of cattle, by class and farm type, annual (head), CANSIM (database). http://www5.statcan.gc.ca/cansim/a05?lang=eng&id=0030032&pattern=0030032&searchTypeByValue=1&p2=35 (accessed July 14, 2016)
—Dairy Cattle	All cattle used in the production of milk and milk products
—Non-dairy Cattle	All other cattle
Bison, Goats, Horses, Llamas and Alpacas, Deers and Elk	Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001, and 2006 (Catalogue #No. 23-502-X), 2011 Census: Statistics Canada. Table 95-640-XWE - 2011 Farm and farm operator data (database). http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0040224&tabMode=dataTable&srchLan=-1&p1=-1&p2=9 - linear interpolation between census years, remains constant after last census
Wild Boars	Census years 2001 to present: Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001, and 2006 (Catalogue #No. 23-502-X), 2011 Census: Statistics Canada. Table 95-640-XWE - 2011 Farm and farm operator data (database). http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0040224&tabMode=dataTable&rchLan=-1&p1=-1&p2=9 - linear interpolation between census years, remains constant after last census Census years[1] 1991, 1996: Laborde, Leon (Statistics Canada). Personal communication received October 26, 2016. - linear interpolation between census years, 1990 kept constant from 1991
Mink and Foxes	Statistics Canada. Table 003-0015 - Supply and disposition of mink and fox on fur farms, annual (Number), CANSIM (database) http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0030015&tabMode=dataTable&s-rchLan=-1&p1=-1&p2=9 (accessed November 6, 2016)
Mules and Asses[1]	Laborde, Leon (Statistics Canada). Personal communication received September 2, 2015. - population held constant prior to 2001 census, and after the last census
Rabbits	Agriculture and Agri-Food Canada, Red Meat Market Information, Alternative Livestock. http://www.agr.gc.ca/eng/industry-markets-and-trade/statistics-and-market-information/by-product-sector/red-meat-and-livestock/red-meat-and-livestock-market-information/supply-sheets-by-species/rabbit-industry-at-a-glance/ - linear interpolation between census years, remains constant after last census - correction factor applied to isolate the breeding population based on expert opinion from Brian Tapscott, Alternative Livestock Specialist, OMAFRA
Sheep and Lambs	Statistics Canada. Table 003-0031 - Number of sheep and lambs on farms, annual (head), CANSIM (database). http://www5.statcan.gc.ca/cansim/a05?lang=eng&id=0030031&pattern=0030031&searchTypeByValue=1&p2=35 (accessed July 14, 2016)
Swine	Statistics Canada. Table 003-0004 - Number of hogs on farms at end of quarter, quarterly (head), CANSIM (database). Years 1990-2006. Statistics Canada. Table 003-0100 - Hogs statistics, number of hogs on farms at end of semi-annual period, (Head), CANSIM (database). Years 2007-2014. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0030100&tabMode=-dataTable&srchLan=-1&p1=-1&p2=9 (accessed July 14, 2016) Subcategories: Boars, Sows, Growers under 20 kg, 20 to 60 kg, and over 60 kg
Poultry	Farm data and farm operator data tables (section 6.5 of publication #95-629) (Statistics Canada [2007a]) Selected historical data from the *Census of Agriculture*, Canada and provinces: census years 1976 to 2006 (Table 2.16 and section 4.6 of Statistics Canada cCatalogue #No. 95-632). (Statistics Canada [2007b]) 2011 Census: Statistics Canada. Table 95-640-XWE - 2011 Farm and farm operator data (database). http://www29.statcan.gc.ca/ceag-web/eng/data-type-selection-type-donnees?geoId=0 (accessed December 20, 2012) - linear interpolation between census years, remains constant after last census

1. These data may be affected by errors due to coverage.

were further disaggregated into subannual production stages to isolate and quantify the effect of specific production practices on gross energy intake and, as a consequence, CH_4 emissions. Data to describe the production environment and associated performance of classes of animals were collected from a combination of production and management practices published in scientific journals, a survey of dairy and beef production practices conducted and administered to regional and provincial beef and dairy cattle specialists across the country, and consultation with scientists at universities and federal research institutions, as well as from provincial/national associations and

Table A3–26 Cattle Production Stage Model

Subcategory	Production Environment	Period of Year[1]	Province
Beef cows	Pregnant, confined	Jan-Apr/Oct-Dec	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef cows	Lactating, pasture	May-Oct	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef cows	Pregnant, confined	Feb-Mar	MB
Beef cows	Lactating, pasture	Jan/Mar-Dec	MB
Breeding bulls	Mature, confined	Jan-Apr/Nov-Dec	PE/NS/QC/ON/MB/SK/AB/BC
Breeding bulls	Mature pasture	May-Oct	PE/NS/QC/ON/MB/SK/AB/BC
Breeding bulls	Young confined	Mar-Apr	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Breeding bulls	Young pasture	May-Oct	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Breeding bulls	Young confined	Nov-Dec/Jan-Feb	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Birth to pasture	Mar	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Pasture	Apr-Sep	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Heifer replacement	Oct-Dec/Jan-Mar	PE/NS/QC/ON/MB/SK/AB/BC
Beef calves	Background heifers	Oct-Dec/Jan-Mar	PE/NS/QC/ON/MB/SK/AB/BC
Beef calves	Background steers	Oct-Dec/Jan-Mar	NL/PE/NS/NB/ON/MB/SK/AB/BC
Beef calves	Finisher heifers	Oct-Dec/Jan-Mar	NL/PE/NS/NB/ON/MB/SK/AB/BC
Beef calves	Finisher steers	Oct-Dec/Jan-Mar	PE/NS/NB/ON/MB/SK/AB/BC
Heifer replacement	Young, not pregant	Apr-May	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Heifer replacement	Early gestation	Jun-Sep	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Heifer replacement	Late gestation	Oct-Dec/Jan-Mar	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Finisher heifers	Feedlot, short-keeps	Apr-Jun	PE/NS/NB/ON/MB/SK/AB/BC
Finisher steers	Feedlot, short-keeps	Apr-Jun	PE/NS/NB/ON/MB/SK/AB/BC
Finisher heifers	Feedlot short-keep long-finish	April-Jul	NS/ON/MB
Finisher steers	Feedlot short-keep long-finish	April-Jul	NS/ON/MB
Background heifers	Confined	Mar-May	NL/NS/ON/MB/SK/AB/BC
Background steers	Confined	Mar-May	NL/NS/ON/MB/SK/AB/BC
Background heifers	Pasture	Jun-Sep	NL/NS/ON/MB/AB/BC
Background steers	Pasture	Jun-Sep	NL/NS/ON/MB/AB/BC
Finisher heifers	Feedlot, long-keeps	Oct-Dec	PE/NS/NB/QC/ON/MB/SK/AB/BC
Finisher steers	Feedlot, long-keeps	Oct-Dec	PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy cows	Lactating, confined	var[2]	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy cows	Lactating, pasture	var	NL/PE/NB
Dairy cows	Lactating, confined (after pasture)	var	PE
Dairy cows	Dry, low-quality feed	var	NL/PE/NS/NB/QC/ON/MB/SK/BC
Dairy cows	Dry, high-quality feed	var	MB/SK/AB/BC
Dairy cows	Dry, pasture	var	NL/ON
Dairy heifers	Confined (243 days year)	Jan-Apr/Oct-Dec	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy heifers	Pasture	May-Oct	NL/PE/NB/ON/SK
Dairy heifers	Confined (365 days year)	Jan-Dec	NB/ON/SK

Notes:
1. Actual period of the year could vary slightly from province to province.
2. Variable dependent on farm, province and animal cycles.

Table A3–27 Typical Characteristics of Dairy Production in 2001 in Canada

Animal Category/Parameters	Production Characteristics[2]	Data Sources[3]
Dairy cows[1]		
Average weight, kg	634 (51)	Okine and Mathison (1991); Kononoff et al. (2000); Petit et al. (2001)
Mature weight, kg	646 (55)	
Conception rate, %	59.2 (7.3)	
Calves		
Birth weight, kg	41 (3.3)	
Average weight, kg	186 (18.5)	
Mature weight, kg	330.5 (37.6)	
Daily weight gain, kg/day	0.7 (0.3)	
Calf crop,[4] %	93 (6)	
Replacement heifers		
Average weight, kg	461.6 (24.7)	
Beginning weight (1 year), kg	327.8 (31.0)	
Mature weight at calving, kg	602.1 (45.9)	
Mature weight, kg	646.1 (54.9)	
Daily weight gain, kg/day	0.77 (0.14)	
Replacement rate, %	32.3 (3.2)	Western Canadian Dairy Herd Improvement Services (2002)

Notes:
1. Values represent typical values observed in Canada but not population-weighted averages quantitatively representating Canadian dairy production, as reported in the CRF.
2. The numbers in parentheses are the standard deviation.
3. Values with no reference were obtained from expert consultations (see Boadi et al. 2004b).
4. "Calf crop" is the percentage of the overwintering cows that produced a live calf.

provincial/regional performance-recording organizations (Boadi et al. 2004a).

These data were used to create an annual cattle production model that takes into account regional and seasonal variations in production practices. The 8 cattle subcategories were broken down into 38 distinct cattle production stages, 29 for non dairy cattle and 9 for dairy cattle, observed throughout the different provinces of Canada (Table A3–26). The model characterizes cattle by physiological status, diet, age, sex, weight, growth rate, activity level and production environment.

The feeding practices for beef and dairy cattle are detailed in the next section.

A3.4.1.1. Dairy Cattle

Production and Performance

Production practices vary across the country because of differences in land prices, climate, forage availability and market access. The predominant management practices for each province are reflected by the province-specific parameters entered into the IPCC Tier 2 equations.

Table A3–27 provides an example of production performance data collected for Canadian dairy cattle, originally used as a quality assurance (QA) verification of the data incorporated in the Tier 2 model.

Currently, it is assumed that all production characteristics of the Canadian dairy herd have remained constant over the 1990–2014 period, including the live weight of dairy cows, as data from Holstein Ontario do not indicate increases in weight over this period. As a result, dairy cows' and dairy heifers' live weights are set constant to the 2001 weight, estimated in Boadi et al. (2004a).

Milk Yield and Fat Data

Milk productivity has increased in all Canadian provinces (Table A3–28), as documented by CanWest DHI, which collects a sample of milk production representing more than two thirds of the Canadian dairy cow population for the period of 1999–2015 (Western Canadian Dairy Herd Improvement Services, 2002). These data represent the best estimate of actual milk production per cow per province in Canada. However, from 1990 to 1998, this data set does not exist for all of Canada. The only data that are available from 1990 to 1998 for all of Canada are publishable data that were reported by Agriculture and Agri-Food Canada. The publishable data are collected for the most productive animals and the quantity of milk that is produced in the first 305 days of their lactation period. The time series 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. The trend of increased milk production is reflected in the emission factor for dairy cows.

Duration of Time in a Production Environment

It was assumed that cows that were dry (not lactating) during the summer months were on pasture; cows that were dry during the remainder of the year were in confinement. Replacement heifers were assumed to calve at 24 months.

Percentage of Cows Pregnant

An estimate of the percentage of cows pregnant in the herd at any given time was calculated in Boadi et al. (2004a) by dividing average gestation

Table A3–28 Average Milk Production from 1990 to 2015 at a Provincial Level

	Average Milk Production (kg/head/day)[1]									
Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC
1990	21.0	20.9	21.0	20.8	20.3	21.7	22.1	22.2	23.2	24.3
1991	21.3	21.2	21.3	21.1	20.6	21.7	22.4	22.5	23.6	24.7
1992	22.1	22.0	22.1	21.9	21.5	22.6	23.3	23.4	24.5	25.6
1993	22.6	22.5	22.6	22.5	21.7	23.2	23.8	23.9	25.1	26.2
1994	23.5	23.4	23.5	23.3	22.4	23.6	24.8	24.8	26.0	27.3
1995	23.1	23.1	23.2	23.0	22.2	24.0	24.2	24.2	25.5	26.8
1996	23.7	23.6	23.7	23.5	23.0	24.7	25.2	25.4	26.5	27.5
1997	24.0	24.0	24.1	23.9	23.2	24.8	25.4	25.8	26.7	27.2
1998	24.4	24.4	24.5	24.3	24.1	25.3	25.7	26.6	27.3	27.9
1999	25.6	25.5	26.4	26.1	25.1	26.4	26.0	26.4	27.1	28.8
2000	27.4	26.1	26.8	26.4	25.5	26.5	27.9	27.7	29.0	30.0
2001	28.3	26.4	27.1	27.2	25.7	26.3	28.0	28.1	29.4	30.4
2002	28.2	26.4	26.9	27.2	26.2	26.7	28.3	29.4	30.4	31.2
2003	28.7	26.2	26.9	26.4	26.0	26.5	28.3	29.1	29.8	31.1
2004	26.1	26.3	26.8	26.3	26.1	26.1	28.1	29.1	29.2	30.7
2005	27.0	27.1	26.9	26.4	25.9	26.7	27.4	29.3	29.3	30.4
2006	27.3	27.3	26.8	26.4	26.3	27.3	27.7	29.3	29.7	30.5
2007	26.5	26.4	26.5	26.7	26.6	27.4	27.9	29.7	29.8	30.5
2008	26.7	26.9	26.9	26.4	26.7	27.3	28.1	29.8	29.8	30.2
2009	26.6	26.7	27.3	26.3	26.6	27.3	28.6	30.7	30.3	30.2
2010	27.4	27.8	27.7	26.8	27.3	27.8	28.8	31.1	30.6	31.1
2011	27.9	28.5	28.3	27.0	27.4	28.0	28.3	30.1	30.2	30.7
2012	27.9	28.5	27.9	27.1	27.4	28.4	28.4	30.6	30.9	30.4
2013	29.6	29.7	29.1	28.5	28.7	30.2	30.7	32.0	32.8	32.7
2014	30.0	29.3	28.4	27.6	28.8	29.5	29.8	32.9	33.0	32.6
2015	30.3	29.4	28.9	27.3	28.7	30.1	30.6	33.1	34.2	33.0

1. Data source: VALACTA Dairy Services/CanWest DHI.

length by the regional average calving interval and subtracting the number of cows that are culled annually due to reproductive failure.

Ration Digestible Energy

Digestible energy (DE) values determined by Christensen et al. (1977) for forages grown on the Prairies were used to estimate DE for Alberta, Saskatchewan and Manitoba. U.S. National Research Council values (NRC 2001) were used to estimate the DE for British Columbia and the eastern provinces. Due to limited information regarding other feed ingredients, total mixed rations for cattle were assumed to be mainly forage and grain. Overall, DE ranged from 60 to 70% depending on rations and feeding regimes. It was also assumed that lactating cows on pasture were supplemented with grain to maintain high lactation rates; therefore, DE values were assumed to be similar to those of rations fed in confinement (Boadi et al. 2004a).

Table A3–29 Typical Characteristics of Beef Production in Canada in 2001[1] from Various Sources

Animal Category/Parameters	Production Characteristics[2]	Data Sources[3]
Beef Cows		
Average weight, kg	603 (36)	Kopp et al. (2004)
Mature weight, kg	619 (52)	AAFRD (2001)
Milk, kg/day	7.3 (1.2)	Kopp et al. (2004)
Milk fat, %	3.6 (0.6)	Kopp et al. (2004)
Conception rate, %	93.7 (1.3)	Manitoba Agriculture and Food (2000); AAFRD (2001)
Replacement Heifers		
Average weight, kg	478 (34)	
Mature weight, kg	620 (51)	
Daily weight gain, kg/day	0.64 (0.14)	
Replacement rate, %	14.4 (3.1)	Manitoba Agriculture and Food (2000)
Bulls		
Yearling weight, kg	541 (18)	
Average weight, kg	940 (98)	
Mature weight, kg	951 (112)	
Daily weight gain, kg/day	1.0 (0.17)	
Calves (including Dairy Calves)		
Birth weight, kg	40 (3)	AAFRD (2001)
Wean weight, kg	258.4 (19.1)	Small and McCaughey (1999)
Age at weaning, days	215 (15)	
Daily Weight Gain, kg/day		
- Replacement heifers	0.67 (0.13)	Kopp et al. (2004)
- Backgrounder	0.98 (0.17)	
- Finisher	1.37 (0.12)	
Calf crop, %	95 (2.3)	
Heifer and Steer Stockers		
Average weight, kg	411 (47)	Kopp et al. (2004)
Mature weight, kg	620 (51)	
Daily weight gain, kg/day	0.98 (0.16)	
Proportion to feedlot, %	65 (30)	
Feedlot Animals		
Average weight, kg		
- Direct finish	540 (25)	
- Background finish	562 (64)	
Mature weight, kg	630 (46)	
Finish weight, kg	609 (28)	
Daily weight gain, kg/day	1.37 (0.12)	

Notes:
1. Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian beef production, as reported in the CRF.
2. The numbers in parentheses are the standard deviations.
3. Values with no reference were obtained from expert consultations compiled in Boadi et al. (2004b).

A3.4.1.2. Non-Dairy Cattle

Production Practices and Performance

Production practices for non-dairy cattle also vary across the country due to climate, land prices and differences in traditional farming practices. The study conducted by Boadi et al. (2004a) characterized the predominant practices in 2001 for each province, according to animal type, physiological status, age, gender, growth rate, activity level and production environment. The values presented in Table A3–29 provide examples of production performance data collected for Canadian beef cattle, originally used as a QA verification of the data incorporated in the Tier 2 model.

Trends in carcass weights are used as an indicator of changes in mature weight from the 2001 benchmark values established by Boadi et al. (2004a) for the specific animal subcategories presented in Table A3–29. Carcass weight data are collected by the Canadian Beef Grading Agency (CBGA) and published by Agriculture and Agri-Food Canada (AAFC 1990–2014). Carcass weights increased from 1990 to 2003 for beef cows, heifers

Figure A3–5 Non-Dairy Cattle Carcass Weight, Based on Data Collected by CBGA and Published by Agriculture and Agri-Food Canada

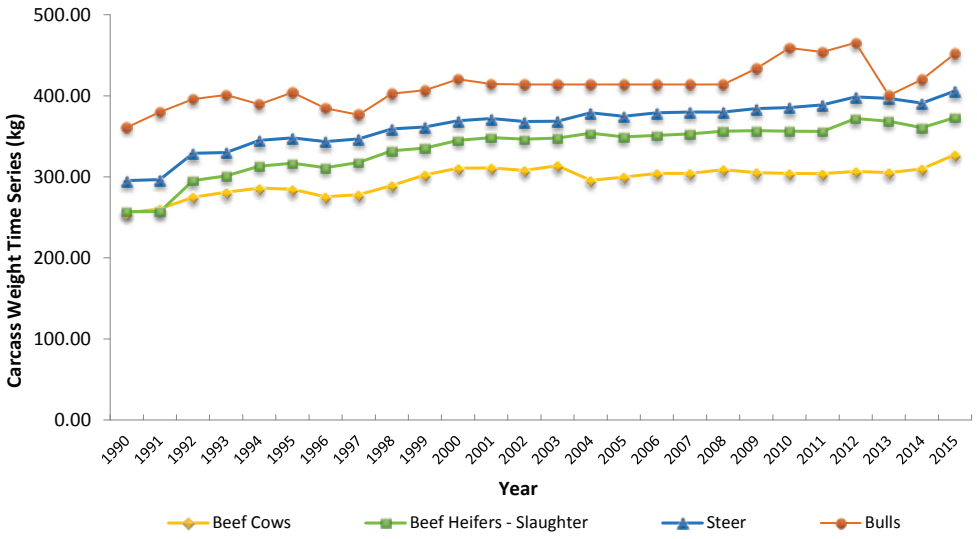


Table A3–30 Carcass Weights Used as an Indicator of Live Body Weight Change Over Time for Non-Dairy Cattle

Cattle Subcategory	Trend in Live Weight Applied
Beef cows	Trends in beef cow carcass weight used as an indicator of live weight.
Heifers for slaughter	Trends in heifer carcass weight used as an indicator of live weight.
Beef heifers	Trends in beef cow carcass weight used as an indicator of live weight.
Steers	Trends in steer carcass weight used as an indicator of live weight.
Bulls	Trends in bull carcass weight used as an indicator of live weight from 1990 to 2002; 2003 to 2008 live weights are set constant to the 2002 live weight; 2009–2015 uses carcass weight trend again.
Calves	No change
Dairy heifers[1]	No change

Note:
1. As dairy cows' live weight did not increase over time, it was assumed that dairy heifers did not increase either.

for slaughter, steers and bulls (Figure A3–5). Since 2003, beef cow carcass weights have remained more or less stable, but slaughter animal weights have continued to increase until recently when weights have stabilized. In 2003, the Canadian beef cattle industry was affected by bovine spongiform encephalopathy (BSE) disease, which shut down beef exports to the United States. After 2003, the slaughtered carcass weight of bulls had evidently increased due to the culling of older bulls. To provide an estimate more representative of the on-farm herd, the average live weights of bulls were retained at their 2002 value. From 2009 to 2015, the slaughter weight of bulls was, once again, used in the time series. Bull weights were observed to decrease considerably in 2013. This observation was verified; in general bull weights are prone to higher variability due to the low numbers being slaughtered on an annual basis.

Duration of Time in a Production Environment

Replacement heifers over 15 months of age are assumed to be bred or pregnant. All replacement stock (breeding bulls, young and replacement heifers over 12 months of age) is assumed to enter the breeding herd (mature breeding bulls and beef cows) at 24 months of age. Slaughter heifers and steers at 12 months of age are either in feedlots or are backgrounded. Animals scheduled for slaughter may be either identified as short- or long-keeps: short-keeps go directly to the feedlot to be slaughtered after 3 to 4 months, whereas long-keeps are typically backgrounded for 6 months before being sent to feedlots, where they are finished after 2 to 4 months.

Ration Digestible Energy (DE)

Forage DE values determined by Christensen et al. (1977) for forages grown on the Prairies were used to estimate DE for Saskatchewan and Manitoba. Values from Alberta Agriculture, Food and Rural Development (AAFRD) and the University of Alberta (2003) were used for Alberta, whereas NRC (2001) values were used to estimate the DE of rations for British Columbia and the eastern provinces. Overall, DE ranged from 60 to 84%, depending on rations and feeding regimes.

Calves were assumed to have a non-functional rumen or to consume very small amounts of dry feed from birth until two or three months of age. Therefore, enteric CH_4 emissions in these first few months are assumed to be zero.

A3.4.2. CH_4 Emissions from Enteric Fermentation

The release of CH_4 from enteric fermentation from all categories of livestock in Canada is calculated using Equation A3–17. CH_4 emissions from enteric fermentation for cattle are estimated using the country-specific emission factors derived from IPCC (2006) Tier 2 equations (Table A3–31). For the other animal categories, the IPCC Tier 1 methodology and default emission factors are applied (see Annex 6).

Equation A3–17:

$$CH_{4EF} = \sum_{T} \left(N_T \times EF_{(EF)T} \right)$$

where:

CH_{4EF}	=	CH_4 emissions from enteric fermentation for all animal categories
N_T	=	animal population for the T^{th} animal category or subcategory in each province
$EF_{(EF)T}$	=	emission factor for the T^{th} animal category or subcategory (Table A3–31 for cattle; for other animal categories, see Annex 6)

A3.4.2.1. Enteric CH_4 Emission Factors for Cattle

Emission factors were derived at the provincial level using IPCC (2006) Tier 2 equations for different subcategories of cattle (dairy cows, dairy heifers,

beef cows, beef heifers, bulls, calves, heifer replacement, heifers > 1 year and steers > 1 year) based on stages of production. Tier 2 enteric fermentation estimates require an approximation of gross energy consumed (GE) calculated according to Equation A3–18.

Equation A3–18:

$$GE = \left[\left[\frac{(NE_m + NE_a + NE_l + NE_p)}{(REM)}\right] + \left[\frac{NE_g}{(REG)}\right]\right] / \left[\frac{DE}{100}\right]$$

where:

GE	=	gross energy, MJ/day
NE_m	=	net energy required for maintenance, MJ/day
NE_a	=	net energy required for activity, MJ/day
NE_l	=	net energy required for lactation, MJ/day
NE_p	=	net energy required for pregnancy, MJ/day
REM	=	ratio of net energy available in a diet for maintenance to digestible energy consumed
NE_g	=	net energy required for growth, MJ/day
REG	=	ratio of net energy available in a diet for growth to digestible energy consumed
DE	=	digestible energy of the ration, %

All net energy estimates are applied according to equations in the 2006 IPCC *Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). Due to the Canadian climate, Equation 10.2 from the guidelines (Equation A3–19) was implemented for non-dairy cattle.

Equation A3–19:

$$Cf_i\ (in\ cold\ ) = Cf_i + 0.0048\ \times (20 - \ ^\circ C)$$

where:

Cfi	=	A coefficient that varies for each animal category relating weight to energy requirements for body maintenance, MJ/day/kg
°C	=	Mean daily temperature during the winter season

The cold-adjusted Cfi was derived by using the average temperature for the period October to April for each Canadian province, weighted based on the geographic location of non-dairy cattle (distributed at the ecodistrict scale) in the province. The cold adjusted Cfi was then corrected based on the percentage of animals kept in barns for different provinces, taken from Sheppard and Bittman (2012), and was applied to all production stages that occur during the winter months. Production stages that occur in both winter and summer, specifically finishing stages for steers and slaughter heifers, were averages of the default Cfi and the cold-adjusted Cfi. As a result of this implementation, considering the different production stages of the animal, average annual Cfi values varied between 0.43 for non-dairy cows in Manitoba the coldest province, to 0.37 for non-dairy cows in Ontario and some of the Maritime provinces. Based on a weighting of production stages, the Cfi would typically be 0.35, not considering the temperature effect. The lower Cfi in eastern Canada is due mainly to milder temperatures, but also to the practice of keeping animals in barns over winter, whereas in western Canada, cattle are mainly kept outdoors. As a result, the impact of cold on the net energy of maintenance is largely observed in western Canada.

Different stages of production require different consumption patterns to supply the necessary energy for specific animal products and environmental conditions, and therefore have different GE values. For example, dairy cattle emissions were estimated for two production categories: dry cows and lactating cows. Lactating cattle require high consumption rates (GE) for milk production. Dry cattle may also be confined or on pasture, which also modifies their required energy intake.

The total duration of time an animal spends in a production stage can also be variable; a weighted average emission factor was therefore calculated. Criteria used in the weighting included duration of time spent in each production stage and relative percentage of the population in each stage of production. Furthermore, some net energy calculations may be modified based on a factor that takes into account the time that the energy is

Table A3–31 CH_4 Emission Factors for Enteric Fermentation for Cattle from 1990 to 2015

	$EF_{(EF)T}$ - (kg CH_4/head/year)[1]							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[2]	Steers[2]	Calves
1990	129.6	78.2	107.9	105.9	82.5	44.6	41.4	43.8
1995	134.9	78.1	117.1	112.1	85.9	48.8	43.5	43.8
2000	143.3	78.3	120.9	117.5	89.4	53.0	47.8	43.8
2005	144.8	78.4	119.8	114.4	87.0	52.8	46.0	43.6
2006	146.1	78.3	119.8	115.2	87.5	52.9	46.7	43.6
2007	146.5	78.4	119.9	115.2	87.6	53.0	47.0	43.6
2008	147.0	78.4	119.8	116.2	88.4	53.0	46.7	43.6
2009	147.4	78.4	123.5	115.4	87.9	52.9	47.0	43.7
2010	148.9	78.4	128.4	115.2	87.7	52.8	47.0	43.6
2011	149.4	78.4	127.5	115.0	87.5	52.7	47.4	43.7
2012	150.0	78.4	129.7	115.5	87.6	53.5	47.9	43.7
2013	155.1	78.4	117.0	115.3	87.3	53.5	48.1	43.7
2014	155.1	78.4	120.9	116.2	87.9	53.1	47.9	43.7
2015	156.3	78.4	127.2	119.9	90.4	53.5	48.5	43.7

Notes:

1. Enteric emission factors are derived from Boadi et al. (2004b), modified to take into account trends in milk production in dairy cattle and carcass weights for several beef cattle categories.
2. Reported as kg/hd/yr; however, emissions are calculated based on time to slaughter.

supplied within a production stage. For each province, an emission factor (EF(EF)) is calculated according to Equation A3–20. Provincial emission factors were weighted on the basis of the proportion of the provincial animal population relative to the national population to calculate a national emission factor for each subcategory, for each year in the time series (Table A3–31).

Equation A3–20:

$$EF_{(EF)T} = \sum_{T} GE_T \times TP_T \times Y_{mT}$$

where:

$EF_{(EF)T}$	=	annual emission factor for defined animal population T, kg/head/year
GE_T	=	gross energy, MJ/day within the defined population T, kg/day
TP_T	=	time (days/year) of a stage of production with defined population T
Y_{mT}	=	methane conversion rate at which the fraction of gross energy is converted to methane by an animal within defined population T, m^3/kg

A3.4.2.2. Verification of Parameter Selection Against Canadian Research

In 2011, an internal Tier 2 quality assurance / quality control (QA/QC) was carried out on the enteric fermentation source category (MacDonald and Liang 2011). In this analysis, a review and compilation of Canadian literature related to methane production from enteric fermentation was carried out. These results were now evaluated in light of the implementation of the 2006 IPCC Guidelines.

Research measuring enteric fermentation in Canada indicates that the average measured methane conversion rates (Y_m), are 6.6% (±2.4) of gross energy (GE) for non-dairy cattle outside of feedlots, 3.2% (±1.9) GE on feedlots and 6.2% (±2.4) for dairy cattle (McCaughey et al. 1997, 1999; Boadi and Wittenberg 2002; Boadi et al. 2002, 2004b; McGinn et al. 2004, 2008, 2009; Beauchemin and McGinn 2005, 2006; Chaves et al. 2006; Kebreab et al. 2006; Ominski et al. 2006; Odongo et al. 2007; Eugène et al. 2008;

Van Haarlem et al. 2008; Beauchemin et al. 2009; Ellis et al. 2010). These values tend to agree with the values published in the 2006 IPCC Guidelines. From the same compilation of research, the emission factor for non-dairy cattle is observed to be 57 (±22) kg CH_4/head/year outside of feedlots and 56 (±24) kg CH_4/head/year in feedlots, and the average measured dairy cattle emission factor is 130 (±34) kg CH_4/head/year.

Caution must be used in interpreting these values, as this data set did not include animals in cold conditions and because the majority of studies focus on yearling heifers and steers. Also, the average value does not take into account the relative importance of different cattle subcategories to the average emission factor. Nonetheless, the emission factor values do agree, in general, with the emission factors used by Canada for non-dairy cattle i.e., 60 to 70 kg CH_4/head/year. However, dairy emission factors calculated using the 2006 IPCC Guidelines tend to be higher, ranging from 130 to 155 kg CH_4/head/year. A recent publication by Jayasundara and Wagner-Riddle (2014) suggests that Ym factors for Canadian dairy cattle may be as low as 5.6% and vary over time. In the current Canadian cattle model, a fixed Y_m is used specifically 6.5% GE for dairy cattle and non-dairy cattle that are not on a finishing ration and 3% GE for non-dairy cattle in feedlots receiving a finishing ration.

As it currently stands, no evident bias could be identified from the review of Canadian literature results. It appears that a bias that is introduced through the use of the Y_m values from the 2006 IPCC Guidelines is compensated for by the estimate of GE for specific animal subcategories. Improvements to the cattle emission model require the development of direct links between the Y_m and animal production, including nutrition, creating consistency with the estimated GE and emission factors. This appears to be the case, in particular for dairy cattle, to ensure that emission factors are not overestimated.

Researchers from Canada have participated in some extensive reviews and validations of the IPCC Tier 2 enteric fermentation model comparing measured and observed emissions using Canadian data. In general, model analysis indicates that the IPCC Tier 2 model tends to underestimate high-emitting animals and overestimate low-emitting animals (Ellis et al. 2007, 2009, 2010).

This literature analysis suggests that it would be difficult to improve Canadian estimates by updates of single parameters. Improving on the current model would require the development and introduction of a country-specific Tier 3 calculation methodology.

A3.4.2.3. Enteric CH_4 Emission Factors for Non-Cattle

For non-cattle animal categories, IPCC Tier 1 emission factors are used to calculate emissions (see Annex 6). When default emission factors are not available for the minor livestock categories, logical proxies are used to estimate emissions; swine emission factors are used for wild boars, and sheep emission factors are used for llamas and alpacas. These proxies are based on species similarities as well as similarities in production practices.

A3.4.2.4. Uncertainty

A comprehensive uncertainty analysis was carried out on all methodologies used in the calculation of methane from livestock for 2010. Uncertainty ranges (percentages) of means were rerun for the 2014 NIR submission and have not been rerun since that submission. In the analysis, a stochastic reproduction of the livestock CH_4 emission model was built in Mathematica© and a Monte Carlo simulation (MCS) was run according to the methodology proposed in the IPCC Good Practice Guidance (IPCC 2000). This analysis built on a recent study (Karimi-Zindashty et al. 2012). However, the

Environment Canada stochastic model (ECSM) built in Mathematica©: (i) applied the exact parameters and equations used in the Canadian inventory methodology based on the Good Practice Guidance (IPCC 2000); (ii) included uncertainty associated with populations and duration of production stages, which impact subcategory emission factors (Table A3–31); and (iii) used the provincial distribution of manure management systems with improved estimates of probability distributions (Table A3–31). The ECSM was run for the years 1990, 2005, 2010 and 2012. A trend analysis was carried out to establish the uncertainty in the estimate of the differences in emissions from 1990 to 2012. The relative uncertainties from the previous analysis were applied to the current year's values.

Currently, the data required to create probability distributions of the coefficients used in the agricultural IPCC Tier 2 models simply do not exist. Some of the default coefficients in Tier 2 equations are provided with an uncertainty range, often estimated by expert opinion; for other coefficients, ranges are taken from a few studies, often using methodologies that are not easily comparable. In general, the analysis of Rypdal and Winiwarter (2001) applies to the agricultural emission model as a whole, and it can be understood that large probability distributions are associated with default Tier 2 coefficients due to a lack of appropriate measurements and subsequent generalizations, uncertainties in measurements, and an inadequate understanding of emission processes. This initial uncertainty analysis has applied a precautionary principle, and for coefficients with very little information, uncertainty bounds were conservative.

Uncertainties in populations of major animal categories, i.e. cattle, swine and sheep, were supplied directly from Statistics Canada based on biannual and quarterly survey statistics. For small provinces with few animals in certain categories, sample variance is large, indicated by uncertain values of >±50%. However, because the data were collected based on a sampling design proportional to population distributions, the overall uncertainty for major animal categories at the national level was low. National non-dairy cattle populations have the lowest uncertainty (±1.8% of the mean), with slightly higher uncertainty for swine (±2.6% of the mean), dairy cattle (±5.4% of the mean) and sheep (±6.0% of the mean).

All other animal population estimates are renewed only through the *Census of Agriculture*. To account for the increase in uncertainty due to the time that has elapsed since the census, a function was developed that increased uncertainty as a function of time from the census. A linear regression was run through census year population estimates from 1991, 1996, 2001, 2006 and 2011. The uncertainties for populations in 2012 were estimated as the agricultural census uncertainty at the provincial level plus the 95% confidence interval for the linear regression multiplied by the number of years since the last census (one year). Due to the recent *Census of Agriculture*, the other animals tended to have lower population uncertainties in the 2012 analysis than the 2010–2011 uncertainties, similar to those animals for which population estimates are taken from biannual and quarterly surveys, though this had little impact on total uncertainty. The national population uncertainties for other animal categories ranged from ±2% of the mean for poultry to ±4% of the mean for bison; however, these animal categories contribute little to total emissions.

The parameters used in the calculation of Tier 2 emission factors for cattle can be divided into two categories: (i) those associated with cattle production and performance (see Section A3.4.2 for detailed descriptions of parameters); and (ii) those that are specific to the IPCC Tier 2 equations (see Section A3.4.2 for details). For the most part, the uncertainty assigned to parameters associated with cattle production and performance is relatively low, as these estimates are collected on a provincial basis, from provincial experts, and are values that are generally known within the industry. The largest source of uncertainty in production practices is the duration and fraction of

animal populations in specific production stages. This source of uncertainty is associated with the number of animals that are backgrounded and the duration of that backgrounding period. These are parameters that are highly dependent on prices and import/export markets, and therefore confidence in the values that are currently being used is low. A high level of uncertainty (30%) was applied to the number of animals backgrounded, and a non symmetrical triangular distribution was applied to the duration of backgrounding as a precautionary approach to account for high levels of potential variability in these production practices. The uncertainty in production population fraction and the duration of production stages was not accounted for directly in Karimi-Zindashty et al. (2012).

The uncertainties for parameters used in IPCC Tier 2 equations were taken, for the most part, directly from Karimi-Zindashty et al. (2012), who took the probability distributions either from Monni et al. (2007) or from the 2006 IPCC Guidelines. Two differences are notable: (i) digestible energy probability distributions became available from data supplied by Valacta Dairy Services after the Karimi-Zindashty et al. (2012) study was completed, allowing the calculation of typical distributions of different types of feed; and (ii) Karimi-Zindashty et al. (2012) used the 2006 IPCC methodology and therefore did not include the effects of weight loss on gross energy. A uniform distribution was therefore incorporated in the ECSM analysis to account for the impact of incorporating an estimate of net energy mobilized through weight loss during lactation (NE_{mob}) that varied according to duration of weight loss between 0 and 20% of the lactation period. As this parameter has been removed from the 2006 IPCC Guidelines, this approach was an effective way to evaluate the overall impact of this parameter.

A trend analysis was carried out using the ECSM in which the uncertainty in the magnitude of the change in emissions over time was calculated. For the long-term trend, emissions for 1990 and 2012 were calculated simultaneously, allowing only time dependent parameters to vary independently in the estimates. These parameters represent the elements of the calculation model that change over time, and therefore an estimate is available for a value in 1990 and in 2012 (noted by a superscript 7 in Table A3–32). The parameters in 1990 and 2012 are considered to be entirely independent and, as a consequence, for each calculation in the Monte Carlo simulation, a value was selected from the probability distribution for 1990 and 2012 independently. In contrast, other parameters used a value selected once from their probability distribution for the calculation of emissions in both 1990 and 2012. The parameters that were allowed to vary independently for the enteric fermentation analysis were animal populations, milk production and fat content in dairy cattle, and body weights in cattle. The relative uncertainty values for the trend analysis were applied to the 2013 results.

The summary results of the uncertainty analysis for emissions from enteric fermentation are reported in Chapter 5, Section 6.2.3. Briefly, the fixed range used in calculating uncertainty ranges for enteric fermentation emissions is 39% (-17% to +22% of the mean) (see Chapter 5). Most uncertainty in the estimate is associated with the Tier 2 emission factors for cattle; they lie within an uncertainty range of 19% to +22% of the mean non-dairy emission factor and -16% and +21% of the mean dairy cattle emission factor. In the case of other animals that use Tier 1 IPCC (2006) default emission factors, uncertainty ranges of ±50% were assigned, with the exception of swine, which was ±37% based on Monni et al. (2007). Relative to cattle, the Tier 1 emission factors for other animals have little impact on the total uncertainty because of the small contribution of other animal categories to total enteric fermentation emissions. Mean emissions for both dairy cattle and non-dairy cattle estimated using the stochastic model are slightly higher than calculated in the inventory database (roughly 2%). This difference is likely due to the introduction of the non-symmetrical triangular distribution that increased the length of backgrounding for slaughter heifers and steers and to

the uniform distribution of the factor that defines energy released from weight loss during lactation in dairy cattle.

The overall uncertainty for each estimate of each individual year changes little over time. The uncertainty range for emissions in 1990 and 2012 is 39~40%. Based on the trend analysis, over the long term, emissions of methane increased between the 1990 base year and 2012 by 9 to 19%, with a most likely value (MLV) of 15% (trend uncertainty 10%). Most of the increase in emissions is associated with enteric fermentation, which increased by 11 to 22% with an MLV of 16%. To estimate the trend uncertainty reported in Chapter 5, the relative trend uncertainties from the previous analysis were applied to the current year's mean change in emissions. In general, this uncertainty analysis was consistent with other agricultural estimates of uncertainty. The paper by Monni et al. (2007) is, to our knowledge, currently the only one detailing agricultural CH_4 emission uncertainty with the use of IPCC Tier 2 methodology. The use of comparable probability distributions for IPCC Tier 2 default parameters provides comparability among the two different national emission estimation methodologies. Monni et al. (2007) estimated the national-scale uncertainty for Finnish agriculture enteric fermentation of different cattle subcategories as ranging from -22 to +29% of the mean to -29 to +39% of the mean. Rypdal and Winiwarter (2001) reported uncertainties for some European countries ranging from ±20% of the mean in the United Kingdom to ±50% of the mean in Austria, but they used mainly Tier 1 estimation methodologies. We did not find comparable publications for trend uncertainty analysis in the field of agriculture.

The results for this uncertainty analysis were, of course, very similar to those produced by Karimi-Zindashty et al. (2012), who also observed an overall uncertainty range for enteric fermentation of 39%, indicating that the uncertainty associated with the production stage duration and population fractions had little impact on the overall uncertainty. The incorporation of the uncertainty associated with weight loss during lactation did not increase overall uncertainty, but tended to skew the uncertainty distribution for dairy estimates towards higher emission estimates. The sensitivity analysis carried out by Karimi-Zindashty et al. (2012) indicated that the large majority of uncertainty in emission estimates associated with the default IPCC Tier 2 parameters, in particular the methane conversion rate (Y_m) and the factor associated with the net energy of maintenance (C_{fi}) applied at the national scale. Uncertainty in the Tier 2 methodology may be reduced through the development of country specific parameters at the regional scale for different animal categories.

A3.4.3. CH_4 Emissions from Manure Management

The IPCC Tier 2 methodology is used to estimate CH_4 emission factors from manure management systems (IPCC 2006). Equation A3–21 is used to calculate CH_4 emissions from manure management for all categories of livestock in Canada with the exception of deer and elk, rabbits, mules and asses, and fur-bearing animals, which were calculated based on IPCC defaults. Wild boar emission factors were calculated based on average swine Tier 2 parameters, but assuming only solid manure. Sources of animal population data are the same as those used in the enteric fermentation estimates and are listed in Table A3–25.

Equation A3–21:

$$CH_{4MM} = \sum_{T} \left(N_T \times EF_{(MM)T} \right)$$

where:

CH_{4MM}	=	emissions for all animal categories
N_T	=	animal population for the T^{th} animal category or subcategory in each province
$EF_{(MM)T}$	=	emission factor for the T^{th} animal category or subcategory calculated according to Equation A3–22

To develop Tier 2 CH_4 emission factors from manure management, country-specific inputs were required that take into account climate, livestock rations and the type of manure storage system included in Equation A3–22. The following equation represents an IPCC Tier 2 estimate of CH_4 emission factors from manure management systems:

Equation A3–22:

$$EF_{(MM)T} = VS_T \times 365\ BO_T \times 0.67\ kg/m^3 \times \sum_{ij} MCF_{ij} \times AWMS_{Tij}$$

where:

$EF_{(MM)T}$	=	annual emission factor for defined animal population T, kg CH_4/head-year
VS_T	=	daily volatile solids excreted for an animal within the defined population T, kg/day
B_{0T}	=	maximum CH_4 producing potential for manure produced by an animal within defined population T, m^3/kg VS
MCF_{ij}	=	CH_4 conversion factor for each manure management system i in climate region j
$AWMS_{Tij}$	=	system distribution factor, defined as the fraction of animal category T's manure that is handled using manure system i in climate region j, often referred to in IPCC documents as management system (MS)
0.67	=	conversion factor of m^3 CH_4 to kilograms CH_4

The following sections outline the sources of input values for VS, DE, ASH, B_0, MCF and AWMS.

A3.4.3.1. Volatile Solids (VS)

Cattle (VS)

Volatile solids (VS) are the organic fraction of total solids in manure. The VS of manure was estimated using the digestible energy (DE) of dietary intake, manure ash content and gross energy (GE) consumed by a given animal subcategory, and the urinary energy (UE) fraction of the gross energy intake, according to the 2006 IPCC Guidelines.

For cattle subcategories, the GE depends on the cattle production model defined for enteric fermentation (Boadi et al. 2004a), as shown in Equation A3–19. Estimates of VS were derived for each cattle subcategory at the provincial level based on regional and seasonal stages of production (Equation A3–23). Increases in milk production in dairy cattle and carcass weight in beef cattle have increased VS and, as a result, CH_4 emission factors over the time series.

Equation A3–23:

$$VS = \left[GE \times \left(1 - \frac{DE}{100}\right) + (UE \times GE)\right] \times \left(\frac{1\text{-}ASH}{18.45\ MJ}\right)$$

where:

VS	=	volatile solids excretion, kg/head/day
GE	=	gross energy consumed by a given animal, MJ/head/day
DE	=	digestible energy of the ration, %
UE	=	urinary energy
ASH	=	ash fraction of the manure, %

Non-Cattle (VS)

Volatile solids for animal categories other than cattle were calculated based on values in Marinier et al. (2004), using the IPCC 2006 Tier 2 approach and taking into account the variability in the values of DMI, DE and ASH derived from expert surveys. The values for DMI, DE and ASH taken from that survey were used to calculate VS for non-cattle livestock categories for each individual province (Equation A3–24). Confidence intervals were developed using a Monte Carlo simulation performed with Crystal Ball® (Decisioneering 2000), resulting in a probability distribution based on the variance in expert opinion and scientific literature (Table A3–34).

Equation A3–24:

$$VS = \left[DMI \times 18.45 \times \left(1 - \frac{DE}{100}\right) + (UE \times DMI \times 18.45)\right] \times \left(\frac{1 - ASH}{18.45\ MJ}\right)$$

where:

VS	=	volatile solids excretion, kg/head/day
DMI	=	dry matter intake, kg/head/day
DE	=	digestible energy of the ration, %
UE	=	urinary energy
ASH	=	ash content of the manure, %

Table A3–32 Uncertainties in Inputs, Sources of Uncertainty and the Spatial and Animal Category at Which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Enteric Fermentation

Parameter Category	Coefficient/ Parameter Source	Distribution Type	Uncertainty Range[1]	Uncertainty Distribution Estimate Source and Notes	Spatial Allocation/ Animal Category Allocation
Population Data[7]					
Cattle Biannual Surveys					
Dairy	Statistics Canada (Table 003-0032)	normal	±6% – ±42%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]	Provincial/subcategory
Non-dairy	Statistics Canada (Table 003-0032)	normal	±5% – ±73%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]	Provincial/subcategory
Other Survey-based Populations					
Swine	Statistics Canada (Tables 003-0004 and 003-0031)	normal	±8% – ±89%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]	Provincial/subcategory
Sheep	Statistics Canada (Tables 003-0004 and 003-0031)	normal	±14% – ±80%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]	Provincial/subcategory
Census of Agriculture					
Goats	Census of Agriculture (Statistics Canada 2012a)	normal	±9% – ±21%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	Provincial/subcategory
Poultry	Census of Agriculture (Statistics Canada 2012a)	normal	±5% – ±12%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	Provincial/subcategory
Bison	Census of Agriculture (Statistics Canada 2012a)	normal	±18% – ±85%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	Provincial/subcategory
Llamas and Alpacas	Census of Agriculture (Statistics Canada 2012a)	normal	±16% – ±42%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	Provincial/subcategory
Horses	Census of Agriculture (Statistics Canada 2012a)	normal	±5% – ±16%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	Provincial/subcategory
Cattle Production Parameters and Performance					
Milk production[7]	Valacta/Canwest DHI	normal	±8%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Fat content[7]	Valacta/Canwest DHI	normal	±8%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Dairy herd efficiency[7]	Valacta/Canwest DHI	normal	±8%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Pregnancy coefficient	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Average daily gain (ADG)	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Pregnancy period	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Production stage duration	Boadi et al. (2004b)	normal except slaughter animals, triangular, non-symetric	±5%, Slaughter animals: MLV[5] from Boadi et al. (2004b) LB: 12% of MLV: UB: 25% of MLV	Expert opinion, Boadi et al. (2004b) - for feeder heifers and steers, a triangular distribution was assumed based on interpretation of potential market effects (Canfax Research Services 2009)	Provincial/production stage subcategory, internal correlation[6]
Production stage population fraction	Boadi et al. (2004b)	normal	±5% – ±30%	Expert opinion, Boadi et al. (2004b)	Provincial/production stage subcategory, internal correlation[6]
Cattle Weight Estimates[7]					
Live weight, 2001	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/production stage subcategory
Mature weight, 2001	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/production stage subcategory
Carcass weight	CBGA[2] and published AAFC[3] (1990–2010)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	National/subcategory
Emissions Factors for Cattle (IPCC Tier 2 Equations)					
Methane conversion rate (Ym)		normal	Feedlot animals – ±30% Other animals – ±15%	Karimi-Zindashty et al. (2012) – IPCC (2006).	National/feedlot vs. non feedlot
Gross Energy for Cattle Calculation IPCC Tier 2 Equation A3–2					
Digestible energy (DE)	Boadi et al. (2004b)	normal	Pasture ±9% Confined ±9% Background ±7.5% Prepared feed ±5.5%	Derived from raw data supplied by Valacta Dairy Services.	Provincial/production stage subcategory

The following sections outline the data for estimating VS developed by Marinier et al. (2004).

Digestible Energy (DE) and Dry Matter Intake (DMI)

The sources of information used for DE for both dairy and non-dairy c attle are detailed in sections A3.4.1.1 and A3.4.1.2, respectively.

Broad regional differences in ration composition were identified for sheep, horses and swine. Regional differences were not considered for goats or poultry, since these data were not available.

Table A3–33 Mean Volatile Solids in Manure of Non-Cattle Animal Categories in 2015 and Associated 95% Confidence Interval, Expressed as a Percentage of the Mean

Animal Category	Mean Volatile Solids (kg/head/day)	95% Confidence Interval (%)
Sheep and Lambs[1]	0.61	31
Mature Horses	3.6	16
Swine	0.23	50
Goats	0.72	41
Bison	3.1	16
Wild Boars[2]	0.23	50
Poultry	0.02	20

Note:
1. Llamas and alpacas are given the same values as sheep, at the provincial level.
2. Wild Boars, equal to swine.

Generally, rations for grazing livestock consist of roughage and grains. Diet digestibility will vary, with grains having a higher digestibility than roughage. The distribution of grain-based and roughage-based diets was estimated for sheep and horses in each province. A weighted estimate of DE was calculated using the known approximate DE for grains and roughage for each animal type and the distribution of grain and roughage usage by province (Table A3–34). This method does not, however, account for additives that may increase or decrease digestibility. The DMI for non-cattle was determined through consultation with experts and published values (Table A3–35).

Manure Ash Content (ASH)

The ash content in the manure is the inorganic portion of the manure. Table A3–36 contains the values used in this inventory for ash content in volatile solid calculations and their sources.

A3.4.3.2. Maximum CH_4 Producing Potential (B_0)

The B_0 is defined as the maximum volume of CH_4 that can be produced from 1 kg of VS loaded into a manure management system and is expressed

Table A3–34 Approximate Digestible Energy (DE) for Selected Livestock Subcategories and Data Sources

Animal Category	DE (%)	Data Sources
Goat	65	W. Whitmore, Manitoba Agriculture and Food
Laying Hen	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Chicken	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkey	78	S. Leeson, University of Guelph
Swine	87	C.F. deLange, University of Guelph
Feeding on Grain Diet		
Sheep	74	Weston (2002)
Horse	70	L. Warren, Colorado State University
Feeding on Roughage Diet		
Sheep	65	W. Whitmore, Manitoba Agriculture and Food
Horse	60	L. Warren, Colorado State University

Note:
1. Data sources: Expert consultations (Marinier et al. 2004).

Table A3–35 Dry Matter Intake for Selected Livestock

Animal Category	DMI (kg/head/day)	Data Sources[2]
Sheep and Lambs		
Ewes	1.2–2.8	NRC (1985)
Rams	2.1–3.0	W. Whitmore, Manitoba Agriculture and Food
Replacement Lambs	1.2–1.5	NRC (1985)
Market Lambs	1.3–1.6	NRC (1985)
Horses		
Mature Idle Horses	7.4–11	NRC (1989); L. Warren, Colorado State University
Mature Working Horses	7.4–13.7	NRC (1989); L. Warren, Colorado State University
Weanlings	3.6–6.3	NRC (1989)
Swine		
Starters (5–20 kg)	0.55–0.72	C. Wagner-Riddle, University of Guelph
Growers (20–60 kg)	1.4–2.1	J. Patience, Prairie Swine Centre
Finishers (60–110 kg)	2.1–3.3[1]	M. Nyachoti, University of Manitoba; C. Pomar, Agriculture and Agri-Food Canada
Sows	2.28	C. Wagner-Riddle, University of Guelph
Boars	2.0–2.5	M. Nyachoti, University of Manitoba; NRC (1998)
Goats		
Does	1.2–2.8	NRC (1981)
Bucks	1.4–2.3	CRAAQ (1999)
Kids	1.4	CRAAQ (1999)
Poultry		
Laying Hens	0.072–0.11	S. Leeson, University of Guelph; D. Korver, University of Alberta
Broilers	0.085–0.088	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkeys	0.023–0.53	Hybrid (2001)

Note:
1. Calculated as 3.5% of body weight.
2. Data sources: Expert consultations (Marinier et al. 2004).

as m^3/kg VS loaded. The values published in the 2006 IPCC Guidelines were used for all animals. For bison, non-dairy cattle values were used.

Table A3–36 Manure Ash Content for Selected Livestock and Data Sources

Animal Category	ASH (%)	Data Sources
Cattle	8	IPCC (2000)
Sheep	8	IPCC (2000)
Goat	8	IPCC (2000)
Horse	4	IPCC (2000)
Laying Hen	10	Marinier et al. (2004)
Chicken	7	Marinier et al. (2004)
Turkey	5	Marinier et al. (2004)
Swine	5	Marinier et al. (2004)
Wild Boar	5	(Taken from Swine)

A3.4.3.3. Methane Conversion Factor (MCF)

The MCF describes the proportion of B_0 that is attained, depending on the storage system and climate region. The values published in the 2006 IPCC Guidelines were used for all animals with the exception of poultry. For poultry on liquid manure management systems, an MCF that was consistent with all other livestock liquid manure management systems was used, as storage methods for liquid poultry manure in Canada do not differ significantly from storage systems used in dairy or swine production.

A3.4.3.4. Animal Waste Management System (AWMS) Distribution Factor

The AWMS factor is the proportional distribution of AWMS of a livestock category within a given area. There is little reliable published information on the distribution of manure management systems in Canada. A survey of experts in manure management and animal production was conducted in 2003–2004 as part of the Tier 2 study by Marinier et al. (2004). National averages of results are summarized in Table A3–37. Briefly, among the dominant animal production categories across the country, swine manure is mainly handled as liquid manure, while poultry manure is stored as solid manure. On average, dairy cattle manure storage is evenly distributed among solid and liquid forms, with roughly 20% being deposited on pasture. However, in certain provinces, the proportion of dairy manure handled as liquid can be as high as 89% (British Columbia) or as low as 20% (Manitoba and Prince Edward Island). Beef cattle manure is equally distributed between solid storage and deposition on pasture, with the exception of British Columbia and Manitoba, where the majority of manure is deposited on pasture.

No specific data were available for covered lagoons and biodigesters; they are assumed to be part of other systems.

A3.4.3.5. Cattle Manure Management CH_4 Emission Factors

Cattle emission factors developed to calculate CH_4 emissions from manure management vary by animal subcategory and over time (Table A3–37). As VS was calculated based on the GE derived from the enteric fermentation cattle production model, an emission factor time series was derived for cattle to reflect: (i) the increase in milk productivity of dairy cows; and (ii) the change in live weight of non-dairy cattle as explained in sections A3.4.1.1 and A3.4.1.2, respectively. Emission factors are highest from dairy cattle, reflecting their high rates of confinement, high proportions of liquid manure management systems and high

Table A3–37 Percentage of Manure Handled by Animal Waste Management Systems (AWMS) for Canada (per Animal Category, Based on the Distribution of Animal Populations in 2015)[1]

Animal Category	Liquid Systems (NL)	Solid Storage and Drylot (NSSD)	Pasture, Range and Paddock (NPRP)	Other Systems (NO)
Non-dairy Cattle	2.6	47	47	3.5
Dairy Cattle	43	40	17	0.1
Poultry	7.1	92	0.6	0.5
Sheep and Lamb	0.2	35	65	0.1
Llamas and Alpacas[2]	0.1	22	77	0.1
Swine	96	3	0	1
Goat	0	42	58	0
Horse	0	32	68	0.7
Bison	0.3	45	50	3.9
Deer and Elk[3]	0	47	50	3.5
Fur-bearing Animals[4]	0	100	0	0
Mules and Asses[5]	0	32	68	0.7
Wild Boars[4]	0	100	0	0

Notes:
1. Totals may not add up to 100% due to rounding.
2. Assumes that manure handled by AWMS is the same for llamas and alpacas as for sheep and lambs, at the provincial level.
3. Identical distributions to non-dairy cattle, except that liquid systems are distributed to pasture, range and paddock (PRP).
4. Assumed 100% solid manure.
5. Assumes that manure handled by AWMS is the same for mules and asses as for horses.

Table A3–38 Emission Factors to Estimate CH_4 Emissions from Manure Management for Cattle Subcategories from 1990 to 2015

	$EF_{(MM,T)}$ (kg CH_4/head/year)							
Year	Dairy Cows	Dairy Heifers[1]	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[2]	Steers[2]	Calves
1990	29	20	4.4	4.1	3.2	1.9	1.8	1.8
1995	30	20	4.7	4.3	3.2	2.0	1.9	1.8
2000	32	21	4.7	4.5	3.3	2.1	1.9	1.8
2005	33	21	4.6	4.3	3.1	2.1	1.9	1.8
2006	33	21	4.6	4.3	3.1	2.1	1.9	1.8
2007	33	21	4.6	4.3	3.1	2.1	1.9	1.8
2008	33	21	4.6	4.4	3.2	2.1	1.9	1.8
2009	33	21	4.7	4.4	3.2	2.1	2.0	1.8
2010	34	21	4.9	4.4	3.1	2.1	2.0	1.8
2011	34	21	4.9	4.4	3.1	2.1	2.0	1.8
2012	34	21	5.0	4.4	3.1	2.1	2.0	1.8
2013	35	21	4.5	4.4	3.1	2.1	2.0	1.8
2014	35	21	4.6	4.4	3.1	2.1	2.0	1.8
2015	36	21	4.9	4.5	3.2	2.1	2.0	1.8

Note:

1. For dairy heifers, emission factors were estimated using B_0, MCF and manure management systems for dairy cows.
2. Reported as kg/hd/yr; however, emissions are calculated based on time to slaughter.

dietary intake for sustained milk production. Beef cattle emission factors are lower, reflecting their lower rates of confinement, lower GE and the fact that the majority of manure is managed in a solid form with a low MCF.

A3.4.3.6. Non-Cattle Manure Management CH_4 Emission Factors

Manure management emission factors for non-cattle animals vary by animal subcategory but are constant over time (Table A3–39). For the largest non-cattle animal categories—swine, sheep and poultry—growth stages for animals are taken into account. The emission factor calculations use VS derived from Marinier et al. (2004). However, emission factors were recalculated to incorporate the latest scientific information available on B_0 and MCF taken from the 2006 IPCC Guidelines (IPCC 2006). The largest emission factors are from swine, varying from 1.8 to 7.9 kg CH_4/head/yr depending on growth stage, due to the high percentage of manure that is stored in liquid form. Emission factors for other minor categories tend to be low due to the large portion of manure that is either deposited on pasture, range or paddock or in solid form in pens and holding yards. When default emission factors or country-specific information sources are not available for the minor livestock categories, logical proxies are used to estimate emissions. Bison manure management emission factors are equal to the non-dairy emission factors for each individual province; horses are used as proxies for mules and asses, swine for wild boars, and sheep for llamas and alpacas. These proxies are based on species similarities as well as similarities in production practices.

A3.4.3.7. Verification of Parameter Selection Against Canadian Research

The Manure Management source category was a part of a Tier 2 QA/QC for the Agriculture Sector for the 2011 subm`ission (MacDonald and

Table A3–39 2015 CH_4 Emission Factors for Manure Management for Non-Cattle

Non-Cattle Animal Categories	Manure Management Emission Factors $EF_{(MM)}$ (kg CH_4/head/year)
Swine	
Boars	7.0
Sows	7.0
Pigs < 20 kg	2.1
Pigs 20–60 kg	4.4
Pigs > 60 kg	8.4
Other Livestock	
Sheep	0.33
Lambs	0.22
Goats	0.32
Horses	2.6
Bison	2.2
Elk and Deer	0.22
Wild Boars[1]	0.56
Foxes	0.68
Mink	0.68
Rabbits	0.08
Mules and Asses	0.76
Poultry	
Chickens	0.03
Hens	0.12
Turkeys	0.10

Note:
1. Emission factor based on swine VS, assuming 100% solid manure.

Liang 2011) including a review and compilation of Canadian literature related to methane production from manure storage.

Few studies have measured emissions from manure storage or quantified the characteristics of manure and manure storage strategies that influence emissions in Canada. Observed emission factors are highly variable, as are measurement techniques. The methodological variability makes comparison of specific parameters used in Tier 2 calculations extremely difficult. When the liquid storage MCF was estimated from in-situ measurements, it varies from greater than 100% (suggesting that B_0 is also underestimated) to as low as 14% in the case of swine and from 4% to 62% for dairy with no mitigation measures in place (Kaharabata et al. 1998; Massé et al. 2003, 2008; Wagner-Riddle et al. 2006; Laguë et al. 2005; Park et al. 2006, 2010; VanderZaag et al. 2009, 2010). Some studies exist in Canada on emissions from solid manures and other storage methods (composting) (Pattey et al. 2005; Xu et al. 2007; Hao 2007; Hao et al. 2001b, 2008, 2009, 2010a, 2010b). As was the case with liquid manure systems, variability in emissions and methodology make comparisons to IPCC parameters difficult.

A recent article with a small sample from eastern Canadian farms suggested that the B_0 values for swine, beef and dairy cattle were 0.47–0.42, 0.21–0.19 and 0.35–0.30, respectively (Godbout et al. 2010). The values for beef cattle and swine are consistent with IPCC default values, though dairy manure is the exception, with observed B_0 being 50% higher than the default value. As this was a single measurement, further analyses of B_0 are required for a wider range of regions and production practices.

Quantities of volatile solids stored in the manure management systems for different animal categories tend to be consistent with quantities estimated in inventory calculations. The variability observed in studies is therefore likely linked to a combination of differences in measurement methodology, variability in manure characteristics (B_0) and differences in a number of physical and biochemical factors for each experimental situation that are not taken into account in the IPCC Tier 2 model. These factors include temperature, manure composition, storage dimension, storage duration and storage cleaning procedures—all of which may influence emissions from manure storage (Pattey et al. 2005; Laguë et al. 2005; Park et al. 2006, 2010; Wagner-Riddle et al. 2006; Massé et al. 2008; VanderZaag et al. 2009, 2010). Furthermore, these factors are not controlled in research, making comparisons even more difficult. More standardized factorial research is required in order to understand the relative weight of factors that influence emissions from manure storage and to refine estimation methodology.

Table A3–40 Uncertainties in Inputs, Sources of Uncertainty and the Spatial and Animal Category at which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Manure Management.

Parameter Category	Parameter/ Animal Category or Subcategory	Distribution Type	Uncertainty Range[1]		Spatial Allocation/ Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[1]		
Volatile Solid Calculations (Equation A3–24 and Table A3–33)						
Dry Matter Intake (DMI)		Triangular				
-Swine						
	Boars		1.2–3.4	2.28	National/Subcategory	Marinier et al. (2004)
	Sows		2.0–2.5	2.25		
	Pigs < 20 kg		0.55–0.72	0.68		
	Pigs 20–60 kg		0.63–2.1	1.75		
	Pigs > 60 kg		2.1–3.3	2.7		
-Poultry						
	Laying hens		7.4–9.9	9.85	National/Subcategory	Marinier et al. (2004)
	Broilers		0.085–0.088	0.086		
	Turkeys		0.23–0.53	0.27		
-Other livestock						
	Sheep		1.2–3.0	2	National/Subcategory	Marinier et al. (2004)
	Lambs		1.2–1.6	1.35		
	Goats		1.4–2.3	1.75		
	Horses		7.4–9.9	9.85		
	Buffalo		6.8–10.1	8.43		
Ash		Triangular				
-Cattle			3.9–11	8	National/Category[2]	Marinier et al. (2004)
-Swine			3.9–11	4.8–5.1		
-Poultry						
	Laying hens		3.9–11	10	National/Category[2]	Marinier et al. (2004)
	Broilers		3.9–11	7		
	Turkeys		3.9–11	5		
-Other livestock						
	Sheep		3.9–11	8	National/Category[2]	Marinier et al. (2004)
	Lambs		3.9–11	8		
	Goats		3.9–11	8		
	Horses		3.9–11	4		
	Buffalo		3.9–11	8		
Digestible Energy (DE)		Normal				
-Cattle			Pasture ±9%/ Confined ±9%/ Background 7.5%/ Prepared feed ±5.5%		Provincial/Production subcategory	Derived from raw data supplied by Valacta Dairy Services
-Swine			±9%		Provincial/Category	
-Poultry						
	Laying hens		±5.5%		National/Subcategory	Derived from raw data supplied by Valacta Dairy Services
	Broilers					
	Turkeys					
-Other livestock						
	Sheep		±9%		Provincial/Category	Derived from raw data supplied by Valacta Dairy Services
	Lambs					
	Goats					
	Horses					
	Buffalo					
Emission Factor Calculation (Equation A3–23)						
Methane Conversion Factor (MCF)		Normal				
	All Animals		±45%		National	Karimi-Zindashty et al. (2012) – expert opinion
Maximum Methane Producing Potential (B_0)		Triangular				
	Dairy cattle		0.1–0.24	0.24	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
	Non-dairy cattle		0.19–0.33	0.19		
	Swine		0.32–0.48	0.48		
	Poultry		0.24–0.39	0.32		

Based on current research results, no specific bias can be determined in manure management results, as there is no clear standard for evaluating whether IPCC parameters are appropriate for estimating emissions from manure management systems.

A3.4.3.8. Uncertainty in Manure Management CH_4 Emissions

Methane emissions from manure management were included in the comprehensive uncertainty analysis discussed in Section A3.4.3.8. As was the case with enteric fermentation, the analysis built on the recent study by Karimi-Zindashty et al. (2012) and applied a precautionary principle such that for parameters with very little information, probability distributions were intentionally conservative (Table A3–40). Data on the probability distributions of the coefficients used in the agricultural manure management IPCC Tier 2 models are scarce, and expert opinions were the main source of probability distributions, particularly those compiled in the Marinier et al. (2004) report. As was the case with enteric fermentation, the relative uncertainty for the 2012 analysis was applied to the 2014 numbers.

Population uncertainty for major animal categories was identical to that discussed in Section A3.4.2.3, and the distributions used to define uncertainties can be found in Table A3–32.

The parameters used in the calculation of Tier 2 manure management emission factors for all animals can be divided into two categories: those associated with volatile solid calculation and those specific to the calculation of IPCC Tier 2 emission factors. The confidence intervals assigned to coefficients used in the calculation of volatile solids were relatively small compared to parameters used in the calculation of emission factors. With the exception of the ash content of manure, parameters tend to be under 10%, largely due to the fact that parameters such as DMI and DE are values with which producers are very familiar and which can provide some degree of confidence. In the case of cattle, volatile solids vary according to the gross energy (GE) of consumption and are subsequently similar in variability to the enteric fermentation emission factor (±19%).

The probability distributions for coefficients used in IPCC Tier 2 equations used to calculate the emission factors were taken, for the most part, directly from Karimi-Zindashty et al. (2012), who derived the distributions either from expert opinion within the Marinier et al. (2004) report or directly from the 2006 IPCC Guidelines. The uncertainty for B_0 was taken from Marinier et al. (2004), but no reliable source was available for the estimate of uncertainty around the MCF. In the current study, a large uncertainty range was used (±45% of the mean) based on expert opinions. However, the choice of this value simply indicates that our confidence in the MCF value is low. The actual value of the total uncertainty estimate for manure management must therefore be taken within the context that it is highly dependent on a value and a probability distribution function that is highly uncertain.

In contrast with the Karimi-Zindashty (2012) study, the current analysis was based on a provincial distribution of manure management systems, and uncertainty ranges were estimated from values observed in different provincial and national reports (Koroluk and Bourque 2003; BPR-Infrastructure 2008) and surveys (Sheppard et al. 2009, 2010, 2011; Sheppard and Bittman 2011). In the case of dairy cattle, the lower bound for liquid manure management systems was based on a comparison between reports that suggested that manure treated by liquid systems could vary by as much as 10% above or below the Marinier et al. (2005) estimate. Furthermore, it was reported that there has been a continual movement towards liquid manure systems over time. Therefore, the upper bound was set as 25% based on the rate of adoption of liquid systems from BPR-Infrastructure (2008) and the number of years that have passed since the Marinier et al. survey (2005). In the case

of swine, liquid manure management systems upper bounds were fixed at 100%. Other manure management systems' lower bounds for all animal types were 0, also tending to skew probability distributions. This approach resulted in non- symmetrical distributions for all manure management systems. While this approach increased the uncertainty of each individual manure management system, relative to the Karimi-Zindashty study, it likely reduced its impact on the national emission uncertainty because the manure systems were disaggregated to the provincial level, and the total manure management systems were held to 100% of total manure management systems.

The trend analysis carried out using the ECSM quantified the uncertainty in the magnitude of the change in emissions over time for manure management. As was the case for enteric fermentation, for the long-term trend, emissions for 1990 and 2013 were calculated simultaneously, allowing only time-dependent parameters to vary independently in the estimates. More detailed description of the trend analysis is found in Section A3.4.2.4. The parameters that were allowed to vary independently for the manure management trend analysis were animal populations, milk production and fat content in dairy cattle, body weights in cattle, and AWMS (noted by a superscript 7 in Table A3–32 and superscript 5 in Table A3–40). Before 2004, lower boundaries for liquid AWMS were calculated based on the rate of adoption of liquid systems and the number of years that have passed since the Marinier et al. survey (2005), as in the case of upper boundaries. This approach resulted in non symmetrical distributions for all manure management systems, and for the trend analysis it also modified the symmetry of probability distributions around liquid systems between the base year and the current year. Trend uncertainty for the 2016 inventory was based on the 2012 trend analysis.

The summary of results of the uncertainty analysis on emissions from manure management is reported in Chapter 5. Briefly, the uncertainty range used to derive the uncertainty reported in Chapter 5 for the 2014 emissions from manure management is 60% (-32% to +27% of the mean). As was the case with enteric fermentation, emission factors account for the majority of uncertainty. Emission factors lie within an uncertainty range of -34% to +62% for non-dairy cattle and a range of -60% to +50% for dairy cattle. The emission factors for swine, the largest single contributor to manure management emissions, lie within an uncertainty range of -51% to +43%. All other animals contribute little to the emission totals, i.e. 0.19 Mt CO_2 eq within an uncertainty range of 0.13 (-35 % of the mean) to 0.23 (+15% of the mean). Overall, as was the case with enteric fermentation, mean emissions for both dairy cattle and non dairy cattle estimated using the stochastic model are slightly higher than those calculated from non-stochastic models and tend to be slightly skewed towards the lower boundary, indicating a tendency towards higher emissions. However, mean emissions from swine and other animals estimated using the stochastic model are slightly lower than emissions estimates, and the distribution of emission estimates tends to be slightly skewed towards the upper boundary, indicating a tendency towards lower emissions. This skewed distribution is evident when looking at the range of uncertainty around the emission factors (e.g. 34% to +62% for non-dairy cattle). The asymmetry of the uncertainty range is likely due to a combination of the skewed probability distributions for manure management systems and the same factors that influenced the distribution of enteric fermentation emission estimates for cattle, specifically the skewed distributions for backgrounding of slaughter animals and the uniform distribution used for net energy mobilized from weight loss during lactation in dairy cattle.

Based on the trend analysis, there has been no detectable increase in emissions from manure management since 1990, where change from 1990 could range from a decrease of 10% to an increase of 8%, though it is most likely that there

has been an increase in emissions of roughly 5.5%. The assumption that liquid manure storage and other manure storages have increased over time affects the trend. For example, for dairy cattle in Ontario in 1990, the triangular distribution used around the percentage of manure treated in liquid manure management systems had a lower boundary of 16%, a most likely value of 40% and an upper boundary of 42%; in 2010, the lower boundary was 37%, the most likely value also 40%, and the upper boundary 59%. The use of a skewed distribution indicating a higher probability that fewer animals were raised on liquid manure management systems in the past balances the increase in animal populations. As a result, it is improbable overall that there is an increase in manure management emissions over time, particularly from cattle.

The uncertainty range of the analysis carried out in 2012 was slightly smaller than that of the previous analysis (2%), likely due to a combination of lower uncertainty for census animal populations and modifications in the uncertainty bounds around AWMS systems with the addition of two years from the time of the original survey. Overall, the uncertainty range around manure management emissions produced by this analysis is slightly smaller than those reported by Karimi-Zindashty et al. (2012), as the proportions of manure treated by different manure management systems were distributed to the provincial level in this analysis, whereas a national average was used in the 2012 publication. Monni et al. (2007) estimated CH_4 manure management emission factor uncertainty to be roughly ±30% based strictly on expert opinion. As was the case with enteric fermentation, Karimi-Zindashty et al. (2012) demonstrated that most uncertainty in the manure management model is associated with the use of default IPCC model parameters that are applied at the national level, specifically the MCF. By deriving MCF factors for different regions and different storage structures, uncertainty would be significantly reduced. Further work on uncertainty will focus on the development of trend uncertainty and the refinement of probability distributions around country-specific parameters already existing in the model.

A3.4.4. N_2O Emissions from Manure Management

N_2O emissions from manure management systems result from mineralization of organic materials, nitrification and denitrification of mineral nitrogen directly and indirectly.

A3.4.4.1. Direct N_2O Emissions from Manure Management

Three factors are required to estimate N_2O emissions manure management systems using the IPCC Tier 1 method: (1) N excretion rates for various animal categories and subcategories; (2) types of AWMS; and (3) emission factors associated with manure management systems.

Nitrogen Excretion Rates for Various Domestic Animals

Manure N excretion from cattle varies by animal subcategory and also over the time series, due to the increase in animal weight. Annual live weights (see Section A3.4.1.2) were multiplied by the IPCC default N excretion rate (IPCC 2006) to produce a time series of manure N excretion rates (Table A3–41). Annual manure N excretion rates from non-cattle animals, according to IPCC Tier 1 default values (IPCC 2006), vary by livestock category. Poultry have high excretion rates (Table A3–42), while horses and bison have the lowest excretion rates. However, on a per-head basis, bison have the highest N excretion rates in the non cattle category. In the case of cattle, dairy cows have very high excretion rates due to the protein

requirements of sustained milk production. Tier 1 default values for fur-bearing animals and rabbits have exceptionally high excretion rates relative to their size (Table A3–42), but are understood to be based on breeding stock and attribute all manure produced on the farm to the breeding stock.

Emission Factors Associated with AWMS

The type of AWMS has a significant impact on N_2O emissions. Less-aerated systems, such as liquid systems, generate little N_2O, whereas drylots produce more. However, there is little scientific information in Canada specifying amounts of N_2O emissions associated with manure management systems. Therefore, IPCC default emission factors, as listed in Annex 6, were used to estimate emissions.

Table A3–37 summarizes the distribution of manure

Table A3–41 Time Series of Manure N Excretion Rates for Cattle (kg N/head/year)[1]

	(kg N/head/year)							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[2]	Steers[2]	Calves
1990	102	54	88	58	45	45	48	27
1995	102	54	99	65	50	55	57	27
2000	102	54	103	70	54	60	61	27
2005	102	54	102	68	52	61	61	26
2006	102	54	102	69	53	61	62	26
2007	102	54	102	69	53	62	62	27
2008	102	54	102	70	53	62	62	27
2009	102	54	107	69	53	62	63	27
2010	102	54	113	69	53	62	63	27
2011	102	54	112	69	53	62	64	27
2012	102	54	114	69	53	65	65	27
2013	102	54	99	69	53	64	65	27
2014	102	54	103	70	53	63	64	26
2015	102	54	111	74	56	65	66	26

Note:
1. N excretion rate for dairy cattle is 0.44 kg N-1000 kg -1-day -1 (IPCC 2006 Table 10.10); N excretion rate for other cattle is 0.31 kg N-1000 kg -1-day -1 (IPCC 2006 Table 10.10). Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.
2. Values are adjusted for the life-span of slaughter animals.

Table A3–42 Manure N Excretion Rates for Non-Cattle

Animal Categories	N Excretion Rate[1] (kg N/1000 kg/day)	Average Body Weight[2] (kg)	Annual Manure N (kg N/head/year)
Swine	0.5	61	11.1
Sheep	0.42	27	4.1
Lambs	0.42	27	4.1
Goats	0.45	64	10.5
Horses	0.3	450	49.3
Llamas and Alpacas	0.42	112	17.2
Bison	0.32	580	67.6
Hens	0.83	1.8	0.5
Broilers	1.1	0.9	0.4
Turkeys	0.74	6.8	1.8
Elk and Deer	0.31	120	14.0
Wild Boars[3]	0.5	61	11.1
Foxes	18.4	1.8	12.1
Mink	7	1.8	4.6
Rabbits	13.9	1.6	8.1
Mules and Asses	0.3	245	26.8

Notes:
1. Data source: IPCC (2006).
2. For buffalo, average live weight was taken from the US NIR.
3. Equivalent to swine.

management systems in Canada by animal category. Emissions of N_2O from manure on pasture, range and paddock systems are not included under the Manure Management category, as they are reported under the Agricultural Soils category (Section A3.4.5.1). Animal population data are detailed in Section A3.4.1.

Direct N_2O emissions from manure management are estimated using the IPCC Tier-1 method (Equation A3–25) as follows:

Equation A3–25:

$$N_2O_{D(mm)} = \sum_i \sum_{AWMS} (N_{i,T} \times N_{i,AWMS} \times N_{EX,T} \times EF_{AWMS} \times \frac{44}{28}$$

where:

$N_2O_{D(mm)}$	=	emissions for all AWMS and livestock categories, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/yr
$N_{i,T}$	=	population for the T^{th} animal category or subcategory in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3–37)
$N_{EX,T}$	=	N excretion rate for the T^{th} animal category or subcategory (see Table A3–41 for non cattle and Table A3–42 for cattle), kg N/head/year
EF_{AWMS}	=	N_2O emission factors from manure management for each specific AWMS (see Annex 6), kg N_2O N/kg N
44/28	=	coefficient converting N_2O-N to N_2O

A3.4.4.2. Indirect N_2O Emissions from Manure Management

During animal manure storage and handling, losses of N occur through the following indirect pathways: (i) volatilization of manure N as NH_3 and NO_x and subsequent re-deposition; and (ii) leaching and runoff of N. These losses of manure N can result in N_2O emissions (Equation A3–26 and Equation A3–27).

Equation A3–26:

$$N_2O_{G(mm)} = \sum_i \sum_{AWMS} (N_{i,T} \times N_{i,AWMS} \times N_{EX,T} \times Frac_{GasMS(T,AWMS)}) \times EF_4 \times \frac{44}{28}$$

where:

$N_2O_{G(mm)}$	=	indirect N_2O emissions due to NH_3 volatilization for Manure Management, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/year
$N_{i,T}$	=	population for livestock category or subcategory, T in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3–37)
$N_{EX,T}$	=	N excretion rate for livestock category or subcategory, T (see Table A3–41 for cattle and Table A3–42 for non-cattle and), kg N/head/year
$Frac_{GasMS(T,AWMS)}$	=	fraction of managed manure N for livestock category, T that volatilizes as NH_3 and NO_x in the manure management system, AWMS (see Table A3–37)
EF_4		emission factor from atmospheric deposition of N, 0.01 kg N_2O N/(kg NH_3-N + NO_x-N volatilized) (IPCC 2006)
44/28		coefficient converting N_2O-N to N_2O

Equation A3–27:

$$N_2O_{L(mm)} = \sum_i \sum_{AWMS} (N_{i,T} \times N_{i,AWMS} \times N_{EX,T} \times FRAC_{LeachMS(T,AW\,MS)}) \times EF_5 \times \frac{44}{28}$$

where:

$N_2O_{L(mm)}$	=	indirect N_2O emissions due to leaching and runoff from Manure Management, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/yr
$N_{i,T}$	=	population for livestock category or subcategory, T in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (Table A3–38)
$N_{EX,T}$	=	N excretion rate for the T^{th} animal category or subcategory (see Table A3–42 for non cattle and Table A3–43 for cattle), kg N/head/year
$FRAC_{LeachMS(T,AWMS)}$	=	fraction of managed manure N losses for livestock category T due to leaching and runoff during solid and liquid storage of manure, AWMS (Table A3–44)
EF_5	=	emission factor for N_2O emissions from N leaching and runoff, 0.0075 kg N_2O N/(kg N leaching/runoff)$^{-1}$ (IPCC 2006)
44/28		coefficient converting N_2O-N to N_2O

A3.4.5. N_2O Emissions from Agricultural Soils

Emissions of N_2O from agricultural soils consist of direct and indirect emissions. The emissions of N_2O that result from anthropogenic N inputs occur through direct pathways, i.e. from the soils to which the N is added, and indirect pathways through (i) volatilization of inorganic N fertilizers and manure N as NH_3 and NO_x and subsequent deposition; and (ii) leaching and runoff of N.

A3.4.5.1. Direct N_2O Emissions from Agricultural Soils

Direct sources of emissions from agricultural soils include inorganic N fertilizers, organic N fertilizers, urine and dung deposited on pasture, range and paddock by grazing animals, crop residues, mineralization associated with loss of soil organic matter, cultivation of organic soil as well as soil organic matter decay as affected by conservation tillage practices, summerfallow and irrigation. The N_2O emission factors for most of the direct emission sources are country-specific and incorporate the influence of moisture regimes, landscape position and soil texture on rates of N_2O production and emissions (Rochette et al. 2008).

The approach involves determining base emission factors "EF_{BASE}" for each of 405 ecodistricts,[16] using long-term growing season precipitation and potential evapotranspiration. The EF_{BASE} is subsequently modified to reflect site-specific practices and conditions. Data on long-term climate normals and topographic characteristics are used to develop an EF_{BASE} (Equation A3–28).

Equation A3–28:

$$EF_{BASE} = EF_{CT,\ \frac{P}{PE}=1} \times F_{TOPO} + EF_{CT} \times (1 - F_{TOPO})$$

where:

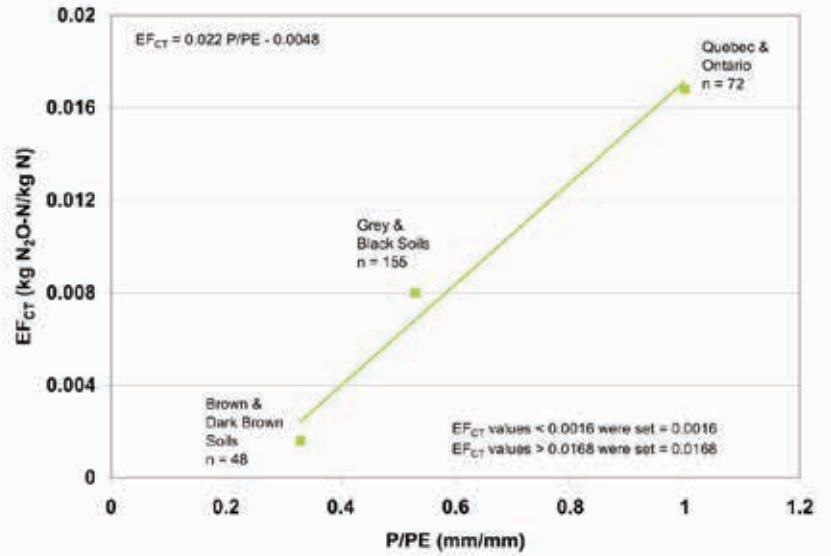
EF_{BASE}	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N/year
EF_{CT}	=	emission factor, estimated at actual P/PE accounting for moisture regime and topography in an ecodistrict, kg N_2O-N/kg N (see Figure A3–8)
$EF_{CT,\ P/PE=1}$	=	emission factor of 0.017 estimated at P/PE = 1, kg N_2O-N/kg N
F_{TOPO}	=	fraction of the ecodistrict area in the lower section of the toposequence See Rochette et al. (2008)
P	=	long-term mean growing season precipitation from May to October in an ecodistrict, mm
PE	=	long-term mean potential evapotranspiration from May to October, mm

Base N_2O Emission Factor (EF_{BASE})

Nitrous oxide is produced mainly during denitrification and is therefore greatly influenced by soil oxygen status. Accordingly, in moisture-limited conditions, N_2O emission factors have been shown to increase with increased rainfall (Dobbie et al. 1999), and climate-variable emission factors have been used in estimating soil N_2O inventory (Flynn et al. 2005). Similarly, this methodology estimates emission factors including winter and spring thaw emissions at the ecodistrict level as a function of the ratio of the long-term normals of precipitation over potential evapotranspiration (P/PE) from May to October (Figure A3–6). The EF_{BASE} factors were determined using the same approach as for the determination of the IPCC Tier 1 emission factor by Bouwman (1996), i.e. EF_{BASE} = slope of the "N_2O emissions versus N fertilizer rate" relationship. The EF_{BASE} was estimated for the three regions where field N_2O measurements are available: Quebec–Ontario; the Brown and Dark Brown soil zones of the Prairies; and the Grey and Black soil zones of the Prairies. The soil N_2O emissions versus fertilizer N relationship determined for the Quebec–Ontario region has a similar slope (0.012 kg N_2O-N/kg N)

16 "Ecodistrict" represents one level within Canada's National Ecological Framework. The country includes 1027 ecodistricts, characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies and fauna.

Figure A3–6 EF_{CT} as a Function of Long-Term Ratio of Precipitation Over Potential Evapotranspiration (P/PE) from 1971 to 2000



(Gregorich et al. 2005) and fit (r^2 = 0.43) as the IPCC Tier 1 default emission factor derived by Bouwman (1996) using global data. In the Prairie region, low and variable N_2O emissions were measured across the range of N fertilizer rates (Brown and Dark Brown soils = 0.0016 kg N_2O-N/kg N; Grey and Black soils = 0.008 kg N_2O-N/kg N). These observations suggest that soil N_2O production in the Prairie region is not limited by mineral N availability but rather by the low denitrification activity under well-aerated soil conditions. Despite the uncertainty in the determination of emission factors in the Prairie region, this approach is deemed a valid option to account for the influence of moisture limitations on N_2O emissions in that region.

To account for a topographical effect, an EF_{BASE} of 0.017 kg N_2O-N/kg N (EF_{BASE} at P/PE = 1) was used for the lower sections of the landscapes. The fraction of the landscape to which this condition was applied differs among landscape types. Landscape segmentation data were incorporated into the calculation of the national N_2O emission estimates, based on the observations that N_2O emissions are greater in lower sections of the landscape, where intermittently saturated soil conditions are favourable to denitrification (Corre et al. 1996, 1999; Pennock and Corre 2001; Izaurralde et al. 2004). The fraction of the landscape occupied by such lower sections (F_{TOPO}) was applied to concave portions of the landscape (i.e. lower and depressional landscape positions) where soils are likely to be saturated for significant periods of time on a regular basis and where they are imperfectly and poorly drained with mottles[17] within 50 cm of the land surface. MacMillan and Pettapiece (2000) used digital elevation models to characterize the areal extent of upper, mid, lower and depressional portions of the landscape and their associated characteristics (slope and length). Their results were used to determine the proportional distribution of different landforms (such as lower sections) in the Soil Landscapes of Canada (SLC), which was the basis for determining the proportion of the landscape to which F_{TOPO} would be applied to derive N_2O emission estimates (Rochette et al. 2008).

17 Mottles are the product of intermittent oxidation/reduction cycles of (generally) iron present in the soil profile. Prevalence, size and colour of mottles are indicative of the soil materials being intermittently saturated for significant periods of time.

N_2O Emissions During Winter and Spring Thaw

Field measurements of N_2O flux using chambers in eastern Canada are usually made during the snow-free period (Gregorich et al. 2005). Average annual snowfall in eastern Canada varies between 1.0 and 4.5 m (Environment Canada 2002). Snowmelt water in the spring creates wet soil conditions that often stimulate N_2O production (Grant and Pattey 1999; Wagner-Riddle and Thurtell 1998). The intensity of soil freezing was also found to influence spring thaw emissions (Wagner-Riddle et al. 2007). Limiting emission estimates to the snow-free period therefore underestimates total annual N_2O emissions in that region. Rochette et al. (2008) reported mean N_2O emissions during the winter and spring thaws in southern Ontario to be 1.2 kg N_2O-N ha^{-1} (Wagner-Riddle et al. 2007; Wagner-Riddle and Thurtell 1998); these emissions were included in the relationship between EF_{CT} and P/PE shown in Figure A3–6.

Emissions of N_2O during spring thaw also occur on the Prairies but are usually lower than in eastern Canada (Lemke et al. 1999). Chamber flux measurements used to estimate EF_{CT} on the Prairies include spring thaw emissions, because low snow accumulation in the region allows chamber deployments during that period. Therefore, no adjustment to the EF_{CT} for the spring thaw emissions is required on the Prairies.

There are 958 weather stations in the AAFC-archived weather database.[18] These stations (80°00′N–41°55′N, 139°08′W–52°40′W) located across Canada (758 stations) and the United States (200 stations) were used to interpolate precipitation and potential evapotranspiration from May to October from 1971 to 2000 to the ecodistrict centroids. Canadian weather data were provided by the Meteorological Service of Canada, Environment and Climate Change Canada.

Soil Texture and N_2O Emissions

Soil texture does not directly influence N_2O production in soils. However, it correlates with several physical and chemical parameters that control N_2O production and transport in the soil profile (Arrouays et al. 2006; da Sylva and Kay 1997; Minasny et al. 1999). Consequently, soil texture-related variables often correlate with N_2O emissions from agricultural soils (Hénault et al. 1998; Corre et al. 1999; Chadwick et al. 1999; Bouwman et al. 2002b; Freibauer 2003).

The impact of soil texture on N_2O emissions from agricultural soils was incorporated in the emission factor using a ratio factor ($RF_{TEXTURE}$) defined as the ratio of N_2O emissions on soils of a given textural class to the mean emissions from soils of all textures (Equation A3–29). A value of 0.8 was assigned to the $RF_{TEXTURE\text{-}COARSE}$ and $RF_{TEXTURE\text{-}MEDIUM}$ and 1.2 for $RF_{TEXTURE\text{-}FINE}$ (Rochette et al. 2008). $RF_{TEXTURE}$ could not be estimated in regions other than Quebec, Ontario and the Atlantic provinces. The assumption of a low influence of soil texture on N_2O emissions ($RF_{TEXTURE}$ =1) is likely justified under dry climates such as in the Prairie region, where low soil water content results in low N_2O emissions, regardless of the soil texture.]

18 Gameda S. Personal communication, Agriculture and Agri-Food Canada (2006).

Equation A3–29:

$$RF_{TEXTURE,i} = \left(RF_{TEXTURE-FINE,i} \times FRAC_{TEXTURE-FINE,i}\right) + \left(RF_{TEXTURE-COARSE,i} \times FRAC_{TEXTURE-COARSE,i}\right) + \left(RF_{TEXTURE-MEDIUM,i} \times FRAC_{TEXTURE-MEDIUM,i}\right)$$

where:

$RF_{TEXTURE,i}$	=	a weighted soil texture ratio factor of N_2O for an ecodistrict i for Ontario, Quebec and the Atlantic provinces
$RF_{TEXTURE-FINE,i}$	=	a ratio factor of N_2O for fine-textured soils for an ecodistrict i
$FRAC_{TEXTURE-FINE,i}$	=	fraction of fine-textured soils in an ecodistrict i
$RF_{TEXTURE-COARSE,i}$	=	a ratio factor of N_2O for coarse-textured soils for an ecodistrict i
$FRAC_{TEXTURE-COARSE,i}$	=	fraction of coarse-textured soils in an ecodistrict i
$RF_{TEXTURE-MEDIUM,i}$	=	a ratio factor of N_2O for medium-textured soils for an ecodistrict i
$FRAC_{TEXTURE-MEDIUM,i}$	=	fraction of medium-textured soils in an ecodistrict i

Organic Nitrogen Fertilizers

Emissions of N_2O from manure N applied as fertilizers include N_2O produced from the application of manure from drylot and solid storage, liquid and other waste management systems on agricultural soils. A country-specific Tier 2 methodology is used for estimating N_2O emissions from organic N fertilizers. The methodology is based on the quantity of manure N produced by domestic animals (see Section A3.4.3.8) and country-specific EF_{BASE} taking into account moisture regime and topographic conditions at the ecodistrict level. Estimates of N_2O emissions from this source are calculated using Equation A3–30.

Table A3–43 Total N, NH_3- and NOx-N Losses Associated with Various Livestock and Manure Management Systems

Animal Categories	Manure Management Systems[4]	$FRAC_{(LossMS)}$ (%)[1]	Leaching Loss (%)[3] ($FRAC_{LeachMS}$)	NH_3-N and NO_x-N Loss (%)[1, 2, 4] ($FRAC_{GasMS}$)
Dairy Cows	Liquid	40 (15–45)	0	40 (15–45)
	Solid Storage	35 (10–55)	10	25 (10–40)
	Pasture and Range	-	-	20 (5–50)
Non-dairy Cattle	Liquid	40 (15–45)	0	40 (15–45)
	Solid Storage	40 (20–50)	10	30 (20–50)
	Pasture and Range	-	-	20 (5–50)
Swine	Liquid	48 (15–60)	-	48 (15–60)
	Solid Storage	50 (20–70)	5	45 (10–65)
Sheep, Lamb, Llamas and Alpacas	Solid Storage	15 (5–20)	-	12 (5–20)
	Pasture and Range	-	-	20 (5–50)
Goat and Horse	Solid Storage	15 (5–20)	3	12 (5–20)
	Pasture and Range	-		20 (5–50)
Elk and Deer	Solid Storage	15 (5–20)	3	12 (5–20)
Wild Boars	Solid Storage	15 (5–20)	3	12 (5–20)
Foxes	Solid Storage	15 (5–20)	3	12 (5–20)
Mink	Solid Storage	15 (5–20)	3	12 (5–20)
Rabbits	Solid Storage	15 (5–20)	3	12 (5–20)
Mules and Asses	Solid Storage	15 (5–20)	3	12 (5–20)
Poultry	Liquid	50	0	50
	Solid Storage	53 (20–80)	5	48 (10–60)
	Pasture and Range	-	-	20 (5–50)

Notes:

1. Numbers in parentheses indicate a range.
2. Data sources: Hutchings et al. (2001); U.S. EPA (2004); Rotz (2004).
3. Leaching loss is the difference between total loss and volatilized loss.
4. Leaching loss from pasture, range and paddock is reported under indirect N_2O emissions from agricultural soils, and is calculated using the same parameters as manure N spread to agricultural soils.

Equation A3–30:

$$N_2O_{MAN} = \sum_i \left(N_{MAN,CROPS,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}\right) \times \frac{44}{28}$$

where:

N_2O_{MAN}	=	emissions from manure N applied to cropland as fertilizers, kg N_2O/year
$N_{MAN\text{-}CROPS,i}$	=	animal manure applied as N fertilizers on cropland in ecodistrict i, kg N/year
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N-year
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict i
44/28	=	coefficient converting N_2O-N to N_2O

The amount of animal manure applied as fertilizer at an ecodistrict level was calculated using Equation A3–31. It was assumed that all manure, excluding that deposited on pasture, range and paddock, is applied to cropland soils.

Equation A3–31:

$$N_{MAN-CROPSi} = \sum_i \left(N_T \times N_{EX,T}\right) \times \left(1 - N_{PRP,T}\right) \times \left(1 - FRAC_{LossMS,T}\right)$$

where:

$N_{MAN\text{-}CROPS,i}$	=	animal manure applied as N fertilizers on cropland in ecodistrict i, kg N/year
N_T	=	population for animal category or subcategory T, heads
$N_{EX,T}$	=	N excretion rate for animal category or subcategory (Table A3–41 and Table A3–42), kg N/head/year
$N_{PRP,T}$	=	fraction of manure N on pasture, range and paddock for each animal category or subcategory T in ecodistrict i (see Table A3–37)
$FRAC_{(LossMS,T)}$	=	fraction of manure N losses (volatilization, leaching, etc.) for each animal category or subcategory T excluding pasture, range and paddock in ecodistrict i (Table A3–43)

Animal population data sources are detailed in Section A3.4.1. Annual livestock population data from each animal category or subcategory at the provincial level are disaggregated into ecodistricts based on the livestock population distribution reported from the *Census of Agriculture*. Between two consecutive census years, livestock population proportions at the ecodistrict level are interpolated.

Inorganic Nitrogen Fertilizers

The method for estimating N_2O emissions from inorganic N fertilizer application on agricultural soils takes into account moisture regimes and topographic conditions. Equation A3–32 is used to estimate N_2O emissions by ecodistrict. Emission estimates at the provincial and national scales are obtained by aggregating estimates at the ecodistrict level.

Equation A3–32:

$$N_2O_{SFN} = \sum_i \left(N_{FERT,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}\right) \times \frac{44}{28}$$

where:

N_2O_{SFN}	=	emissions from inorganic N fertilizers, kg N_2O/year
$N_{FERT,i}$	=	inorganic N fertilizer consumption in ecodistrict i, kg N/year; N_{FERT} at an ecodistrict level is estimated using Equation A3–33
$EF_{BASE,i}$	=	a weighted average of emission factors at ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N-year
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict i
44/28	=	coefficient converting N_2O-N to N_2O

Data for inorganic N fertilizer sales are available by province only and were disaggregated to the ecodistrict level. The approach (Equation A3–33) was based on the assumption that the amount of inorganic N fertilizers applied (N_{APPLD}) is equal to the difference between recommended N rates (N_{RCMD}) and manure N available for application on cropland ($N_{MAN\text{-}AV,CROPS}$).

Equation A3–33:

$$N_{APPLDP,i} = N_{RCMD.i} - N_{MAN-AV,CROPS,i}$$

where:

$N_{APPLDP,i}$	=	total N fertilizer potentially applied in ecodistrict i, kg N/year
$N_{RCMD,i}$	=	recommended fertilizer application in ecodistrict i, kg N/year
$N_{MAN-AV,CROPS,i}$	=	available N from manure applied to crops in ecodistrict i, kg N/year

Based on the work of Yang et al. (2007), N_{RCMD} was estimated as the sum of the products of each crop type and the recommended fertilizer application rate for that crop in an ecodistrict (Equation A3–34):

Equation A3–34:

$$N_{APPLDP,i} = N_{RCMD.i} - N_{MAN-AV,CROPS,i}$$

where:

$N_{APPLDP,i}$	=	total N fertilizer potentially applied in ecodistrict i, kg N/year
$N_{RCMD,i}$	=	recommended fertilizer application in ecodistrict i, kg N/year
$N_{MAN-AV,CROPS,i}$	=	available N from manure applied to crops in ecodistrict i, kg N/year

$N_{MAN-AV,CROPS}$ was calculated as the sum of all manure N from all farm animals (Equation A3–35) in the ecodistrict as follows:

Equation A3–35:

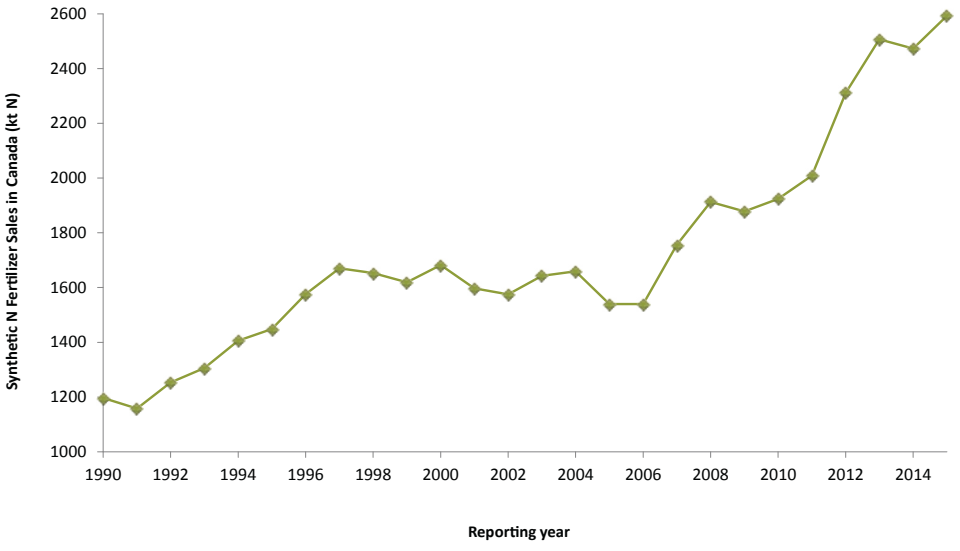
$$N_{MAN-AV,CROPS,i} = N_{MAN,CROPS,i} \times (1 - UNAV)$$

where:

$N_{MAN-AV,CROPS,i}$	=	available N from manure applied to crops in ecodistrict i, kg N/year
$N_{MAN,CROPS,i}$	=	total amount of manure N applied as fertilizers to cropland in ecodistrict i, kg N/year
UNAV	=	fraction of manure N that is either in organic form or unavailable for crops: 0.35 (Yang et al. 2007)

Because the potential amount of fertilizer needs to be reconciled with the total amount sold in the province (N_{SALES}) to estimate the actual amount applied (N_{FERT}), N_{APPLD} is adjusted in each ecodistrict as follows:

Figure A3–7 Synthetic Nitrogen Fertilizer Sales in Canada from 1990 to 2015



Equation A3–36:

$$N_{FERT,i} = N_{APPLDi} \times \left[\frac{\sum_i^p N_{APPLDi}}{N_{SALESp}}\right]$$

where:

N_{FERTi}	=	total fertilizer N actually applied to all crops in ecodistrict i, kg
N_{APPLDi}	=	total fertilizer N potentially applied to all crops in ecodistrict i, kg
N_{SALESp}	=	total amount of fertilizer N sold in province p, kg

For years between census years (census years are 1991, 1996, 2001, 2006 and 2011), N_{RCMD} was linearly interpolated to successively estimate annual values of N_{APPLD} and N_{FERT} at the ecodistrict level. The consumption of synthetic N fertilizers in Canada has significantly increased since 1990, from 1.2 Mt to 2.6 Mt N, mainly because of the intensification of cropping systems from 1991 to 1997 and increased conversion from perennial to annual crops due to favourable grain prices since 2007 (Figure A3–7).

From 1990 to 2002, Agriculture and Agri-Food Canada collected annual fertilizer N consumption data at the provincial level and published *Canadian Fertilizer Consumption, Shipments and Trade*. From 2003 to 2006, fertilizer N data were collected and published by the Canadian Fertilizer Institute.[19] Since 2007, Statistics Canada has collected and published fertilizer sales data annually (Statistics Canada 2015a).

19 Available online at http://www.statcan.gc.ca/daily-quotidien/150213/dq150213f-eng.htm.

Animal Manure Deposited on Pasture, Range and Paddock by Grazing Animals

Canada uses a country-specific method for estimating N_2O emissions from urine and dung deposited on pasture, range and paddock by grazing animals. The N_2O emission factors for all livestock types were determined on the basis of a research project carried out between 2009 and 2011 for dairy cows in eastern Canada and for beef cattle in western Canada. Results from dairy manure in eastern Canada are available in Rochette et al. (2014). Results from beef manure in western Canada are summarized in Table A3–44 (Lemke et al. 2012). In comparison with the IPCC default EF for major livestock (2%), emission factors were 3.2 times lower in eastern Canada and 46.5 times lower in western Canada. 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 the ratio of precipitation to potential evapotranspiration during the growing season—is a major contributing factor for N_2O emissions on arable cropland in Canada. For Ontario, Quebec and the Atlantic provinces, N_2O EFs are 0.0078 kg N_2O-N kg_{-1} N for fine-textured soil, 0.0062 kg N_2O-N kg_{-1} N for medium-textured soil and 0.0047 kg N_2O-N kg^{-1} N

Table A3–44 Emissions of Nitrous Oxide from Beef Urine and Dung on Pasture in Western Canada[1]

Site	Treatment	Flux	Target N Rate	Standard Deviation	Emission Factor
			kg N ha^{-1}		kg N_2O-N $kg^{-1}N$
Swift Current, Saskatchewan	Control	0.07		0.04	
	Dung	0.07	500	0.05	0.000002 ± 0.00003
	Urine	0.79	750	1.56	0.001 ± 0.002
Lacombe, Alberta	Control	0.59		0.33	
	Dung	0.50	500	0.41	0 ± 0.0002
	Urine	0.72	750	0.58	0.0002 ± 0.0003
Overall Mean					
	Dung				0 ± 0.0001
	Urine				0.0006 ± 0.0012

1. Unpublished data (Lemke et al. 2012); urine and dung applied in spring, summer and fall, and repeated one more time along with three replicates, and N_2O flux measurement frequency varied from three times a week immediately after urine and dung application down to once in four weeks depending on the intensity of the flux and weather conditions.

for coarse-textured soil (Rochette et al. 2014). A weighted N_2O EF based on soil texture is calculated for each ecodistrict based on Equation A3–29, assuming 75% of excreted N in urine (Rochette et al. 2014). In western Canada, the N_2O EF is 0.00043 kg N_2O-N kg_{-1} N (Table A3–44). Emissions of N_2O are calculated using a fixed emission factors-based approach (Equation A3–37).

Equation A3–37:

$$N_2O_{PRP} = \sum_{T,i} [(N_T \times N_{EX,T} \times N_{PRP,T} \times EF_{PRP,i})] \times \frac{44}{28}$$

where:

N_2O_{PRP}	=	emissions from urine and dung deposited on pasture, range and paddock from grazing animals, kg N_2O/year
N_T	=	animal population of category or subcategory T in a province, heads
$N_{EX,T}$	=	annual N excretion rate for animal category or subcategory T, kg N/head-year (Table A3–41 and Table A3–42)
$N_{PRP,T}$	=	fraction of manure N excreted on pasture, range and paddock by animal category or subcategory T (Table A3–37)
$EF_{PRP,i}$	=	emission factor for manure N deposited by animals on pasture, range and paddock in ecodistrict i
44/28	=	coefficient converting N_2O-N to N_2O

Animal population data and data sources are detailed in Section A3.4.1.

Crop Residue Decomposition

The transformation (nitrification and denitrification) of the N released during the decomposition of crop residues results in N_2O emissions into the atmosphere. A country-specific Tier 2 methodology similar to that for inorganic and organic N fertilizers is used to estimate N_2O emissions from crop residues, based on Equation A3–38, Equation A3–39, and Equation A3–40. The amount of N contained in the above-ground crop residues subjected to field burning at the provincial level is removed from the emission estimate to avoid double counting (see Section A3.4.7).

Equation A3–38:

$$N_2O_{RES} = \sum_i \left(N_{RES,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}\right) \times \frac{44}{28}$$

where:

N_2O_{RES}	=	emissions from crop residue decomposition, kg N_2O/year
$N_{RES,i}$	=	total amount of crop residue N that is returned to the cropland for ecodistrict i, excluding N losses due to residue burning, kg N/year (see Equation A3–39)
$EF_{BASE,i}$	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N/year
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict, i
44/28	=	coefficient converting N_2O-N to N_2O

Equation A3–39:

$$N_{RES,i} = \sum_{T,i} \left[P_{T,i} \times FRAC_{RENEW,T,i} \times \left(R_{AG,T} \times N_{AG,T} + R_{BG,T} \times N_{BG,T}\right)\right]$$

where:

$N_{RES,i}$	=	total amount of crop residue N that is returned to the cropland for ecodistrict i, excluding N losses due to residue burning, kg N/year
$P_{T,i}$	=	total production of the T^{th} crop type that is renewed annually in ecodistrict i, kg DM/year (see Equation A3–40)
$FRAC_{RENEW,T,i}$	=	fraction of total area under crop T that is renewed annually in ecodistrict i
$R_{AG,T}$	=	ratio of above-ground residues to harvested yield for crop T, kg dry matter (DM)/kg
$N_{AG,T}$	=	N content of above-ground residues for crop T, kg N/kg DM
$R_{BG,T}$	=	ratio of below-ground residues to harvested yield for crop T, kg DM/kg
$N_{BG,T}$	=	N content of below-ground residues for crop T, kg N/kg DM

Equation A3–40:

$$P_{T,i} = \frac{A_{T,i} \times Y_{T,i}}{\sum_{i=1}^{N}(A_{T,i} \times Y_{T,i})} \times P_{T,p} \times (1 - H_2O_T)$$

where:

$P_{T,i}$	=	total production of the T^{th} crop type that is renewed annually in ecodistrict i, kg DM/year
$A_{T,i}$	=	area under crop type T in ecodistrict i, ha
$Y_{T,i}$	=	average crop yield for crop type T in ecodistrict i, kg/ha-year
$\sum_{i=1}^{n}(A_{T,i} \times Y_{T,i})$	=	sum of total production for crop type T over all ecodistricts in a province
$P_{T,P}$	=	total crop production for crop type T in province p, kg DM/year
H_2OT	=	water content of crop T, kg/kg

Statistics Canada collects and publishes annual field crop production data by province (Statistics Canada 2015b, CANSIM, Table 001-0010). Crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, sugar beets, tame hay, dry peas, soybean, dry white beans, coloured beans, chick peas and lentils. The area seeded and the yield of each crop are reported at the census agricultural region and provincial levels, and yields have been allocated to Soil Landscapes of Canada (SLC) polygons through area overlays by Agriculture and Agri-Food Canada. Specific parameters for each crop type are listed in Janzen et al. (2003).

Mineralization Associated with Loss of Soil Organic Matter

The amount of N in mineral soils that is mineralized in association with loss of soil organic matter as a result of changes to land management practices can result in additional N_2O emissions from the Cropland remaining Cropland category. A database containing soil organic carbon and N for all major soils in Saskatchewan (a data set of about 600) was used to derive an average C:N ratio of 11 with a standard deviation of 1.9. No such comprehensive data on C:N ratios for other provinces exist, and the C:N ratio of agricultural soils is considered to be consistent among regions. The 2006 IPCC Guidelines propose a range of C:N ratios from 8 to 15. A country-specific method is used for emission estimates (see Equation A3–41 and Equation A3–42).

Equation A3–41:

$$F_{SOM} = \sum_{LM}[(\Delta C_{Mineral,\,LM} \times \frac{1}{R}) \times 1000]$$

where:

F_{SOM}	=	the net annual amount of N mineralised in mineral soils as a result of loss of soil organic carbon through change in land management practices, kg N
$\Delta C_{Mineral,\,LM}$	=	average annual loss of soil organic carbon for each land management practice (LM), Mg C
R	=	C:N ratio of the soil organic matter (11.0±1.9)

Equation A3–42:

$$N_2O_{FSOM} = \sum_{i}\left[\left(F_{SOM,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}\right)\right] \times \frac{44}{28}$$

where:

N_2O_{FSOM}	=	emissions associated with loss of soil organic matter due to changes in land management practices, kg N_2O/year
$EF_{BASE,i}$	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N/year
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict, i
44/28	=	coefficient converting N_2O-N to N_2O
$F_{SOM,i}$	=	the net annual amount of N mineralised in mineral soils as a result of loss of soil organic carbon through change in land management practices for ecodistrict i, kg N

Activity data on soil organic carbon loss at an ecodistrict level from 1990 to 2014 are transferred from the data reported in the LULUCF Cropland remaining Cropland category.

Cultivation of Organic Soils (Histosols)

Cultivation of organic soil (histosols) for annual crop production produces N_2O. The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils (Equation A3–43).

Equation A3–43:

$$N_2O_H = \sum_i \left(A_{OS,i} \times EF_{HIST}\right) \times \frac{44}{28}$$

where:

N_2O_H	=	emissions from cultivated histosols, kg N_2O/year
$A_{os,i}$	=	area of cultivated organic soils in province i, ha
EF_{HIST}	=	IPCC default emission factor for mid-latitude organic soils, 8.0 kg N_2O-N/ha-year (IPCC 2006)
44/28	=	coefficient converting N_2O-N to N_2O

Areas of cultivated histosols at a provincial level are not collected as part of the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada indicate that the total area of cultivated organic soils from 1990 to 2015 in Canada was 16 kha (Liang et al. 2004).

Change in N_2O Emissions from Adoption of No-Till and Reduced Tillage

This category is specific to Canada and does not derive from additional N inputs such as fertilizer, manure and crop residue, but rather is implemented as modifications to EF_{BASE} due to the switch from conventional to conservation tillage practices—namely no-till (NT) and reduced tillage (RT).

Field studies in Quebec and Ontario showed that NT practices increased N_2O emissions, whereas on the Prairies the opposite was observed (Gregorich et al. 2005). To quantify the impact of tillage practices on N_2O, a tillage ratio 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}), Equation A3–44 is used (Rochette et al. 2008):

Equation A3–44:

$$N_2O_{TILL} = \sum_i \left[\left(N_{FERT,i} + N_{MAN,CROPS,i} + N_{RES,i}\right) \times \left(EF_{BASE,i} \times FRAC_{NT-RT,i} \times \left(F_{TILL} - 1\right)\right)\right] \times \frac{44}{28}$$

where:

N_2O_{TILL}	=	change in N_2O emissions resulting from the adoption of NT and RT, kg N_2O/year
$N_{FERT,i}$	=	inorganic fertilizer N consumption in ecodistrict i, kg N/year
$N_{MAN-CROPS,i}$	=	amount of manure N applied as fertilizers to cropland in ecodistrict i, kg N/year
$N_{RES,i}$	=	amount of crop residue N that is returned to the cropland for ecodistrict i, kg N/year
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N-year
$FRAC_{NT-RT,i}$	=	fraction of cropland on NT and RT in ecodistrict i
F_{TILL}	=	a ratio factor adjusting EF_{BASE} due to the adoption of NT and RT: F_{TILL} = 1.1 in eastern Canada; F_{TILL} = 0.8 on the Prairies (Rochette et al. 2008)
44/28	=	coefficient converting N_2O-N to N_2O

The fraction of cropland under NT and RT ($FRAC_{NT-RT}$) for each ecodistrict was derived from the *Census of Agriculture* and is identical to that used in the LULUCF Cropland remaining Cropland category for NT and RT practices (see Section 3 – Cropland in Annex 3.5). These data are published at the census agricultural region, census division and provincial and national levels. Annual FRACNT-RT between two consecutive census years is interpolated.

N_2O Emissions Resulting from Summerfallow

Summerfallow is a farming practice typically used on the Prairies to conserve soil moisture by leaving the soil unseeded for an entire growing season of a crop rotation. During the fallow year, no fertilizer or manure is applied. Several factors may stimulate N_2O emissions relative to a cropped situation, such as higher soil water content, temperature and available carbon and N. Field studies have shown that N_2O emissions in fallow fields are similar to

emissions from continuously cropped fields (Rochette et al. 2008). In order to account for these emissions not captured by the default IPCC input-driven approach, the following country-specific method is used to estimate the effect of summerfallow on N_2O emissions. During a crop year, direct N_2O emissions from a given field are summarized as follows:

Equation A3–45:

$$N_2O_{CROP} = N_2O_{BACK} + N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES}$$

where:

N_2O_{CROP}	=	emissions from a cropped rotation, kg N_2O/year
N_2O_{BACK}		the background soil N_2O emissions that are not due to crop residue-N, fertilizer-N or manure-N additions
N_2O_{SFN}	=	emissions from inorganic N fertilizers, kg N_2O/year
N_2O_{MAN}	=	emissions from organic N fertilizers, kg N_2O/year
N_2O_{RES}	=	emissions from crop residue decomposition, kg N_2O/year

In the absence of external N inputs, N_2O emissions during the fallow year (N_2O_{FALLOW}) can be seen as consisting of: (1) background emissions that would have occurred regardless of fallow (N_2O_{BACK}); and (2) emissions due to the modifications to the soil environment by the practice of summerfallow ($N_2O_{FALLOW-EFFECT}$):

Equation A3–46:

$$N_2O_{FALLOW} = N_2O_{BACK} + N_2O_{FALLOW-EFFECT}$$

where:

N_2O_{FALLOW}	=	emissions due to the effect of summerfallow, kg N_2O/year
N_2O_{BACK}	=	background emissions, kg N_2O/year
$N_2O_{FALLOW-EFFECT}$	=	emissions due to the modifications to the soil environment by summerfallow, kg N_2O/year

Since N_2O emissions are estimated to be equal during fallow and cropped years ($N_2O_{CROP} = N_2O_{FALLOW}$) and assuming that N_2O_{BACK} is the same in cropped and fallow situations, $N_2O_{FALLOW-EFFECT}$ can be empirically estimated as follows:

Equation A3–47:

$$N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES} = N_2O_{FALLOW-EFFECT}$$

where:

N_2O_{SFN}	=	emissions from inorganic N fertilizers, kg N_2O
N_2O_{RES}	=	emissions from crop residue decomposition, kg N_2O
N_2O_{MAN}	=	emissions from organic N fertilizers, kg N_2O
$N_2O_{FALLOW-EFFECT}$	=	emissions occurring under fallow land, kg N_2O

The N_2O emissions due to the practice of summerfallow are therefore calculated for each ecodistrict by applying emissions from N inputs to annual crops (crop residues, fertilizers and manure) to the area of the ecodistrict under summerfallow:

Equation A3–48:

$$N_2O_{FALLOW} = \sum_i \left[\left(N_2O_{SFN,i} + N_2O_{RES,i} + N_2O_{MAN,i} \right) \times FRAC_{FALLOW,i} \right]$$

where:

N_2O_{FALLOW}	=	emissions from summerfallow, kg N_2O
$N_2O_{SFN,i}$	=	emissions from inorganic N fertilizers in ecodistrict i, kg N2O
$N_2O_{RES,i}$	=	emissions from crop residue decomposition in ecodistrict i, kg N2O
$N_2O_{MAN,i}$	=	emissions from organic N fertilizers in ecodistrict i, kg N2O
$FRAC_{FALLOW,i}$		fraction of cropland in ecodistrict i that is under summerfallow

Estimates of N_2O_{SFN}, N_2O_{RES} and N_2O_{MAN} at an ecodistrict level are those derived from synthetic N fertilizers, manure N applied as fertilizers and crop residue N. The fraction, $FRAC_{FALLOW}$, is derived from the *Census of Agriculture* for each ecodistrict and is identical to that used in the LULUCF Cropland remaining Cropland category for the summerfallow practice (see Section 3 – Cropland in Annex 3.5). Annual $FRAC_{FALLOW}$ between two consecutive census years is adjusted through interpolation.

N_2O Emissions Resulting from Irrigation

Higher soil water content under irrigation increases N_2O emissions by increasing biological activity and reducing soil aeration (Jambert et al. 1997). Accordingly, highest N_2O emissions from agri cultural soils in the northwestern United States (Liebig et al. 2005) and western Canada (Hao et al. 2001a) were observed on irrigated cropland, followed by non-irrigated cropland and rangeland. Field studies directly comparing N_2O emissions under irrigated and non-irrigated conditions are lacking in Canada. Therefore, an approach was used based on the assumptions that (1) irrigation water stimulates N_2O production in a way similar to rainfall, (2) irrigation is applied to eliminate any moisture deficit such that "precipitation + irrigation water = potential evapotranspiration," and (3) the effect of irrigation on N_2O emissions is in addition to effects of the non-irrigated area within an ecodistrict. Consequently, the effect of irrigation on N_2O emissions from agricultural soils was accounted for using an EF_{BASE} estimated at a P/PE = 1 (EF_{BASE} = 0.017 N_2O-N/kg N) for the irrigated areas of an ecodistrict:

Equation A3–49:

$$N_2O_{IRRI} = \sum_i [(N_{FERT,i} + N_{MAN,CROPS,i} + N_{RES,i}) \times (0.017 - EF_{BASE,i}) \times FRAC_{IRRI,i}] \times \frac{44}{28}$$

where:

N_2O_{IRRI}	=	emissions from irrigation, kg N_2O/year
$N_{FERT,i}$	=	inorganic N fertilizer consumption in ecodistrict i, kg N/year
$N_{MAN,CROPS,i}$	=	amount of organic N fertilizers to cropland in ecodistrict i, kg N/year
$N_{RES,i}$	=	amount of crop residue N that is returned to the cropland in ecodistrict i, kg N/year
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N-year for ecodistrict i
$FRAC_{IRRI,i}$	=	fraction of irrigated cropland in ecodistrict i
44/28	=	coefficient converting N_2O-N to N_2O

The fraction $FRAC_{IRRI}$ is derived from the Census of Agriculture for each ecodistrict (see Section 3 – Cropland in Annex 3.5). Annual $FRAC_{IRRI}$ between two consecutive census years is adjusted through interpolation.

A3.4.5.2. Indirect N_2O Emissions from Agricultural Soils

Volatilization and Redeposition of Nitrogen

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from volatilization and redeposition of fertilizer and manure N. The emission calculation is shown in Equation A3–50.

Equation A3–50:

$$N_2O_{VD} = \sum_i [(N_{FERT,i} \times FRAC_{GASF}) + (MAN_{PRP,iT} \times FRAC_{GasMS-PRP,T}) + (N_{MAN-CROPS,i} \times FRAC_{GASM})] \times EF_4 \times \frac{44}{28}$$

where:

N_2O_{VD}	=	emissions from volatilization and redeposition of N, kg N_2O/year
$N_{FERT,i}$	=	inorganic N fertilizer consumption in ecodistrict i, kg N/year
$FRAC_{GASF}$	=	fraction of inorganic fertilizer N applied to soils that volatilizes as NH_3- and NO_x-N
$MAN_{PRP,iT}$	=	the amount of manure N excreted on pasture, range and paddock by animal category or subcategory T in an ecodistrict i, kg N/year
$FRAC_{GasMS-PRP,T}$	=	fraction of volatilized manure N deposited on pasture, range and paddock by animal category or sub-category T: 0.2 kg (NH_3-N + NOx-N)/ kg N (IPCC 2006)
$N_{MAN-CROPS,i}$	=	organic N fertilizers on cropland in eco-district i, kg N/year (see Equation A3–30)
$FRAC_{GASM}$	=	fraction of volatilized organic N fertil-izers in ecodistrict i: 0.2 kg (NH_3-N + NO_x-N)/kg N (IPCC 2006)
EF_4	=	emission factor due to volatilization and redeposition: 0.01 kg N_2O-N/kg N (IPCC 2006)
44/28	=	coefficient converting N_2O-N to N_2O

Table A3–45 Coefficients for Crop Type, Inorganic N Fertilizers, Method of Fertilizer Application, Soil Chemical Properties and Climate Developed by Bouwman et al. (2002)

Conditions where coefficient used		Coefficients
Crop Type	Annual crops	-0.045
	Perennialcrops	-0.158
Fertilizer Type	Urea	0.666
	Urea ammonium nitrate	0.282
	Anhydrous ammonia	-1.151
	Other N sources	-0.238
Method of Application	Broadcast onto surface	-1.305
	Incorporated	-1.895
Soil Chemical Properties	Soil pH<7.25	-1
	Soil pH 7.25 ~ 8.5	-0.608
	Soil CEC <250 mmol kg^{-1}	0.0507
	Soil CEC >250 mmol kg^{-1}	0.0848
Climate	Temperate	-0.402

In the 2017 national inventory submission, a country-specific method was used to estimate ammonia emissions from mineral fertilizer application. The method for deriving ammonia emission factors closely follows the approach of Sheppard et al. (2010), who applied the regression model developed by Bouwman et al. (2002a) to derive regionally specific emission factors for different ecoregions in Canada. This model derives ammonia emission factors based on the type of inorganic N fertilizers, degree of incorporation into soil, crop type and soil chemical properties (Equation A3–51).

Equation A3–51:

$$FRAC_{GASF\ TN,\ i} = 100 \times EXP^{(sum\ of\ relevant\ coefficients)}$$

where:

$FRAC_{GASF\ TN,\ i}$	=	ammonia emission factor for each type of inorganic N fertilizer in ecodistrict i, %
sum of relevant coefficients	=	coefficients for crop type, type of inorganic N fertilizers, method of N application, soil chemical properties, and climate, unitless (see Table A3–45)
100	=	conversion of fraction to percent
EXP	=	exponential

Table A3–46 Ammonia Emission Factors of Inorganic Nitrogen Fertilizers Applied to Annual Crop Weighted Based on Soil Properties for Each Province (%)

Sub-category	Urea	Anhy-drous NH_3	UAN	Other
AB	5	4.2	3.8	5.4
BC	4.8	4	3.7	5.2
MB	5.8	4.9	4.5	6.3
NB	7.4	3.9	4.5	4.5
NL	7.4	3.9	4.5	4.5
NS	7.3	3.9	4.4	4.4
ON	8.2	4.4	5	4.9
PE	7.3	3.9	4.4	4.4
QC	7.4	4	4.5	4.5
SK	5.1	4.2	3.9	5.5

Table A3–47 Fractions of N Volatilized ($FRAC_{GASF}$) as Ammonia Resulting from the Application of Inorganic N Fertilizer, from Select Years, 1990-2015, at a Provincial Scale

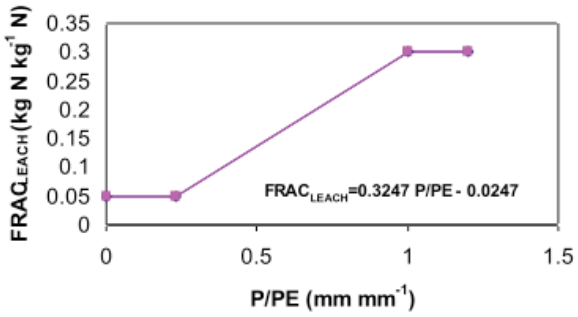
Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.06	0.08	0.06	0.06	0.03	0.07	0.08	0.06	0.08	0.06
1995	0.06	0.08	0.06	0.06	0.03	0.07	0.08	0.06	0.07	0.06
2000	0.06	0.10	0.06	0.05	0.03	0.06	0.08	0.05	0.07	0.06
2005	0.06	0.10	0.07	0.06	0.03	0.07	0.08	0.05	0.06	0.06
2006	0.06	0.10	0.07	0.05	0.04	0.06	0.08	0.05	0.06	0.06
2007	0.06	0.10	0.07	0.07	0.03	0.08	0.09	0.06	0.08	0.06
2008	0.06	0.09	0.07	0.06	0.03	0.08	0.07	0.06	0.07	0.06
2009	0.06	0.10	0.07	0.05	0.03	0.06	0.08	0.05	0.06	0.06
2010	0.06	0.09	0.07	0.05	0.03	0.06	0.07	0.05	0.06	0.06
2011	0.06	0.09	0.07	0.05	0.03	0.06	0.07	0.05	0.06	0.06
2012	0.06	0.09	0.06	0.05	0.03	0.06	0.07	0.04	0.06	0.06
2013	0.06	0.08	0.07	0.06	0.03	0.07	0.07	0.05	0.06	0.06
2014	0.06	0.08	0.06	0.05	0.03	0.06	0.07	0.05	0.06	0.06
2015	0.06	0.08	0.06	0.05	0.03	0.07	0.07	0.05	0.06	0.06

The method of application for each type of inorganic N fertilizers for eastern and western Canada is provided in Sheppard et al. (2010). Soil properties, pH and cation exchange capacity (CEC) are derived from CANSIS soil polygon information and are based on fractional distributions of soil series having pH<7.25 and CEC<250 me kg^{-1}, pH<7.25 and CEC>250 me kg^{-1}, pH>7.25 and CEC <250 me kg^{-1}, and pH>7.25 and CEC >250 me kg^{-1}. Statistics Canada (2015a) has collected and published annual inorganic N fertilizer sales data including urea, urea ammonium nitrate, anhydrous ammonia and others. The application of this equation results in spatially specific emission factors for inorganic N fertilizers applied to annual crops. Provincial averages by fertilizer type (Table A3–46) are calculated based on the spatial distribution of soil chemical properties and climate for each individual ecodistrict in each province and, as a consequence, the fraction ($FRAC_{GASF}$) of ammonia volatilized by province varies slightly from year to year based on fertilizer sales (Table A3–47). More detail on methods of estimating ammonia emission factors from inorganic N fertilizers can be found in Sheppard et al. (2010), and simplifications used to convert monthly emissions calculated in the original publication to an annual estimate are documented in Liang (2014). Briefly, based on the data provided in Sheppard et al. (2010), it is assumed that fertilizers are applied either in spring or fall when temperatures are similar. Therefore, a single temperature representing annual applications per ecoregion is used to estimate emissions. Based on this approach, the fraction of fertilizers emitted during fertilizer application ranges from roughly 3% to a maximum of 10% (Table A3–47), depending on the year and province.

Leaching and Runoff

A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching and runoff of inorganic and organic N fertilizers, and crop residue N from agricultural soils:

Figure A3–8 Determination of the Ecodistrict $FRAC_{LEACH}$ Values



Equation A3–52:

$$N_2O_L = \sum_i \left[\left(N_{FERT,i} + N_{MAN-CROPS,i} + MAN_{PRP,i} + N_{RES,i} \right) \times FRAC_{LEACH,i} \times EF_5 \right] \times \frac{44}{28}$$

where:

N_2O_L	=	emissions from leaching and runoff of N, kg N_2O/year
$N_{FERT,i}$	=	inorganic N fertilizers applied for ecodistrict i, kg N
$N_{MAN-CROPS,i}$	=	organic N fertilizers for ecodistrict i, kg N
$MAN_{PRP,i}$	=	urine and dung deposited on pasture, range and paddock for ecodistrict i, kg N
$N_{RES,i}$	=	crop residue N for ecodistrict i, kg N
$FRAC_{LEACH,i}$	=	fraction of N that is lost through leaching and runoff for ecodistrict i, as defined below
EF_5	=	leaching/runoff emission factor: 0.0075 kg N_2O-N/kg N (IPCC 2006)
44/28	=	coefficient converting N_2O-N to N_2O

Determining the Fraction of Nitrogen that is Leached ($FRAC_{LEACH}$) at the Ecodistrict Level in Canada

In Canada, leaching losses of N vary widely among regions. In some farming systems of southern British Columbia, high N inputs in humid conditions may lead to losses greater than 100 kg N/ha-year (Paul and Zebarth 1997; Zebarth et al. 1998). Those farming systems, however, represent only a small fraction of Canadian agroecosystems. In Ontario, Goss and Goorahoo (1995) predicted leaching losses of 0~37 kg N ha^{-1}, representing between 0 and 20% of N inputs. Leaching losses in most of the Prairie region may be smaller due to lower precipitation and lower N inputs on an areal basis. Based on a long-term experiment in central Alberta, Nyborg et al. (1995) suggested that leaching losses were minimal, and Chang and Janzen (1996) found no evidence of N leaching in non-irrigated, heavily manured plots, despite large accumulations of soil nitrate in the soil profile.

The values for $FRAC_{LEACH}$ can be as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration, such as in the Prairie region of Canada, or as high as 0.3 in humid regions (IPCC 2006) of eastern Canada. Accordingly, it was assumed that $FRAC_{LEACH}$ would vary from 0.05 to 0.3, depending on the ecodistrict.

For ecodistricts with a P/PE value for the growing season (May through October) greater than or equal to 1, the maximum $FRAC_{LEACH}$ value of 0.3 (IPCC 2006) was assigned. For ecodistricts with the lowest P/PE value (0.23), a minimum $FRAC_{LEACH}$ value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged from 0.23 to 1, $FRAC_{LEACH}$ was estimated by the linear function that joins the two-end points (P/PE, $FRAC_{LEACH}$) = (1,0.3; 0.23,0.05) (Figure A3–8).

Data sources for N_{FERT}, $N_{MAN\text{-}CROPS}$, MAN_{PRP} and NRES (Section A3.4.5.1) at an ecodistrict level are provided in the previous sections.

Long-term normals of monthly precipitation and potential evapotranspiration from May to October, 1971–2000 (AAFC-archived database) were used to calculate $FRAC_{LEACH}$ at an ecodistrict level.

A3.4.6. Uncertainty Estimates of N_2O Emissions

A comprehensive uncertainty analysis was completed for all methodologies used in the calculation of N_2O from livestock and agricultural soils for 2010 (Karimi-Zindashty et al. 2014). The analysis has not yet been published, and limited depth of analysis could be carried out due to the size of the Canadian N_2O model and the upper limits of the data processing capability of the Analytica software. However, the analysis did provide the uncertain bounds around the principal emission source categories. For this submission, the uncertainty ranges (percentages) developed for 2010 means were applied to means for 2015. In the analysis, a stochastic reproduction of the complete N_2O emission model was built in Analytica© at the ecodistrict scale, and a Monte Carlo simulation (MCS) was run according to the methodology proposed in the Good Practice Guidance (IPCC 2000). A sensitivity analysis was carried out to identify the parameters that contributed most to different emission source categories.

The parameters used in the calculation of N_2O emissions can be divided into three categories: (1) those associated with information at the ecodistrict scale; (2) provincial-scale data; and (3) IPCC/national-scale parameters (Table A3–48). The majority of national-scale parameters are taken directly from the 2006 IPCC Guidelines (IPCC 2006) or from the original country-specific methodological development work carried out by Rochette et al. (2008), derived either analytically or through expert opinion based on a panel of four experts in agricultural GHG emissions. Provincial-scale parameters include fertilizer sales and characteristics of crop production, the source of uncertainty being the Statistics Canada survey uncertainty and expert opinion on characteristics of crop production. The uncertainty of livestock populations and management parameters for animal categories were identical to that discussed in sections A3.4.2.4 and A3.4.3.8; the distributions used to define uncertainties can be found in Table A3–32 and Table A3–40. Landscape-scale parameters were derived from the agricultural soil landscape parameter database developed by AAFC and used in the production of cropland estimates for LULUCF. Specific landscape-parameter uncertainty was based on the general rules used in the production of uncertainty estimates for cropland carbon, which postulates that the uncertainty of a parameter at the landscape scale is inversely proportional to the relative size of the landscape unit, i.e. smaller parameters associated with smaller ecodistricts have greater uncertainty. The bounds of the uncertainty for different parameters varied. For example, uncertainties around animal distribution was ±30% for small ecodistricts and ±5% for large ecodistricts, whereas for the fraction of lowland soil in a given ecodistrict, variability was bounded as ±10% for small ecodistricts and ±1.25% for large ecodistricts. The current analysis does not include new country-specific emission factors for N_2O emissions from animal manure deposited on pasture, range and paddock, but does include the analysis of emissions considering the 2006 IPCC Guidelines leaching emission factor.

The summary results of the uncertainty analysis on emissions of N_2O are reported in Chapter 5. The relative uncertainty range for N_2O emissions from agricultural sources is 56% (-27% to +29% of the mean). Most uncertainty is associated with indirect emissions and specifically with the indirect emission factors for volatilized and leached N, with the

Table A3–48 Uncertainty Parameters Used in the Calculation of Agricultural N_2O Emissions

Parameter	Coefficient/ Parameter Source	Distribution Type	Uncertainty Range	Most Likely Value[2]	Uncertainty Distribution Estimate Source and Notes
IPCC and National Scale Parameters					
Animal populations and characterization data[1]					Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]
N excretion	IPCC, 2006 Guidelines	Normal	±50%	IPCC default	
$FRAC_{GAS}$/ $FRAC_{LOSSMS}$		Triangular	IPCC default	IPCC default	See Table 10.22/10.23 IPCC, 2006 Guidelines
AWMS emission factor		Triangular	Liquid 0.0005–0.002 PRP -0.007–0.06	Minimum liquid 0.001 Maximum PRP -0.02	IPCC, 2006 Guidelines,[4] variable depending on the manure storage type
Crop characteristics					
H_2O content	Janzen et al. (2003)	Normal	±15%		Expert consultation
Relative DM allocation of residue (product, above ground and below ground)					
$FRAC_{Renew}$ (duration)					
N concentration in residue (aboveground and belowground)					
Direct and indirect emission factors/modifiers					
P/PE regression parameters	Rochette et al. 2008	Normal	Intercept +/- 54% Slope +/- 21%		Expert consultation
$FRAC_{LEACH}$ calculation parameters			Intercept +/- 54% Slope +/- 21%		
F_{TILL}			±100%		
$RF_{TEXTURE}$			±30%		
EF_{LEACH}	2006 IPCC Guidelines	Triangular	0.002–0.12	0.025	IPCC, 2006 Guidelines
EF_{VD}			0.002–0.05	0.01	
EF_{HIST}			2–24	8	
Provincial–Scale Parameters					
Fertilizer application rate (kg/ha)	Factors are drawn from common usage in AAFC[3] literature and modelling studies.	Normal	±15%		Expert Opinion
Provincial fertilizer sales	Statistics Canada	Normal	±15%		Interpretation of data quality evaluation in Statistic Canada Report
Ecodistrict–Scale Parameters					
P and PE	Weather Station Data	Normal	5–15%		Based on individual weather station data, 30-year average
Total ecodistrict area	AAFC[3], Geographically referenced soil landscape agricultural database, derived from *Census of Agriculture*, 1991-2011	Normal	Function of Relative Ecodistrict Size: Maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter.		Based on the uncertainty methodology used in the carbon quantification methodology for croplands.
Crop areas					
Animal population distribution to ecodistrict					
F_{TOPO} (proportion of lowland soils in ecodistrict)					
Extent of organic soils					
Irrigated soil area					
Perennial soil texture					

1. Uncertainty associated with most livestock parameters can be found in Section A3.4.2.4 and Section A3.4.3.8, and the distributions used to define uncertainties can be found in Table A3–34 and TTable A3–42.
2. Reported where applicable when using a triangular distribution.
3. Agriculture and Agri-Food Canada.

estimate of indirect emissions uncertainty of 126% (-58% to +68% of the mean). The emissions are skewed to the lower end of the emission probability distribution, because emission factor uncertainty is bounded by zero and emission factor variability is expressed as a factor on the lower scale; a change from 1% to 0.2% has a lower impact on total emissions than a change from 1% to 5% at the upper end of the probability distribution. The uncertainty range of direct N_2O emissions from agricultural soils is 69% (31% to +38% of the mean). There have been few complete studies of uncertainty from emissions of N_2O in the literature. In a study directly comparable to this particular uncertainty analysis, Monni et al. (2007) estimated that total N_2O emissions in Finland ranged from -50% to +70% of the mean emission estimate. Their methodology included a mixture of country specific and default Tier 1 methodology to produce emission estimates. In a recent study of uncertainty in the United Kingdom, Milne et al. (2013) observed high uncertainty ranges for direct, indirect and total N_2O emissions, specifically -56% to +140%, -91% to +370%, and -55% to +110%, respectively. Our parameter uncertainty was similar to that used by the UK researchers, but it is suspected that the high degree of spatial disaggregation in the Canadian N_2O model resulted in slightly lower overall uncertainty. The uncertainty associated with the fraction of emission(s) from inorganic N fertilizers would be reduced from ±200% by the IPCC default (IPCC 2006) given the country-specific approach applied in this submission. However, because the uncertainty associated with EF_4 (N volatilization and re-deposition) is ±400% (IPCC 2006), it is unlikely that the overall uncertainty of N_2O emissions would decrease.

Sensitivity analysis indicated that indirect EF uncertainties were the largest contributors to overall uncertainty. Uncertainty of direct soil emissions was dominated by the use of uncertainty in the Tier 1 emission factor for emissions from pasture, range and paddock (PRP), the slope of P/PE regression equation, and the emission factor modifier for tillage and texture (RF_{TILL}, RF_{TEXT}). The EF for solid manure systems was the largest source of uncertainty in the estimate of N_2O emissions from AWMS. Reduction of uncertainty will require the replacement of Tier 1 default emission factors and modifiers in the methodology.

Table A3–49 Burning of Crop Residues by Crop Types in 2006 (FEMS 2006)

	Spring wheat	Winter wheat	Oats	Barley	Mixed grains	Flaxseed	Canola
	% Crop Residue Burned (by Weight)						
Newfoundland and Labrador	0	0	0	0	0	0	0
Prince Edward Island	3	0	0	1	0	0	0
Nova Scotia	33	0	0	0	0	0	0
New Brunswick	0	0	1	0	0	0	0
Quebec	0	0	1	0	0	0	0
Ontario	0	0	0	1	2	0	0
Manitoba	2	3	3	1	0	17	1
Saskatchewan	0	0	0	0	0	15	1
Alberta	0	0	0	0	0	8	0
British Columbia	0	0	0	0	0	0	0

A3.4.7. CH_4 and N_2O Emissions from Field Burning of Agricultural Residues

Crop residues are sometimes burned in Canada, for convenience and as a means of disease control through residue removals, although expert opinion suggests that this practice has declined in recent years because of soil quality and environmental issues.

Field burning of agricultural residues emits CH_4 and N_2O. The quantity of crop residue burning in Canada can be estimated as follows:

Table A3–50 Crop Residue Burning by Province in Canada for 1991, 1996, 2001 and 2006

	1991	1996	2001	2006
	% of Crop Residue Burned (by Weight)			
Newfoundland and Labrador	0	0	0	0
Prince Edward Island	0.4	0.4	0.4	0.4
Nova Scotia	0.5	0.5	0.5	0.5
New Brunswick	0.5	0.5	0.5	0.5
Quebec	0.4	0.4	0.4	0.3
Ontario	0.7	0.7	0.7	0.3
Manitoba	12.6	10.1	8.9	2.3
Saskatchewan	8.1	5.8	3.9	1.5
Alberta	0.8	0.7	0.2	0.2
British Columbia	0	0	0	0

Data sources: data for 2001 and 2006 were extracted from FEMS 2001 and FEMS 2006 collected by Statistics Canada;, and data for 1991 and 1996 were gathered through consultations by Coote et al. (2008).

Equation A3–53:

$$Q_{BURN} = \sum_T (PRODUCTION_T \times (1 - MOISTURE_T) \times RatioAR/P_T \times PCB_T \times RATIO_{SCALE})$$

where:

Q_{BURN}	=	quantity of crop residue burned from crop T for each province, Mg dry matter/year
$PRODUCTION_T$	=	total production of crop T, Mg/year
$MOISTURE_T$	=	moisture content of the product from crop T, fraction
$RatioAR/P_T$	=	ratio of above-ground crop residue to the crop product for crop T , unitless
PCB_T	=	percent of crop residue that is subject to field burning for crop T, fraction
$RATIO_{SCALE}$	=	a scaling factor or an intensity factor adjusted for burning in 2006, unitless

Data collected in 2001 and 2006 by Statistics Canada through its Farm Environmental Management Survey (FEMS)[20] include crop residue burning. The type of crop and the extent of crop residue burning for each province were only available for 2006; these data were collected in FEMS and are summarized in Table A3–49. To establish a complete time series of activity data, additional information on crop residue burning for 1991 and 1996 has been gathered through expert consultations (Coote et al. 2008). Thus, a crop that was subject to field burning in 2006 was also assumed to be subject to field burning for the entire time series.

The intensity of crop residue burning in each province for 1991, 1996, and 2001 was adjusted as a ratio based on the average burning for 2006. Basic characteristics of crops, such as moisture content of crop product and ratio of above-ground crop residue to crop product, are reported by Janzen et al. (2003). Annual production of each crop subject to residue burning is available (CANSIM, Table 001-0010), Other parameters, such as fraction of biomass actually burned, and emission factors required for emission estimates were obtained from the 2006 IPCC Guidelines.

20 Available at http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5044.

Emissions of N_2O and CH_4 from crop residue burning are estimated using the following equation:

Equation A3–54:

$$EMISSION_{BURN} = \sum_{Province,i} \left(Q_{BURN,i} \times C_F \times G_{EF}\right) / 1000$$

where:

$EMISSION_{BURN}$	=	emissions of N_2O or CH_4 from the burning of crop residues for Canada (kt N_2O or CH_4)
Q_{BURNi}	=	quantity of crop residue burned from province i, Mg, dry matter/year
C_F	=	fuel efficiency (IPCC 2006), unitless
G_{EF}	=	emission factor (IPCC 2006), g N_2O or CH_4 kg^{-1} of dry matter burned
1000	=	converting Mg to kt

A3.4.8. CO_2 Emissions from Liming and Urea Fertilization

A3.4.8.1. CO_2 Emissions from Liming

With the implementation of the 2006 IPCC Guidelines, the reporting of limestone emissions has been transferred from the Cropland remaining Cropland category of LULUCF to the Agriculture Sector. Limestone ($CaCO_3$) is often used to neutralize acidic soils, increase the availability of soil nutrients, in particular phosphorus, reduce the toxicity of heavy metals, and improve the crop growth environ-ment. During this neutralization process, CO_2 is released in bicarbonate equilibrium reactions that take place in the soil.

The rate of CO_2 release varies with soil conditions and the types of compounds applied. In most cases, lime is applied repeatedly. Thus, for the purposes of the inventory, it is assumed that the annual rate of lime is in near equilibrium with the consumption of lime in previous years. Emissions associated with lime application are calculated from the amount of lime applied annually.

The amount of C released as a result of limestone application is calculated using the default IPCC Tier 1 approach (IPCC 2006):

Equation A3–55:

$$CO_2\text{-}C\ Emission = \sum \left(M_{Limestone/dolomite,i} \bullet EF_{Limestone/dolomite}\right)$$

where:

CO_2-C Emission	=	annual C emissions from lime application, Mg C/year
$M_{Limestone/dolomite,i}$	=	annual amount of limestone and dolomite consumption in province i, Mg/year
$EF_{Limestone//dolomite}$	=	0.12, limestone emission factor or 0.13 dolomite emission factor (IPCC 2006)

The quantity of lime and dolomite used for agricultural purposes is not collected through the *Census of Agriculture* by Statistics Canada, but rather through Natural Resources Canada's *Canadian Minerals Yearbook* (1990 to 2006). For more recent years, this information is only available on request[21]. This data source provides a consistent and complete time series of activity data on agricultural lime consumption in Canada. As this data source provides no information on the ratio of dolomite to limestone, the ratio from data collected through consultation with the Canadian Fertilizer Institute was used.

The 95% confidence limits associated with annual lime consumption data were estimated to be ±30%. This uncertainty was assumed to include the uncertainty of lime sales, the uncertainty of when lime sold is actually applied, and thus the uncertainty in the timing of emissions. The uncertaintyin the emission factor was assumed to be 50% based on the 2006 IPCC Guidelines.

21 [NRCan] Natural Resources Canada. 2007-2015. Canada, Production of Limestone – Stone. Unpublished data. Natural Resources Canada, Mineral & Mining Statistics Division.

A3.4.8.2. CO_2 Emissions from Urea Fertilization

When urea or urea-based nitrogen fertilizer is applied to soil to augment crop production, CO_2 is released upon hydrolysis as follows:

$$(NH_2)_2 CO_2 + H_2O \rightarrow NH_4^+ + OH^- + CO_2$$

In addition to urea, Canadian farmers also use significant amounts of urea ammonium nitrate (28-0-0) with a mixture of 30% $CO(NH_2)_2$. CO_2 emissions from urea fertilization can be estimated using Equation A3–56:

Equation A3–56:

$$CO_2\text{-}C\ Emission = \sum (M_{Urea,i} \times EF_{Urea})$$

where:

CO_2-C Emission	=	annual C emissions from urea application, Mg C/year
$M_{Urea,i}$	=	annual amount of urea fertilization, Mg/year
EF_{Urea}	=	0.20, emission factor (IPCC 2006)

Statistics Canada collects and publishes annual fertilizer sales data, including urea and urea ammonium nitrate (Statistics Canada 2015a).The uncertainty estimate associated with the emissions is assessed based on simple error propagation using survey uncertainty of ±15% for the activity data and an uncertainty of -50% associated with the EF specified in the 2006 IPCC Guidelines.

A3.5. Methodology for the Land Use, Land-use Change and Forestry Sector

The Land Use, Land-use Change and Forestry (LULUCF) Sector of the inventory includes estimates of greenhouse gas (GHG) emissions and removals associated with managed lands and with the conversion of land from one category to another.

As in Chapter 6, the structure of this annex attempts to maintain the land-based reporting categories, while grouping related data collection and estimate development methodologies. Section A3.5.1 summarizes the spatial framework for estimate development and area reconciliation. The general approach for estimating carbon stock changes, emissions and removals in all forest-related categories, including Forest Land, Forest Land converted to other land uses and Land converted to Forest Land, is briefly described in Section A3.5.2; this description is not repeated under the Forest Land converted to Cropland, Forest Land converted to Wetlands and Forest Land converted to Settlements categories. The approach for estimating emissions associated with the use and disposal of Harvested Wood Products (HWPs) from wood harvested in Canada is described in Section A3.5.3. Section A3.5.4 describes methods to quantify the effect of management practices on agricultural land for the Cropland category. Likewise, the sections on the Grassland (A3.5.5), Wetlands (A3.5.5.1) and Settlements (A3.5.6) categories focus on category-specific estimation methodologies.

A3.5.1. Spatial Framework for LULUCF Estimate Development and Area Reconciliation

Canada's monitoring system for LULUCF draws on the close collaboration among several scientists and experts in different disciplines. Early on, it was recognized that the approaches, methods, tools and data that are available and most suitable for monitoring human activities in one land category are not always appropriate for another. Differences exist in the spatial framework specific to each land category, and these differences create a risk that activity data and estimates would be spatially inconsistent. A hierarchical spatial framework was agreed upon by all partners contributing to the LULUCF Sector to ensure the highest possible consistency and spatial integrity of inventory estimates.

The LULUCF Sector of the GHG inventory reports information in 18 reporting zones (Chapter 6, Figure 6-1). These reporting zones are essentially the same as the ecozones of the National Ecological Framework, a hierarchical, spatially consistent national ecosystem classification (Marshall et al. 1999). For the purpose of reporting LULUCF estimates, three ecozones are split in smaller land units: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairie ecozone is divided into a semi-arid and a subhumid component. These subdivisions do not alter the hierarchical nature of the spatial framework. Land and water areas for each reporting zone are compiled according to McGovern (2014) and reported annually in Chapter 6.

Analysis units are the finest level of spatial resolution and are specific to each estimation system. In managed forests, the analysis units are the geographic intersection of reporting zones (Chapter 6, Figure 6-1) and provincial/territorial forest management units. For the purpose of this assessment, managed forests were classified into 607 analysis units across 12 provinces and territories (Nunavut excluded since there is no managed forest area in this northern region) (Table A3–51). Changes in the number of spatial analysis units may occur from one submission to the next and reflect refinements in the integration of multiple spatial layers. For example, the modification of administrative boundaries, timber areas and parks can result in units that do not meet the criteria for separate analysis; these units are therefore regrouped.

Table A3–51 Spatial Analysis Units of Managed Forests

Province/Territory	Number of Analysis Units
Newfoundland and Labrador	24
Prince Edward Island	1
Nova Scotia	1
New Brunswick	1
Quebec	129
Ontario	52
Manitoba	70
Saskatchewan	40
Alberta	181
British Colombia	65
Yukon	13
Northwest Territories	30
Nunavut	0
Canada	**607**

The most suitable spatial framework for GHG monitoring of cropland are the polygons of the Soil Landscapes of Canada[22] (SLC). A soil landscape describes a group of soils and their associated landscapes and provides information, such as surface form, slope, typical soil carbon content under native and dominant agricultural land use, and water table depth. Soil landscapes are spatially associated with SLC polygons (the analysis units) that may contain one or more distinct soil

22 Available online at http://sis.agr.gc.ca/cansis.

landscape components. The SLC polygons are the basic units of Canada's National Ecological Framework: the 12 353 SLC polygons are nested in the next level of generalization (1027 ecodistricts), which are further grouped into 194 ecoregions and 15 ecozones. SLC polygons span in the order of 1000 to 1 000 000 hectares (ha) and are appropriate for mapping at the scale of 1:1 million.

Analysis units for estimating the areas of forest converted to other land uses are the result of the spatial intersection of forest conversion strata (Figure A3–14) with ecological and administrative boundaries. Forest conversion strata were developed on the basis of expected conversion rates and characteristics. The sampling approach used to monitor forest conversion requires analysis units to be (i) as consistent as possible with respect to the patterns of forest conversion and (ii) large enough to provide an acceptable sample size given the predetermined sampling rate.

The analysis units of different land-use categories can overlap. Most often, the exact location of events, within a unit is not known. Therefore, the activity data pertaining to different land-use categories cannot be harmonized at the level of analysis units. The spatial harmonization is conducted within 60 reconciliation units (RUs), which are derived from the spatial intersection of reporting zones with provincial and territorial boundaries. Quality control and quality assurance procedures are conducted at the level of analysis units during estimate development and at the level of RUs during estimate compilation.

A3.5.2. Forest Land and Forest-related Land-use Change

A3.5.2.1. Carbon Modelling

The estimation of carbon stock changes, emissions from and removals by managed forests, forest conversion to other land uses, and land converted to forest land is conducted with version 3 of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) (Kurz et al. 2009), the most recent of a family of models whose development goes back to the late 1980s (Kurz et al. 1992). The

Table A3–52 Forest Carbon Pools in IPCC and CBM-CFS3

IPCC Carbon Pools		Pool Names in CBM-CFS3
Living Biomass	Above-ground biomass	Merchantable stemwood Other (submerchantable stemwood, tops, branches, stumps, non-merchantable trees) Foliage
	Below-ground biomass	Fine roots Coarse roots
Dead Organic Matter (DOM)	Dead wood	Above-ground fast Below-ground fast Medium Softwood stem snag Softwood branch snag Hardwood stem snag Hardwood branch snag
	Litter	Above-ground very fast Above-ground slow
Soils	Soil organic matter	Below-ground very fast[1] Below-ground slow Black carbon[2] Peat[2]

Notes:
1. Below-ground very fast pool includes dead and decaying fine roots, which in practice cannot be separated from soil.
2. Black carbon and peat are currently not estimated.

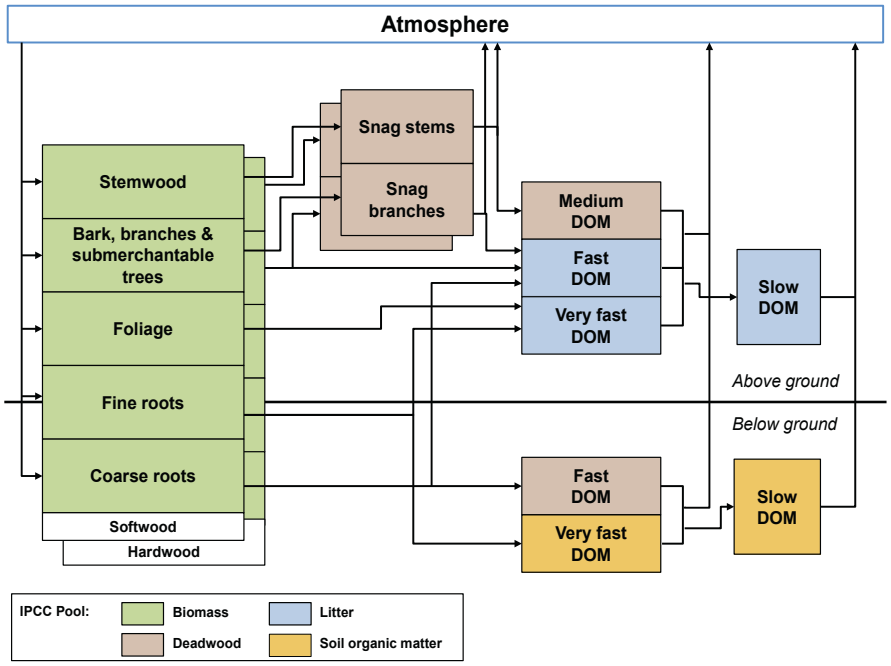
model integrates forest inventory information (stand age, area and species composition), curves of merchantable volume over age, equations to convert stand merchantable volume into total biomass, data on natural and anthropogenic disturbances, and simulations of carbon transfers between pools and exchanges with the atmosphere that are associated with ecosystem processes and various events.

The ecosystem processes modelled by the CBM-CFS3 to generate the estimates submitted in this report are growth, litterfall, non-disturbance tree mortality and decomposition. The CBM-CFS3 also models events, such as management activities, forest conversion and natural disturbances. Management activities represented are clear-cutting, shelterwood harvesting, seed tree harvesting, selection harvesting, commercial thinning, pre-commercial thinning, salvage cutting, residential firewood harvesting and the burning of harvest residues. Different practices of forest conversion are also simulated, including controlled burning.

The forest carbon pools represented in the CBM-CFS3 can be matched to the Intergovernmental Panel on Climate Change (IPCC) forest carbon pools (Table A3–51. Although not shown here, living biomass pools are further subdivided into two sets, for each of hardwood and softwood tree species.

Annual ecosystem processes events are simulated as carbon transfers between carbon pools executed at each time step (annually) in every inventory record (Figure A3–9). During annual processes, carbon is taken up in the biomass pool and some biomass carbon is transferred to dead organic matter (DOM) pools. The decay of DOM results in carbon transfer to another DOM pool (e.g. stem snags to medium deadwood pool), to a slow soil pool or to the atmosphere. More information on pool structure and decay rates is provided in Kurz et al. (2009). Rates of carbon transfer are defined for each pool, based on pool-specific turnover rates (for biomass pools) or decay rates (DOM and soil pools). Turnover rates can be either very

Figure A3–9 Carbon Pools and Transfers Simulated by the CBM-CFS3



Source: White et al. (2008), updated

high (e.g. 95% for hardwood foliage) or very low (e.g. < 1% for stemwood). Annual decay rates are defined for a reference mean annual temperature of 10°C and exhibit temperature sensitivity according to defined Q_{10} relationships; the decay rates vary between 50% (very fast DOM pools, such as dead fine roots) and 0.0032% (slow soil pool).

Growth is simulated as an annual process. Each of the records (≈ 3 million) in the 607 analysis units of the forest inventory is associated with a yield curve that defines the dynamics of merchantable volume over time. Assignment of an inventory record to the appropriate curve is based on a classifier set that includes province, ecological stratum, leading species, site productivity class and several other classifiers that differ between provinces and territories. Curve libraries for each province and territory in Canada are similar to those used by resource management agencies in the forest planning processes and are derived from permanent or temporary sample plots or from forest inventory information.

Conversion of merchantable volume curves to above-ground biomass curves is performed with a set of equations developed for Canada's National Forest Inventory (Boudewyn et al. 2007). These equations derive the above-ground biomass of each stand component from merchantable stemwood volume (per ha), for each province/territory, ecozone, leading species or forest type. Finally, below-ground biomass pools are estimated using regression equations (Li et al. 2003). Mean annual increments are not used in this derivation.

Modelling of carbon transfers triggered by disturbances is based on the disturbance type and severity, the forest ecosystem affected and the ecological region. For modelling purposes, different

Figure A3–10 Disturbance Matrix Simulating the Carbon Transfers Associated with Clearcut Harvesting and Salvage Logging applicable in all ecozones except those in Alberta and Quebec

	13	14	15	16	17	18	19	24	25	Products
1. Softwood merchantable					0.15					0.85
2. Softwood foliage	1									
3. Softwood others			1							
4. Softwood sub-merch			1							
5. Softwood coarse roots			0.5	0.5						
6. Softwood fine roots	0.5	0.5								
7. Hardwood merch					0.15					0.85
8. Hardwood foliage	1									
9. Hardwood other			1							
10. Hardwood submerch			1							
11. Hardwood coarse roots			0.5	0.5						
12. Hardwood fine roots	0.5	0.5								
13. Above-ground very fast soil C	1									
14. Below-ground very fast soil C		1								
15. Above-ground fast soil C			1							
16. Below-ground fast soil C				1						
17. Medium soil C					1					
18. Above-ground slow soil C						1				
19. Below-ground slow soil C							1			
20. Softwood stem snag					0.5					0.5
21. Softwood branch snag			1							
22. Hardwood stem snag					0.5					0.5
23. Hardwood branch snag			1							
24. Black C								1		
25. Peat									1	

practices of forest conversion are also implemented as disturbances. The impact of a disturbance is represented by a disturbance matrix, which specifies, for one or more disturbance types, the proportion of carbon in each ecosystem pool that is transferred to other pools, released to the atmosphere or transferred to Harvested Wood Products (Figure A3–10). In the 2017 submission, the simulation uses a total of 139 disturbance matrices. The number of different disturbance matrices is dependent on the availability of activity data (e.g. the spatial and temporal resolution of disturbance data) and on the knowledge required to parameterize the matrices for more distinct regions or intensities of disturbance.

Within disturbed lands, the proportion of CO_2-C emitted from each pool at the time of disturbance, documented in each disturbance matrix, can be specific to the pool, the types of forest and disturbance intensity, and the ecological zone. There are therefore no CO_2 emission factors applicable to all disturbances of a given type, such as fires. With a few exceptions, the proportion of total carbon emitted in each carbon containing GHG (CO_2, CO, and CH_4) due to fire is constant: 90% of carbon is emitted as CO_2, 9% as CO and 1% as CH_4 (Cofer et al. 1998; Kasischke and Bruhwiler 2003).

While the CBM-CFS3 can model carbon fluxes at various spatial scales, generating national estimates involves harmonizing, integrating and ingesting vast quantities of data from a great diversity of sources. The next section documents the key data sources used for this submission.

A3.5.2.2. Data Sources

A3.5.2.2.1. Managed Forest Land

Canada's forests are classified as "managed" or "unmanaged" based on the occurrence of management activities for timber or non-timber and on the level of protection against disturbances (Figure A3–11). Managed forests occur within all provinces and territories of Canada, with the exception of Nunavut (Figure A3–12). The estimation of the managed forest area required the spatial delineation and combination of boundaries of many different forest areas, including all operational forest management units, timber supply areas, tree farm licences, industrial freehold timberland, private woodlots and any other land in the Forest category where there is active management for timber or non-timber resources, as well as forest areas where there is intensive protection against natural disturbances. All these layers are aggregated and intersected with underlying forest inventory data. The procedures are documented in Stinson et al. (2006b).

The model tracks managed forest lands disturbed by harvesting before and after 1990, lands affected by various natural disturbances since 1990, and lands not affected by any disturbances since 1990. Lands not affected by disturbances since 1990 are broken down into stands created by harvesting or by stand-replacing wildfires prior to 1990. All areas of land in 1990 that were not identified as being of harvest origin were assumed to be of wildfire origin (there is no information on insect disturbances prior to 1990). These distinctions are used to separate stands dominated by anthropogenic and natural emissions and removals (see Section A3.5.2.3).

Forest management activities are documented in the National Forestry Database[23] and additional information on specific activities is obtained directly from provincial and territorial forest management agencies. The Canadian provincial and territorial governments, whose jurisdiction includes natural resource management, provides essential information—notably detailed forest inventory data, details on forest management activities and practices, disturbance information including prevention or control, regional yield tables (volume/age

23 National Forestry Database, available online at http://nfdp.ccfm.org/about_us_e.php.

Table A3–53 Main Sources of Information and Data, Managed Forests

Description	Source	Spatial Resolution	Temporal Coverage	Reference
Climate data	CFS	Analysis units	1961–1990 normals	McKenney et al. 2001
Forest inventories & merchantable volume data[1]	Canada's National Forest Inventory (CanFI)	CanFI grid cell	1949–2004	https://nfi.nfis.org/index.php
	Newfoundland	Analysis units	1991–2006	Provincial experts
	Prince Edward Island	Analysis units	2000	Provincial experts
	Nova Scotia	Analysis units	2006	Provincial experts
	Quebec	Analysis units	2000	Provincial experts
	Ontario	Analysis units	2000	Provincial experts
	Alberta[2]	Analysis units	1949–1999	Provincial experts
	British Columbia	Analysis units	2011	Provincial experts
Conventional Harvest data3	National Forestry Database	Provincial boundaries	1990–2015	http://nfdp.ccfm.org/
	National Forestry Database	Analysis units	1990–2015	http://nfdp.ccfm.org/
Slash Bburning	National Forestry Database and British Columbia	Provincial boundaries	1990–2015	Provincial experts and http://nfdp.ccfm.org/
Residential firewood harvest data	Energy Sector data for residential firewood use	Provincial boundaries	1990–2015	Section A3.1.4.1.4
Insect data	Forest Insect and Disease Survey	Spatially explicit	1990–2015	Atlantic Forestry Centre and Pacific Forestry Centre
	Newfoundland	Spatially explicit	2000–2003	Provincial experts
	Manitoba	Spatially explicit	1990–1998	Provincial experts
	Saskatchewan	Spatially explicit	1998–2001	Provincial experts
	Alberta	Spatially explicit	1990–2015	Provincial experts
	British Columbia	Spatially explicit	1990–2015	Provincial experts
	Yukon	Spatially explicit	1994–2005	Provincial experts
Fire data	National Burned Area Composite	Spatially explicit	2004–2015	http://www.nrcan.gc.ca/node/13159
	Canadian National Fire Database	Spatially referenced	1959–2003	http://www.nrcan.gc.ca/node/13159

Note:

1. Forest inventory and merchantable wood volume yield data were obtained from Canada's National Forest Inventory and/or obtained from provincial experts where specified.
2. Alberta's forest inventory database is comporised of provincial forest inventory for the province's Forest Management Areas, and CanFI inventory for the remainder of the managed forest landbase.
3. Given the absence of complete harvest data for the most recent reporting year for all provinces and territories, 2015 harvest data are estimated by assuming them to be equal to 2014 values.

Figure A3–11 Decision Tree for the Determination of Managed Forest Area

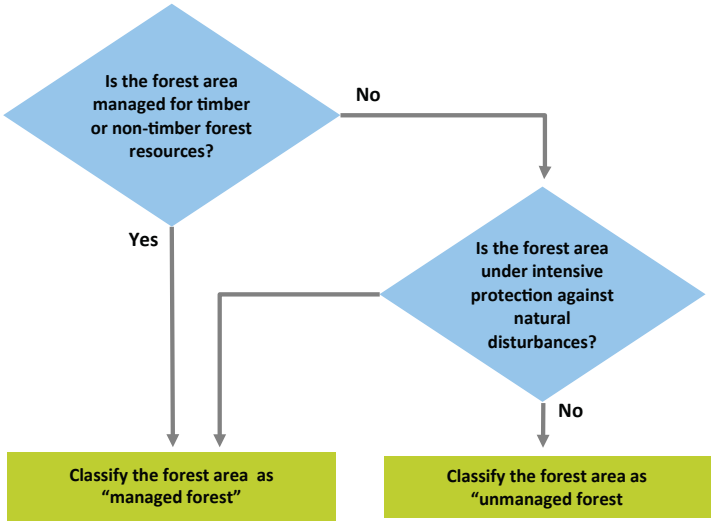
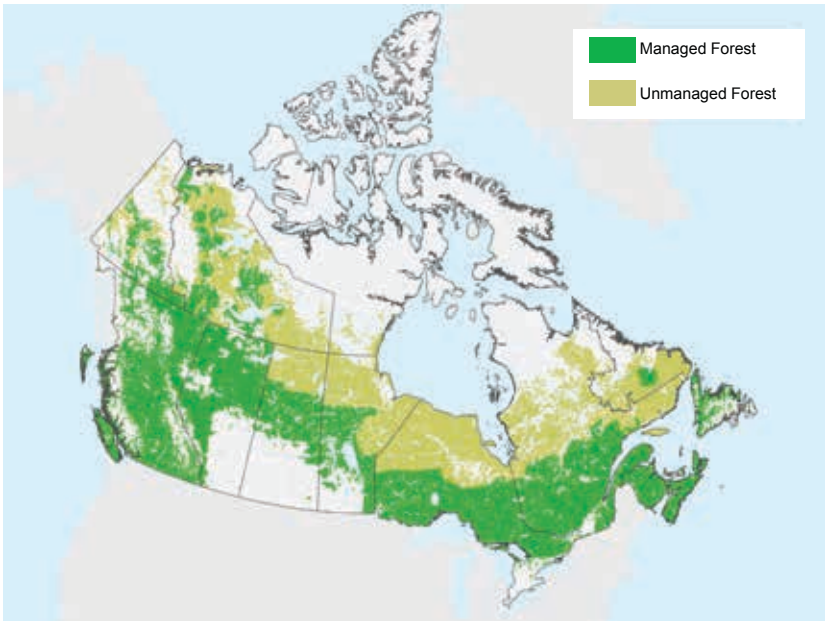


Figure A3–12 Lands with Managed and Unmanaged Forests in Canada



curve), site indices—and regional expertise (Table A_3–53). The forest inventory data in Canada's National Forest Inventory (CanFI 2001) were used for New Brunswick, Manitoba, Saskatchewan, Yukon and the Northwest Territories. More recent and higher-resolution inventory data were provided by Prince Edward Island, Newfoundland and Labrador, Nova Scotia, Quebec, Ontario, British Columbia and Alberta. A series of "methods papers" describe the compilation process for each provincial and territorial forest inventory. Since forest inventory data were not collected in the same years, additional steps were necessary to synchronize the inventory data to the year 1990 (Stinson et al. 2006a).

Activity data for the burning of harvest residues ("slash") are obtained from the National Forestry Database for all regions except specific areas of British Columbia where expert opinion is used[24]. Data on biomass used as residential firewood are obtained from surveys of residential wood use and origin (TNS 2006, TNS 2012) Section A3.1.4.1.4 of the present report provides additional information. Areas specifically attributed to firewood harvest are defined by the model based on those volume estimates.

Areas disturbed by wildfires were extracted from the Canadian National Fire Database for the years 1990 to 2003 and from the Canadian Wildland Fire Information System's National Burn Area Composite (NBAC) for the years 2004 to 2015 (Table A3–53). The NBAC is a composite of low- and medium-resolution remote sensing data and fire mapping data prepared by the Canadian Forest Service and combined with data provided by resource management agencies from across Canada. The NBAC provides complete mapping of wildfires using medium-resolution remote sensing data when available; data from resource management agencies are given second priority; and low resolution remote sensing data are used only where no other fire mapping data are available.

Insect disturbances are monitored by aerial surveys (Table A3–53), which record the area impacted by the disturbance and assign an impact severity

24 In British Columbia, expert opinion indicates that the proportion of areas harvested using clear-cutting where slash burning is applied is 15% on the coast and 50% for the rest of the province.

class that indicates the degree of tree mortality or defoliation. The area of impact is assigned to the appropriate analysis unit and host species within it, and the severity of the impact is reflected in the parameters of the disturbance matrix applied (Kurz et al. 2009).

A3.5.2.3. Quantifying Anthropogenic Emissions and Removals

Interannual variations and trends in emissions and removals from managed forests are dominated by the impact of wild fires and periodic forest insect outbreaks, making it difficult to detect trends due to human actions in the forest (Kurz et al., 2008; Stinson et al., 2011; Kurz et al. 2013).

The IPCC does not currently provide default methods for separating anthropogenic emissions and removals from those occurring due to natural disturbances, although it has recognized the issues of reporting emissions from natural disturbances for some countries (IPCC 2010). Furthermore, the IPCC (2010) has encouraged countries that use Tier 3 methodologies to work towards the development of new approaches that can improve the identification of anthropogenic emissions and removals. The CBM-CFS3 model now has the capabilities to track and separate emissions and removals in managed forest stands dominated by the impact of anthropogenic activities, from those in stands dominated by the impact of natural disturbances.

The management and natural disturbance history of each individual stand (inventory record) in the managed forest area is used to assign stands in two groups. Emissions and removals are defined as being anthropogenic when i) a stand's growth trajectory has been significantly modified by human intervention – this definition includes commercial clearcut and partial harvest, commercial and pre-commercial thinning, salvage logging, site preparation, and rehabilitation and planting on stands that have undergone both stand replacing and partial natural disturbances – ii) regardless of its origin, a stand has attained commercial maturity and therefore is actively considered within forest management planning scenarios (eligible to be scheduled for harvest). Once a stand originating from natural disturbance has reached this age, emissions and removals re-enter the reported category.

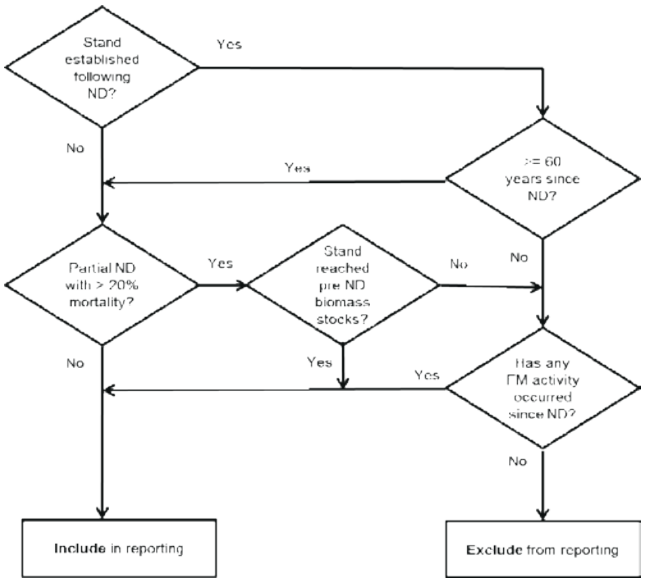
In contrast, emissions and removals resulting from natural disturbance are defined as (i) originating from stands that have been affected by a stand replacing natural disturbance up to the period that stands reach commercial maturity or (ii) originating from stands that have been affected by partial disturbance resulting in reduced standing biomass until that stand has attained pre-disturbance equivalent biomass.

In this initial implementation of the approach, the return period to commercial maturity has been defined as 60 years, as this is approximately the minimum harvest return interval observed in Canada. Regionally specific re-entry criteria based on differences in forest management practices or stand dynamics among regions are currently under development.

In the current modeling framework partial natural disturbances occur mainly due to insect infestations. In these cases, aboveground biomass recovery was used to define a recovery period as the growth trajectory of the stand is only temporarily modified. Stands subject to insect disturbances causing less than or equal to 20% biomass mortality are not deemed to be dominated by natural disturbances; at this low severity level, disturbances are considered agents that contribute to stand density reductions.

Separating stands where emissions and removals are dominated by natural disturbance dynamics is carried out by querying model results based on a decision tree approach in which key decision

Figure A3–13 Decision Tree for the Inclusion and Exclusion of Emissions and Removals from the Reporting



Note: ND = Natural Disturbance, FM=forest management.

points are based on stand origin, type of disturbance (partial or stand replacing), and an annual assessment of post-disturbance status, either commercial maturity threshold or pre-disturbance biomass. Stands dominated by natural disturbance dynamics are temporarily excluded from the reporting (Figure A3–13).

After exclusion of the non-anthropogenic emissions and removals, the final reported values represent all forest stands in the managed forest land base that that have attained commercial maturity or have had their growth trajectory modified by a direct anthropogenic management action in the forest. The area temporarily excluded from reporting in any given year remains relatively constant, within a variation of approximately 2%, as stands undergoing natural disturbance in a given year are removed from reporting and lands that were disturbed historically re-enter reporting. The sum total of each of the stand categories included and excluded is equivalent to the sum of emissions and removals quantified using the methodological approach for reporting total emissions from the managed forest in previous inventory submissions.

A3.5.2.4. Forest Conversion

In order to account for long-term residual effects of forest conversion, conversion rates were estimated starting in 1970. The approach for estimating forest areas converted to other land uses is based on three main information sources: systematic or representative sampling of remote sensing imagery, records and expert judgement/opinion. The basic methods have been tested in several pilot projects (Leckie 2006a), and the methodology has been implemented across the country.

The core method involves remote sensing mapping of forest conversion based on samples from Landsat images dated circa 1975, 1990, 2000, 2007 and 2011. Change enhancements between two dates of imagery are produced to highlight areas of forest cover change and identify possible forest conversion events (i.e. "candidate events"). The imagery is then interpreted to determine: (1) whether the land cover of the candidate event was forest initially (at Time 1); and (2) the actual land-use change at Time 2 (Leckie et al. 2002, 2010a). This forest conversion interpretation process

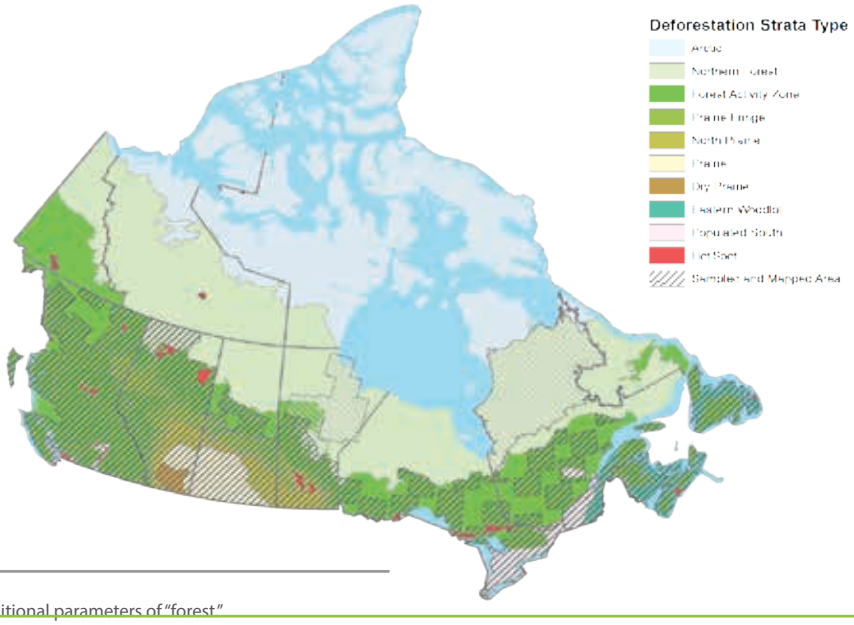
is strongly supported by additional spatial data, including digitized aerial photographs; snow-covered, leaf-off, winter Landsat imagery; secondary Landsat images from other dates and years; ancillary data, such as maps of road networks, settlements, wetlands, woodland coverage and mine and gravel pit locations; and specialized databases giving locations of oil and gas pipelines and well pads (Leckie et al. 2006; Dyk et al 2015). When readily available, detailed forest inventory information is also used.

Change imagery is interpreted and analyzed; each forest conversion event larger than 1 ha is manually delineated. The forest type, maturity and density prior to forest conversion is interpreted,[25] and the post-deforestation land use recorded ("post-class"). Confidence ratings on the land use at the initial time and a later time period are used in subsequent quality control and field validation procedures.

Monitoring of forest conversion activity covers all forest areas of Canada and is not limited to the managed forest. The entire forested area of Canada is broadly stratified into regions of expected forest conversion level and dominant cause, which dictate the target sampling intensity. Depending on the expected spatial patterns and rates of forest conversion, sampling approaches range from complete mapping to systematic sampling over the entire analysis unit of interest to a representative selection of sample cells within a systematic grid. For example, in populated areas of southern Quebec and in the Prairie fringe, a 12% sampling rate was generally achieved, with 3.5 × 3.5-km sample cells at the nodes of a 10 x 10-km grid (Figure A3–15). A lower sampling rate is used in some of the forest activity zones characterized by low population density, where the main economic activities are forestry and other resource extraction. Special cases of known, localized and large forest conversion activities are also identified, such as hydroelectric reservoirs and oil sands development in Alberta. In such cases, the entire areas are handled as single events ("Hot Spot" in Figure A3–14), with spatially complete mapping.

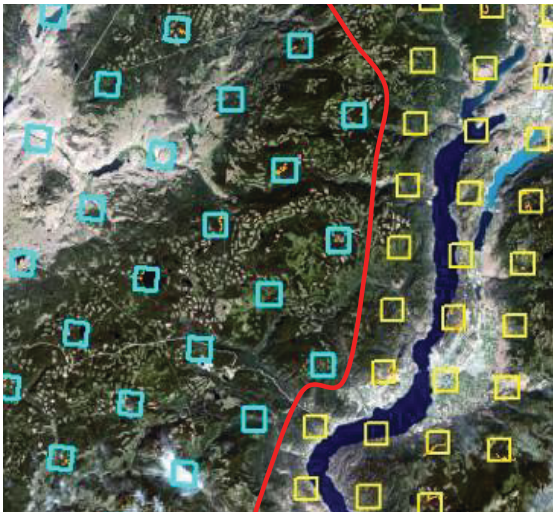
In practice, resource constraints limit the size of the remote sensing sample; wherever possible, a target sampling rate of 12% or 6% was achieved.

Figure A3–14 Forest Conversion Strata and Areas Sampled



25 See Chapter 6 for the definitional parameters of "forest"

Figure A3–15 Sampling Grids Over Satellite Imagery for Forest Conversion Mapping.



Background Imagery: Area Near Kelowna, British Columbia, Landsat TM, Summer 2000.
Denser grid cells at right represent a 12% sampling density; lighter grid on the left is 6% intensity

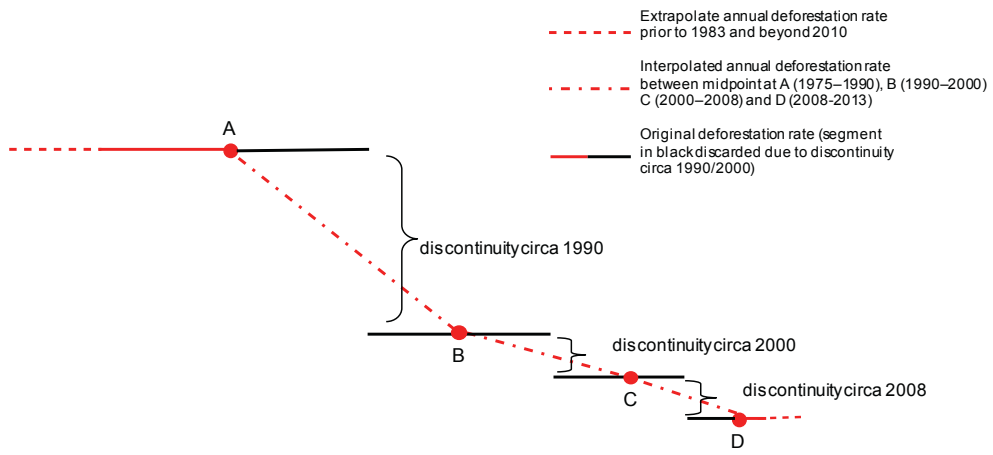
It is also important to note that different sampling rates may be applied for each time period, in an effort to track differing activity rates between time periods. The total areas, either fully mapped or sampled, cover a large portion of the Canadian land base (Figure A3–14, i.e. approximately 346 million hectares (Mha), of which over 17 Mha were mapped for 1975–1990, 41 Mha were mapped for 1990–2000, 22 Mha were mapped for 2000–2008 and 23 Mha were mapped for 2008–2013.

Records were gathered when available. They consist mostly of information on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs (Leckie et al. 2006). The temporal coverage, availability and applicability of these records are assessed to determine the most appropriate information sources (records or imagery). Records data are sometimes used to aid in the validation of estimates made through image interpretation. In particular for British Columbia, records data are used to provide estimates of conversion activity for power lines and oil and gas activity. In northern Quebec, a mix of remote sensing image interpretation and records data are used to assess the areas of forest converted as a result of hydroelectric development.

Expert opinion is only called upon when remote sensing sampling is insufficient and records data are unavailable or of poor quality. Expert judgement is also used to reconcile differences between records and remote sensing information and to resolve large discrepancies in the 1975–1990, 1990–2000, 2000–2008 and 2008–2013 area estimates. In such cases, available expert opinion and data sources are brought together, remote sensing and records data are reviewed, and decisions are made (Leckie 2006b; Leckie et al. 2010b; Dyk et al 2015). For most estimates and certainly for those with large impact, estimates are derived directly from remote sensing samples.

The activity data are compiled and summarized initially by analysis unit. All conversion events are assembled into a database. A compilation is made to summarize events for detailed post-conversion classes for each reconciliation unit. This compilation process also involves insertion of records data and expert judgement. In the course of these procedures, each event is compiled to yield a local forest conversion rate (ha/year) based on the time interval between the images. Since the available imagery was not necessarily

Figure A3–16 Procedure for Developing a Consistent Time Series of Rates of Forest Conversion



dated 1975, 1990, 2000, 2008 or 2013, the rates cover different time periods. At the data compilation phase, forest conversion events are assigned to one of four time periods (1975–1990, 1990–2000, 2000–2008, 2008–2013), and the corresponding rate of forest conversion is assigned to that period. For example, a 7.0-ha event encountered on imagery from the period 1975–1989 would yield a 0.5 ha/year rate (7.0 ha/14 years) and then would be assigned to the period 1975–1990. The total area interpreted in an analysis unit for that time period is then used to determine a relative rate of forest conversion ([ha/year]/km2 interpreted) for all events of the same type. Relative rates are scaled up for each analysis unit. Data are finally grouped by end use (e.g. the change rate for agricultural crop or rural residential) and, in turn, are summarized by broader categories when recompiled by reconciliation unit.

The remote sensing data are derived using medium-resolution imagery from circa 1975, 1990, 2000, 2007 and 2011, whereas records data are annual or summarized over time periods. As explained above, the remote sensing core method provides four distinct average rates of forest conversion for 1975–1990, 1990–2000, 2000–2008 and 2008–2013, but no annual estimates of these rates. The preparation of annual forest conversion rates for 1970–2015 requires the simultaneous application of two procedures: (1) extrapolation of annual rates prior to 1983 and beyond 2010; and (2) linear interpolation between the mid-points in 1975–1990, 1990–2000, 2000–2008 and 2008–2013 data (Figure A3–16). Added to the interpolated data are individual large events for which actual disturbance information is known either from records information or detailed mapping activity. One example of this would be the case of hydroelectric reservoirs.

Quality Assurance/Quality Control of Forest Conversion Data

Great care was taken in understanding the records data, their suitability and their limitations. Documentation of the records data was examined, personnel involved in managing and implementing the data collection and storage were interviewed and, where available, numbers were checked against independent data sources, sampling of high-resolution imagery and the knowledge of experts.

The remote sensing interpretation follows defined procedures (Leckie et al. 2010a; Dyk et al. 2015), although it is conducted by a variety of organizations, including provincial government forestry

or geomatics groups, remote sensing or mapping companies, research and development organizations and in-house government staff. The basic image analysis quality control (QC) process includes: internal checks within the mapping agency or company by a senior person; real-time quality assurance (QA) by Canadian Forest Service specialists during interpretation, with feedback provided within days of interpretation of an area; and a final QA and vetting of the interpretation by the Canadian Forest Service. Field validation is conducted on an ongoing basis as resources permit. Each QC point and revision is documented within the Geographic Information System (GIS) database of conversion events (Dyk et al. 2015).

Records of decision as to data used and expert judgement applied, as well as decisions on the resolution of contradictory data, are documented within the overall processing database (Leckie 2006b) and updated for each new submission (Dyk et al. 2015). Data sources and limitations are recorded, and remote sensing data and interpretations archived.

Uncertainty of Forest Conversion Data

The development of an uncertainty estimate for forest conversion is a complex and difficult task because of its spatial and temporal variability. Compared to earlier estimates, current estimates benefit from several years of experience and knowledge gained through the development of previous estimates (Leckie 2011; Dyk et al. 2015). Specific improvements include:

1. Expanded data sets with additional Earth Observation (EO) data, Landsat (MSSS/TM/ETM/Winter), SPOT-5, aerial photography, and high-resolution satellite imagery.
2. Expansion of the sampled area for targeted and other areas.
3. Analysis and validation of records data with high-resolution imagery (for example, co-disturbance of pipelines and access roads).
4. Extending the temporal coverage to the 2008–2013 period, replacing the previous extrapolation done beyond 2004 with estimates based on more current spatial analysis.
5. Greater knowledge resulting from increased experience and expertise gained through QC review and validation activity.

These improvements result in enhanced detection, delineation and determination of event size and cause, as well as a more accurate estimate of timing of conversion events.

Two approaches were considered to estimate uncertainties: an empirical approach and an analytical approach. The resulting estimate is based on consideration of these approaches and provides an estimate of uncertainty associated with activity area estimates. The additional sources of uncertainty related to the forest type being converted, post-conversion land category and event timing are not considered.

The empirical approach is an attempt to estimate an overall uncertainty in the forest conversion area estimate. This approach provides an estimate that considers all of its varied components and their potential interactions.

The empirical estimate was developed by making estimates of extreme low, low, high and extreme high forest conversion rates for each reconciliation unit and end-use class. These estimates were based on expert knowledge of activity and practices at a regional scale. All of these estimates were then compiled on a national basis. Comparisons between extreme and non-extreme estimates provided some insight into the possible range for which conversion activity could occur. Based on this exercise, an estimate for overall uncertainty for forest conversion was determined to be in the range of ±20% to ±30%.

The analytical approach breaks the uncertainty down into subcomponents and then combines them through simple error propagation. The components considered are omission and commission, sampling, and boundary delineation errors.

Omission and commission errors are influenced by a number of factors, but in particular are dependent on the date and quality of pre- and post-imagery. Throughout the time series, there

is a tendency for omitted events to be smaller in size, whereas commission errors are usually from a misinterpretation rather than an oversight, and thus are less size-dependent. Commission and omission errors tend to offset each other. For the post 2000 time periods, commission errors are likely to be greater than omission errors, particularly because of an insufficient post-disturbance time lapse to confirm that areas are in fact permanently deforested.

Uncertainty associated with boundary delineation errors considers the errors resulting from the displacement of the event boundary from the actual or true boundary of the event. Both underestimation and overestimation of area can result. This source of uncertainty is greatly influenced by the quality and resolution of imagery used in the delineation process; improvements made in resolution and image quality reduce this source of uncertainty.

Estimates of sampling uncertainty take into account the uncertainty associated with the sampling process and the scaling of estimates to large regions (strata/reconciliation units). The sampling process is a mixture of wall-to-wall mapping and systematic sampling. In some areas, the sample coverage and design differed between all of the mapping periods. The sample error depends on the amount of activity in each region within each time period sampled. In addition, it is dependent on the conversion event size and spatial distribution (Leckie et al. 2015). Uncertainty due to sampling and scaling activity is therefore regionally variable, and, because conversion activity causes may vary by region, the uncertainty is variable.

The results of this analytical approach are consistent with those made based on an empirical approach. Based on these efforts, a conservative estimate is taken, which sets the uncertainty at the higher range of ±30%. Further work will help improve the current understanding of the various sources of uncertainty, their interaction, and approaches used to combine these components.

The ±30% range is an overall estimate considering all time periods, regions and forest conversion types. Caution should also be exercised in applying the 30% range to the cumulative area of forest land converted to another category over the last 20 years, or 10 years for reservoirs (land areas reported in the CRF tables).

Land Converted to Forest Land

Records of land conversion to forest land in Canada were available for 1990–2002 from the Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) initiative (White and Kurz 2005). Conversion activities for 1970–1989 and 2003–2008 were estimated based on activity rates observed in the FAACS data. Additional information from the Forest 2020 Plantation Demonstration Assessment was included for 2004 and 2005, and an environmental scan was performed to identify additional sources of information on afforestation rates during 2000–2008. Each event, regardless of date, source, type or location, was converted to an inventory record for the purposes of carbon modelling. All events were compiled in a single data set of afforestation activity in Canada from 1970 to 2008. No new afforestation activity data were identified for the 2009–2015 inventory years. Renewed efforts are underway to obtain additional data on recent afforestation activities in Canada.

For 1990–2008, the area planted was stratified by ecozone, province and tree species. Total area planted by province and ecozone, in conjunction with the proportion of species planted for each province, was used to calculate area planted by species, resulting in estimates of the area converted to forest, by species, for each reconciliation unit.

Yield curves are not always available for some plantation species or growing conditions (stocking level or site history); those used to estimate growth increments were taken from a variety of sources, most often directly from provincial experts. Where species do not have their own yield curve, they are given the yield curve of another species with similar growth characteristics or the species most

likely to have been present in that area. 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 is minimal.

A3.5.2.5. Estimation of Carbon Stock Changes, Emissions and Removals

At the beginning of each annual time step and when an afforestation or forest conversion event is processed, the CBM-CFS3 first assigns the new land-use classification before the impacts of that event are recorded to ensure that the impacts of land-use change (conversion to forests and conversion of forests) are reported in the new land category. The selection of forest stands affected by land-use change and non–land-use change disturbances is based on eligibility rules (Kurz et al. 2009).

Once the model has computed the immediate effect of disturbances on all forest stands, it simulates forest growth, litterfall and turnover, and decomposition as well as the associated carbon transfers (annual processes) for all records (managed forest, land converted to forest and land converted from forest), including both stocked and non-stocked stands. The model output consists of carbon stock changes, fluxes and immediate emissions from burning from which the net GHG balance of managed forests can be calculated. Component fluxes include growth, immediate emissions due to disturbances (carbon stock changes, carbon losses to the atmosphere and to forest products), and decay of both DOM and soil organic matter, including on stands affected by disturbances. During this stage, inventory records that have been in a "Land converted to" category for 20 years are converted into the "Land remaining" category, and the simulation of C dynamics—usually decay—continues in this new category.

The same data output are available on converted forest lands (except tree growth), but are reported in the new land category—e.g., the Land converted to Cropland (CRF Table 4.B Row 2), Land converted to Wetlands (CRF Table 4.D Row 2), and Land converted to Settlements (CRF Table 4.E Row 2) categories. Exceptions consist of estimates of soil organic matter emissions on forest land converted to cropland and peat extraction fields, which are developed separately; methods are described in sections A3.5.4.3 and A3.5.6.1. Likewise, estimation methods for emissions (as opposed to carbon stock changes) from forest land converted to flooded lands are described in Section A3.5.6.2.

A3.5.2.6. Uncertainties

Good practice recommends the use of numerical methods for assessing uncertainties within complex modelling frameworks with multiple interactions between data and parameters. These methods are data-intensive, and computational requirements can quickly become a limiting factor. Not all model parameters or input data have equal influence on model outputs. Careful consideration must therefore be given to balance available computing capacity and the inclusion in the uncertainty assessment of input data, parameters and other functions with a large influence on model outputs.

The general approach to uncertainty assessment emphasizes model inputs and parameters as the main sources of uncertainty. The specific uncertainty sources are forest inventory data, influential model parameters and the initialization of soil and dead organic matter C stocks prior to model runs. Additional randomization steps are also fed into the development of confidence intervals, by randomly selecting 10 000 bootstrap samples of

the output from 100 national-scale Monte Carlo runs. Not all sources of uncertainty have been captured. Importantly, the analysis did not consider the impact of processes that are currently not simulated (Kurz et al. 2013); hence, the results should not be used to assess potential bias (or accuracy) of estimates. The following paragraphs provide details on the characterization of uncertainty sources.

The forest inventory data used in model simulations are developed for planning and operational purposes. Methods, standards, definitions and quality differ by jurisdiction, depending on their objectives. Although documentation on the different inventory techniques and procedures used across the country is usually available, it seldom contains any quantitative assessment of uncertainty. While it is currently impossible to quantify uncertainties about, for example, managed forest areas, the influence of this uncertainty source can be indirectly built into the uncertainty about the biomass increment simulated by the model. For the purpose of this assessment, a 50% uncertainty about biomass increment is assumed. In addition to managed forest areas, it incorporates uncertainties about the age-class distribution, yield curves and allometric equations that enter the estimation.

The areas of managed forests affected annually by both natural and anthropogenic disturbances have a large influence on forest carbon dynamics as a whole. Disturbances affect emissions and removals of C in the short term, and in the long term through residual decay and age-class distribution. Uncertainties of 10% and 25% are assumed on the areas of managed forests subject annually to wildfires and insect infestations, respectively.

The uncertainties about the carbon removed in harvested material are regionally specific and incorporate error ranges in harvested volume (±1%) and standard deviations about roundwood specific gravity and bark adjustment factor (Table A3–54). No error was assumed for the carbon proportion of biomass. The annual coefficient of variation was multiplied by 2 to approximate a normal distribution with a triangular one.

The assessment also provides uncertainties about emissions due to forest conversion. Here, a 30% uncertainty about areas converted annually is used. The "Forest Conversion" section of this annex describes the derivation of this value.

Soil and DOM pools contain a considerable amount of carbon. Previous work has shown that the initial DOM C stocks, at the beginning of a complete run, are sensitive to historical disturbance rates. In this assessment, initial C stocks in the soil and DOM pools were allowed to vary by modifying the historical (pre-1990) fire return intervals. Even though the rates of soil organic matter decay modelled by the annual processes are very low, they do, by virtue of the pool size and forest areas, strongly influence emissions from annual processes. A sensitivity analysis of carbon emissions from the dead organic matter and soil pools revealed that the most influential model parameters included decay rates for soil organic matter and the decay

Table A3–54 Uncertainty Ranges for Harvested Carbon, by Canadian Province and Territory

Province/Territory	Minimum Multiplier	Maximum Multiplier
Newfoundland	0.96	1.04
Prince Edward Island	0.88	1.12
Nova Scotia	0.88	1.12
New Brunswick	0.92	1.08
Quebec	0.86	1.14
Ontario	0.92	1.08
Manitoba	0.86	1.14
Saskatchewan	0.92	1.08
Alberta	0.90	1.10
British Columbia	0.92	1.08
Yukon	0.84	1.16
Northwest Territories	0.74	1.26

Source: Metsaranta et al. (2014)

and release to the atmosphere of carbon from very-fast cycling pools, such as dead fine roots and litter (White et al. 2008).

For the purpose of this analysis, 28 model parameters are allowed to vary in the Monte Carlo runs:

- base decay rates for DOM pools (11 parameters);
- proportion of decayed material that is oxidized, versus that which is transferred to another DOM pool (5 parameters);
- turnover rates for biomass pools (12 parameters).

In the absence of evidence to support more complex functions, all input probability distribution functions for biomass increments, activity data on human and natural disturbances and decay parameters are triangular. A gamma probability distribution function is used for fire intervals (Metsaranta et al. 2014).

It is thought that significant uncertainty in the modelling framework may result from the random selection of forest stands subject to fire and deforestation disturbances (Kurz et al. 2008b), which interacts with the uncertainty about forest inventory data. The random effect of stand selection algorithms is included in the analysis by allowing different seed values to initiate the random selection algorithms.

It is important to note the interactions between input data and parameters. For example, the uncertainty about the age of a forest stand (or age-class structure of a forest landscape) may affect the simulated stand (or landscape) productivity, depending on the yield curves and the particular locations of a given age category along those curves. Emissions due to disturbances—including the conversion of forests to other land categories—are driven not only by the areas affected, but also the pre-conversion standing carbon stocks, the parameters of the disturbance matrices that re-allocate carbon among pools or "release" it to the atmosphere, and the post-conversion decay rates. Hence, uncertainties about estimates cannot be obtained from a simple combination of "activity data" and "emission factor" uncertainties.

Uncertainty estimates were developed for both reported emissions and removals representing anthropogenic drivers and non-reported emissions and removals due to natural disturbances. Total uncertainty estimates were allocated to the reported and non-reported categories using the same categorization procedures used to estimate reported and excluded values (see Section A3.5.2.3).

Additional considerations may be warranted to identify the direct human-induced effects, and their uncertainties, on forest carbon dynamics. Improvements are expected to occur over coming years, due to better knowledge, refined procedures, improved computer software implementations, and access to more computing capacity.

A3.5.3. Harvested Wood Products

The LULUCF Sector of the inventory includes an estimate of the CO_2 emissions associated with the use and disposal of harvested wood products (HWP) manufactured from wood coming from forest harvest and forest conversion activities in Canada, and consumed either in Canada or elsewhere in the world, in accordance with the general framework of the production approach described in the Annex to Volume 4, Chapter 12 of the 2006 IPCC Guidelines (IPCC 2006). The approach tracks the fate of C in all woody biomass harvested domestically and taken off-site. Emissions of CO_2 from HWP use and disposal are estimated and reported by the LULUCF Sector, while CH_4 and N_2O emissions from HWP combustion or domestic decomposition are estimated and reported by the Energy and Waste sectors.

General Approach and Methods

A country-specific model, called the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP), was developed to estimate and report on the fate of C harvested in Canada's forests.

Model Inputs and Data Sources

Input to the model includes the annual mass of C transferred to forest products that result from conventional harvesting, deforestation harvesting, and residential firewood harvesting in forest lands and from forest conversion activities since 1990. It is spatially distributed by RUs (see Section A3.5.1), as calculated by the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3, see Section A3.5.2.1), thus ensuring there are no gains or losses as C flows from forests to products.

Data on the annual volume of residential firewood and industrial wood waste used for bioenergy are provided by the Energy Sector. In the case of residential firewood, the data come from a third party survey (referred to as Canadian Facts 1997, TNS 2006, and TNS 2012), funded by Natural Resources Canada and Environment and Climate Change Canada, of residential wood use conducted in 1996, 2006 and 2012. The survey results are interpolated between survey years or extrapolated for the years prior to 1996 and after 2012, based on provincial data on number of households using firewood collected by province and grouped into five major appliance categories: conventional stoves, stove/fireplace inserts with advanced technology, conventional fireplaces, furnaces, and other equipment (see Section A3.1.4.1.4 for more details on these surveys). In the case of the industrial consumption of firewood (biomass and spent pulp liquors), the quantities of wood biomass come from the annual *Report on Energy Supply and Demand in Canada* (RESD).

For historical harvest, the C input comes from commodity production data from Statistics Canada, at a national level of spatial resolution and covering the period 1941–1989.

Model Flow and Parameters

The model uses a conceptual flow network describing the movement and transformation of harvested wood once it leaves the forest (Figure A3–17). The model takes the C inputs and, in annual time steps, exports some of the harvested roundwood, converts all harvested wood into commodities (sawnwood and other-industrial roundwood, wood-based panels, paper and market pulp, and residuals referred to as 'milling waste'), exports some of the commodities produced, and keeps track of the additions to and retirement from HWP in-use and used for bioenergy. The complete model consists of 15 such networks—one for each province and territory (except Nunavut), plus one each for the United States and Japan, and one that combines all other importers of Canadian wood products. The on-site decay of harvest residues continues to be captured in C stock changes in the DOM pool of the Forest Land category.

The FAO database of forestry trade flows was used to determine the proportion of Canadian roundwood and commodity production exported to the three main destinations. For example, in any given year, around 98% of industrial roundwood from domestic harvest remains in Canada for further transformation, of which about 67% is converted to sawnwood, wood-based panels, other industrial roundwood or pulp and paper products. Likewise, over the entire time series, around 32% of sawnwood, between 19% and 65% of wood-based panels and less than 10% of pulp and paper are used domestically. The proportion of HWP transferred out of the in-use pool is determined through the application of Equation 12.1 from the IPCC 2006 Guidelines (IPCC 2006). Upon being retired from the in-use pool, all C is assumed to be instantly

Figure A3–17 A Simplified Schematic of Carbon Flows in Harvested Wood Products

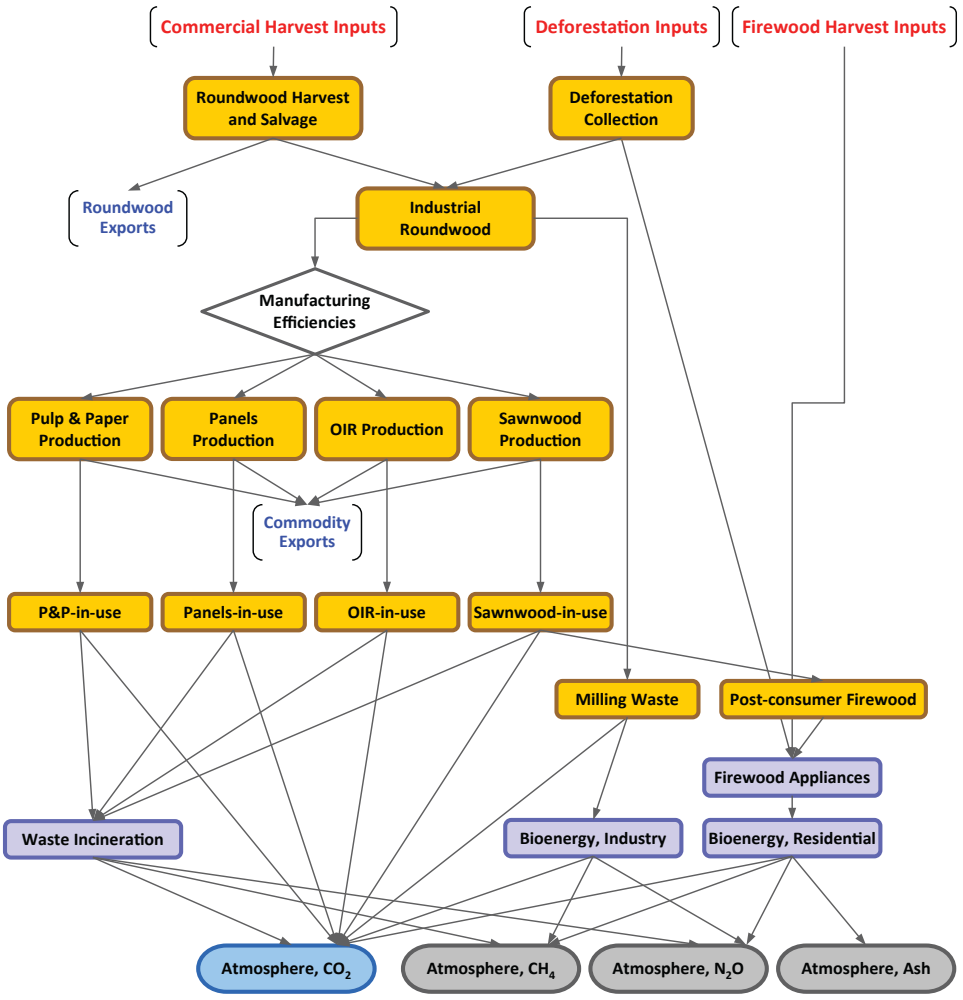


Table A3–55 Default Parameter Values Used in HWP Analysis

Description	Units	Value	Source
Bark expansion factor, Softwoods	dimensionless	1.11	IPCC 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Hardwoods	dimensionless	1.15	IPCC 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Mixedwoods	dimensionless	1.13	IPCC 2006 (Vol. 4, Table 12.5)
C content of wood	tonnes C/od tonne[1]	0.5	IPCC 2006 (Vol. 4, Table 12.4)

1. Tonnes carbon per oven dry tonne of wood material

oxidized. Emissions from residential firewood use and industrial processes flowing from milling waste (e.g. industrial bioenergy) have been represented separately to prevent any potential overlap with estimates reported by the Energy Sector.

Manufacturing efficiencies determine the proportion of industrial roundwood biomass converted into commodities—the unused fraction being milling waste. These proportions are calculated using a mass-balance approach that reconciles domestic

Table A3–56 Wood Densities of Commodities

Country/ Countries	Description	Units[1]	Value	Source
Canada	Species-weighted average density, Roundwood	od tonne/m^3	0.386	Derived
Canada	Species-weighted average density, Sawnwood	od tonne/m^3	0.481	Derived
Canada	Species-weighted average density, Other Industrial Roundwood	od tonne/m^3	0.583	Derived
Canada	Species-weighted average density, Panels	od tonne/m^3	0.643	Environment and Climate Change Canada
Canada	Species-weighted average density, Bioenergy	od tonne/m^3	0.523	Derived
U.S.	Coniferous (C) roundwood	od tonne/green m^3	0.455	FAO 2010
U.S.	Nonconiferous (NC) roundwood	od tonne/green m^3	0.527	FAO 2010
U.S.	C+NC roundwood	od tonne/green m^3	0.465	FAO 2010
U.S.	Hardwood (HW) plywood & veneer	tonnes C/m^3	0.28	Skog 2008
U.S.	Softwood (SW) lumber	tonnes C/m^3	0.22	Skog 2008
U.S.	HW lumber	tonnes C/m^3	0.26	Skog 2008
U.S.	Particle board	tonnes C/m^3	0.29	Skog 2008
U.S.	Hardboard	tonnes C/m^3	0.42	Skog 2008
U.S.	Medium Density Fibreboard	tonnes C/m^3	0.32	Skog 2008
U.S.	Fibreboard, compressed	tonnes C/m^3	0.37	Derived
U.S.	Pulp, paper & board	tonnes C/ad tonne	0.42	Skog 2008
U.S.	Insulating board	tonnes C/m^3	0.45	Skog 2008
All	Sawnwood - C	od tonne/m^3	0.45	IPCC 2006 (Vol. 4, Table 12.4)
All	Sawnwood - NC	od tonne/m^3	0.45	IPCC 2006 (Vol. 4, Table 12.4)
All	Panels, structural	od tonne/m^3	0.628	IPCC 2006 (Vol. 4, Table 12.4)
All	Panels, non-structural	od tonne/m^3	0.628	IPCC 2006 (Vol. 4, Table 12.4)
All	Paper	od tonne/ad tonne	0.9	IPCC 2006 (Vol. 4, Table 12.4)
All	Wood Pulp	od tonne/ad tonne	0.9	IPCC 2006 (Vol. 4, Table 12.4)

Note:
1. od tonne = oven dry tonne of wood material, ad tonne = air dry tonne of product

Table A3–57 Half-Life Parameters (Years) of Harvested Wood Products In-Use

Country/ Countries	Description[1]	Value	Source
Canada	Sawnwood	35	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Wood panels	25	Derived from IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Pulp and paper	2	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Other industrial roundwood	35	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Sawnwood	40	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Wood panels	27	Derived from IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Pulp and paper	3	Derived from IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Other industrial roundwood	40	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Sawnwood	35	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Wood panels	25	Derived from IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Pulp and paper	2	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Other industrial roundwood	35	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)

1. Firewood and mill residue assumed to be burned for the former, or disposed of for the latter, in the year of harvest.

harvest with FAO data on commodity production and trade. Manufacturing efficiencies are calculated annually for each commodity type: for Canada, the U.S. and Japan separately; and jointly for all other export destinations. Default bark expansion factors and wood carbon content were used for all countries (Table A3–55. Default parameters were used to convert product volume to units of carbon for countries other than Canada and the United States and where country-specific parameters are not available for Canada or the United States (Table A3–56. Canada-specific wood density values were used for domestic roundwood, sawnwood, other industrial roundwood (OIR) and panels, and default values were used for domestic paper and market pulp (P&P). Country-specific values were used for all domestic quantities for the United States. Default values were used for domestic and imported quantities for Japan and elsewhere. It is assumed that all wood fibre feedstock produced in a given year is processed by the forest products manufacturing sector in the same year.

The model starts the pool in 1941 and applies product in-use half-life parameters to wood product types based on geographic location. Half-life parameters are sourced directly from Table 3a.1.3 of IPCC (2003), or derived from that table using production-weighted averages to fit the wood product categories of the NFCMARS-HWP (Table A3–57).

Biomass Combustion

Biomass emissions as reported in the Energy Sector are grouped into three main sources: (i) residential firewood; (ii) industrial wood wastes (including spent pulp liquor); and (iii) fuel ethanol/biodiesel (assumed not to come from wood waste or pulp liquors).

Residential firewood combustion produces CO_2, CH_4, N_2O and ash in amounts that are dependent on the combustion technology used. Emissions are derived by multiplying the amount of wood burned in each appliance type by the emission factor for that appliance type. The relevant emission factors are given in Table A6-32, expressed as grams of gas emitted per kilogram of fuel combusted, which for the purpose of the model have been converted to tonnes of C per kilogram of fuel.

Emissions from industrial use of wood-based energy (managed as 'milling waste' in the model) are assumed to result from the combustion of wood wastes (i.e. hog fuel) and spent pulping liquors by the pulp and paper manufacturing sector. As with residential bioenergy use, emissions from industrial use of biomass energy are derived by multiplying the amount of fuel consumed by the emission factor for that fuel type. The emission factors for both industrial wood waste and spent pulp liquors are also given in Table A6-32. Note that the emission factors for industrial wood waste and spent pulp liquors are expressed as grams of gas emitted per kg of fuel consumed, assuming 50% moisture content of the fuel.

The processing of residential firewood data ensures consistency with the Energy Sector and that the impacts of this type of harvest to the forest ecosystem are represented in forest land emission modelling. All biomass C inputs to the firewood pool are based on the annual volumes provided by the Energy Sector and taken from the forest ecosystem based on the following distribution: (i) 53% of the biomass comes from the living biomass pool, of which 43% is direct harvest and 8% is from forest conversion; (ii) 34% comes from the dead organic matter pool, of which 7% comes from collection after commercial logging and 27% comes from collection after natural disturbances; and (iii) the remaining 13% comes from post-consumer products that are subsequently burned as residential firewood.

Uncertainty

Uncertainty estimates associated with this category are based on the uncertainty of the carbon inputs, namely: (i) the carbon estimated as forest products from forest harvest and forest conversion in the CBM-CFS3 model; (ii) the volume of residential firewood

provided by the Energy Sector; and (iii) available statistics of pre-1990 commodity production.

The current implementation uses two approaches: (i) model parameters are varied for Monte Carlo simulations while holding the carbon inputs constant based on the output from the CBM-CFS3 forest ecosystem model; (ii) model parameters are held constant while carbon inputs from the CBM-CFS3 forest ecosystem model are varied.

For the first approach, several parameters of the model, including those related to product allocation values and product-in-use half-lives, are considered in the uncertainty analysis (Metsaranta et al. 2016). For each of these parameters, an expected range and distribution are assigned, based on published values and/or expert judgement. Distributions of parameter values are either triangular or uniform, using the latter in cases where knowledge about a parameter is low. For each Monte Carlo model run, the baseline model parameters are replaced with values randomly drawn from relevant distributions, thereby creating 100 distinct sets of model parameters. Parameters are drawn independently, thus assuming that there are no correlations among their values, except where parameters represent proportions that must add to one, in which case it is ensured that the sum of the proportions is exactly one. Each set of parameter values is applied to both contemporary and historical model runs, such that 200 simulation runs are required for this approach. The second approach uses the highest and lowest quantities of carbon inputs available from the CBM-CFS3 model's uncertainty processing, such that two simulation runs are required. Given that inputs coming from the CBM-CFS3 model only inform contemporary HWP simulations, no historical model runs are needed here.

A3.5.4. Cropland

The methodologies described in this section apply to: carbon stock changes in mineral soils subject to cropland management and to the conversion of land in the Forest and Grassland categories to the Cropland category; CO_2 emissions from the cultivation of histosols; changes in the biomass of woody perennial crops; and N_2O emissions from soil disturbance upon conversion to cropland. The estimation methodologies for carbon stock changes and GHG emissions from the biomass and DOM pools upon conversion of forest land to cropland are provided in Section A3.5.2.5.

A3.5.4.1. Cropland Remaining Cropland

A detailed description of the methodologies used for this category can be found in McConkey et al. (2007a).

Change in Carbon Stocks in Mineral Soils

Changing Management Practices

The amount of organic carbon retained in soil represents the balance between the rates of input from crop residues and losses through soil organic carbon (SOC) decomposition. How the soil is managed determines whether the amount of SOC stored in a soil is increasing or decreasing. The development of the CO_2 estimate methodology is based on the premise that, on long-existing cropland, changes in soil C stocks over time occur following changes in soil management that influence the rates of either C additions to, or C losses from, the soil. If no change in management practices occurs, the C stocks are assumed to be at equilibrium, and hence the change in C stocks is deemed zero.

A number of management practices are generally known to increase SOC in cultivated cropland, such as reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting

practices and re-establishment of perennial vegetation (Janzen et al. 1997; Bruce et al. 1999). Adoption of reduced tillage (RT) or no-till (NT) can result in significant accumulation of SOC compared with intensive tillage (IT) (Campbell et al. 1995, 1996a, 1996b; Janzen et al. 1998; McConkey et al. 2003). Many cropping systems can be intensified by increasing the duration of photosynthetic activity through a reduction of summerfallow (Campbell et al. 2000, 2005; McConkey et al. 2003) and greater use of perennial forage (Biederbeck et al. 1984; Bremer et al. 1994; Campbell et al. 1998). Intensification of cropping systems not only increases the amount of C entering the soil, but may also reduce decomposition rates by cooling the soil through shading and by drying the soil. Conversely, switching from conservative to conventional tillage or from intensive to extensive cropping systems will generally reduce C input and increase organic matter decomposition, thereby reducing SOC.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management practices on SOC. This compendium, as well as the availability of activity data from the *Census of Agriculture*, provided the basis for identifying key management practices and management changes used to estimate changes in soil C stocks. Emissions and removals of CO_2 from mineral soils are estimated for the following land management changes (LMCs):

1. Change in mixture of crop type
   a) Increase in perennial crops
   b) Increase in annual crops

2. Change in tillage practices
   a) IT to RT
   b) IT to NT
   c) RT to IT
   d) RT to NT
   e) NT to IT
   f) NT to RT

3. Change in area of summerfallow
   a) Increase in area of summerfallow
   b) Decrease in area of summerfallow

Where nutrients are greatly limiting, proper fertilization can increase SOC. In such conditions, however, fertilizer or other nutrient-enhancing practices are generally applied. Irrigation in semi-arid areas can affect SOC, but the impact is unclear, and the area of irrigated land has been relatively constant in Canada. Therefore, it is assumed that the selected LMCs represent the most important and consistent influences on SOC in mineral soils.

Carbon Stock Change Factor

To estimate C emissions or removals, an SOC stock change factor specific to each combination of SLC polygon and management change is multiplied by the area of change. The factor is the average rate of SOC change per year and per unit of area of LMC.

Equation A3–57:

$$\Delta C = F \times A$$

where:

ΔC	=	change in SOC stock for inventory year, Mg C
F	=	average annual change in SOC subject to LMC, Mg C/ha/year
A	=	LMC area, ha

Areas of LMC, such as changes in tillage, crop type and fallow, are obtained from the *Census of Agriculture*. Census data provide information on the net change in area over five-year census periods. In practice, land probably both enters and leaves a land management practice, and combinations of management changes occur. However, because only net change data are available, two assumptions are made: additivity and reversibility of SOC factors. Reversibility assumes that the factor associated with an LMC from A to B is the opposite of that associated with the LMC from B to A. Additivity assumes that the C changes from each individual LMC occurring on the same piece of land are independent and

therefore additive. This assumption is supported by the findings of McConkey et al. (2003), who reported that the impact of tillage and crop rotations on SOC is generally additive.

There is a relatively large set of Canadian observations of long-term changes in SOC for LMCs such as adoption of NT and reduced frequency of summerfallow (VandenBygaart et al. 2003; Campbell et al. 2005). However, even this large data set does not cover the whole geographical extent of Canadian agriculture. In addition, there are difficulties in comparing measurements among research sites, in determining the duration of an effect, in estimating full uncertainty from a range of initial soil conditions, and in determining the variability of soil C stocks without management change.

Because of these limitations, a well-calibrated and validated model of SOC dynamics, the Century model (Parton et al. 1987, 1988), is used to derive individual SOC factors for changes between NT and IT, RT and IT, RT and NT, annual and perennial crops, and area of summerfallow. The Century model has been widely used to simulate SOC change for Canadian conditions (Voroney and Angers 1995; Liang et al. 1996; Monreal et al. 1997; Campbell et al. 2000, 2005; Pennock and Frick 2001; Carter et al. 2003; Bolinder 2004).

Figure A3–18 Method for Deriving Carbon Factors for a Land Management Change of Interest

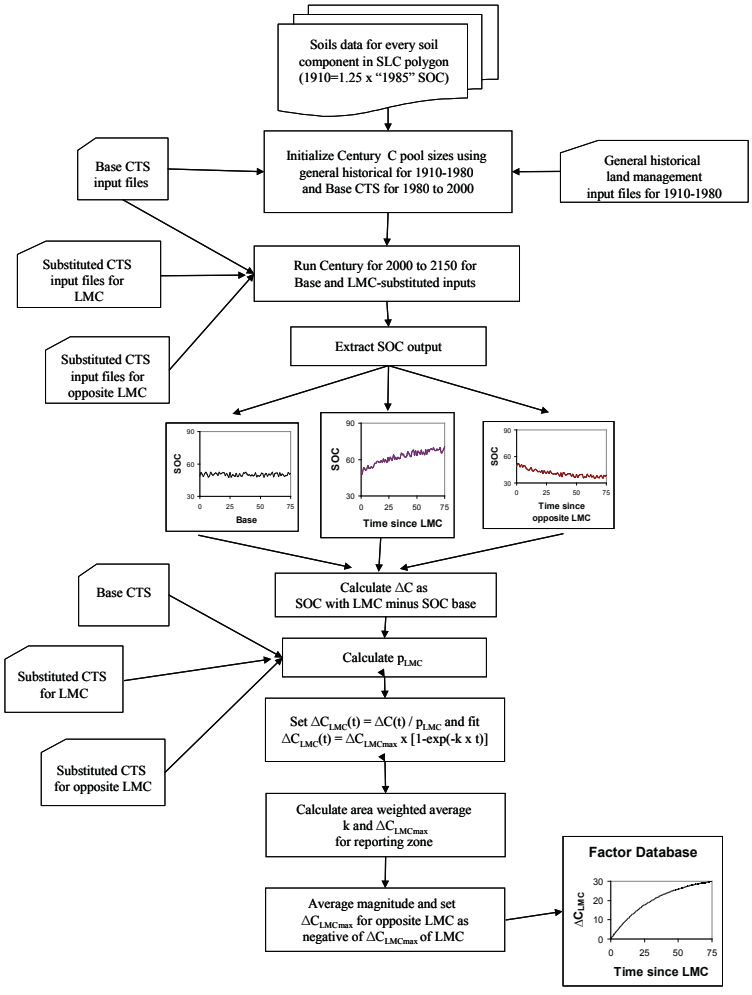
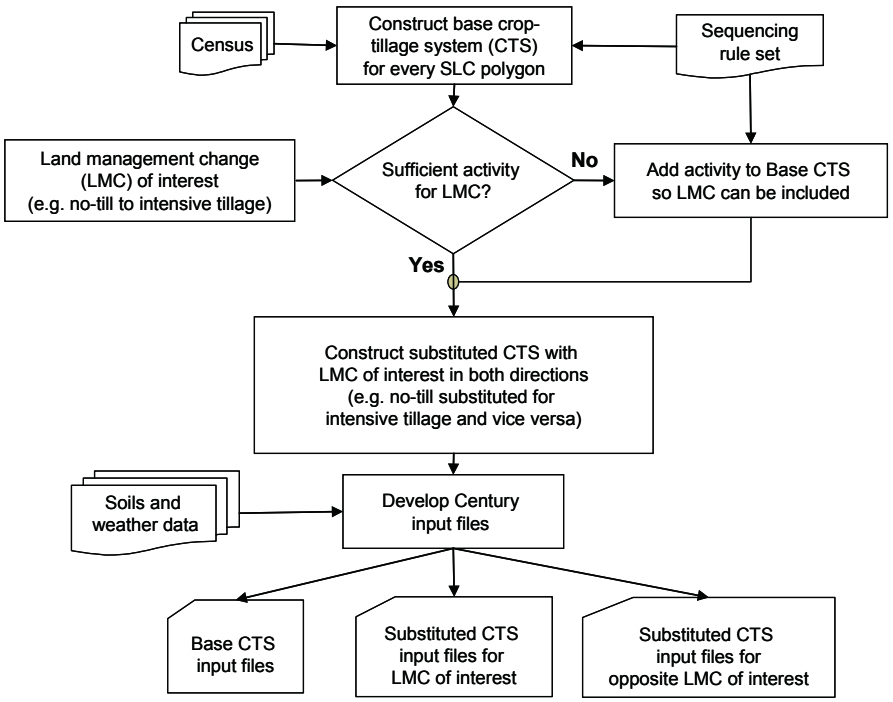


Figure A3–19 Method for Deriving Land Management Input Files to Use with Century Model to Estimate the Carbon Factor for a Land Management Change of Interest



Smith et al. (1997, 2000, 2001) developed an approach using the Century model to estimate SOC change on agricultural land in Canada. To estimate C change, it was necessary to develop a generalized description of land use and management from 1910 onwards on cropland for a sample of soil types and climates across Canada. These scenarios were generated from a mixture of expert knowledge and agricultural statistics of land management, including crop types, fallow and fertilizer application (Smith et al. 1997, 2000). These have been used for the first comprehensive assessments of SOC change on agricultural land within a broader assessment of soil health (McCrae et al. 2000).

The starting points for developing C factors were the SOC values in the SLC polygon attribute database (CanSIS) (Figure A3–18 and Figure A3–19). These database SOC values were derived from measurements made for soil surveys and land resource studies (Tarnocai 1997) and were assumed to represent average SOC on cropland in 1985. Initial SOC in 1910 was estimated as 1.25 times the SOC in the SLC polygon. Changes in SOC factors were estimated using the difference in SOC stocks over time between simulation of a generalized land use and management scenario with and without the LMC of interest (Smith et al. 2001).

10-year crop-and-tillage system (CTS) was developed for each analysis unit and census year, using data from the *Census of Agriculture*. The CTS focused on seven crops or crop types (grain, oilseeds, pulses, alfalfa, root crops, perennial crops and summerfallow) and three tillage practices (IT, RT and NT). Essentially, each CTS represents a mix of crops and tillage practices in space as a mix of crops and tillage practices in time. Under this scheme, a polygon with 20% of cropland area in grain and 20% of cropland area in NT, for example, has 2 of 10 years in grain and 2 of 10 years in NT. Temporal sequences of crop and tillage practices are developed from expert-defined rule-sets, such as "summerfallow never follows summerfallow" and

"corn typically follows soybeans." The construction allows a base CTS and substitutions of LMCs in the CTS to be readily input to the Century model.

The SOC change factor is determined as Factor = (C for CTS with LMC – C for base CTS) / [(fraction of CTS substituted with the LMC) × (duration considered)]. If a land management system is defined as a particular mix of crops and tillage practices on a specified land area, a change in SOC due to an LMC (ΔC_{LMC}) can be estimated as the difference in SOC stock between two land management systems divided by the proportion of the land area subject to an LMC.

Equation A3–58:

$$\Delta C_{LMC\,(t)} = \frac{\Delta C}{P_{LMC}}$$

where:

$\Delta C_{LMC(t)}$	=	the difference in SOC between land management systems from year to year (Mg SOC/ha)
ΔC	=	the change in SOC due to the LMC
P_{LMC}	=	the proportion of the land area under a given land management system subject to the LMC

This proportion (P_{LMC}) can be derived as the proportion of the particular LM in the base system less the amount of the LM in the new system after the LMC. That is,

Equation A3–59:

$$P_{LMC} = P_{LMbase} - P_{LMnew}$$

where:

P_{LMC}	=	the proportion of the land area under a given land management system subject to the LMC
P_{LMbase}	=	the fraction of land management of interest in the base land management system
P_{LMnew}	=	the fraction of land management of interest in the new land management system

The following provides an example of Century runs for a Lethbridge loam (Orthic Dark Brown Chernozem) in the Semi-arid Prairies reporting zone. A base model run was made using a 10-year base mix of crops based on the *1996 Census of Agriculture* and weather data covering the years 1951–2000. Century simulations of SOC were made by substituting perennial crops for the 7 annual crops out of 10 in the base mixture.

Figure A3–20 Soil Organic Carbon (SOC) for a Base Crop Mix, for Perennial (Alfalfa) Substituted for Annual Crops (Wheat), and for No-Till (NT) Substituted for Intensive Till (IT) Based on Century Runs for a Lethbridge Loam

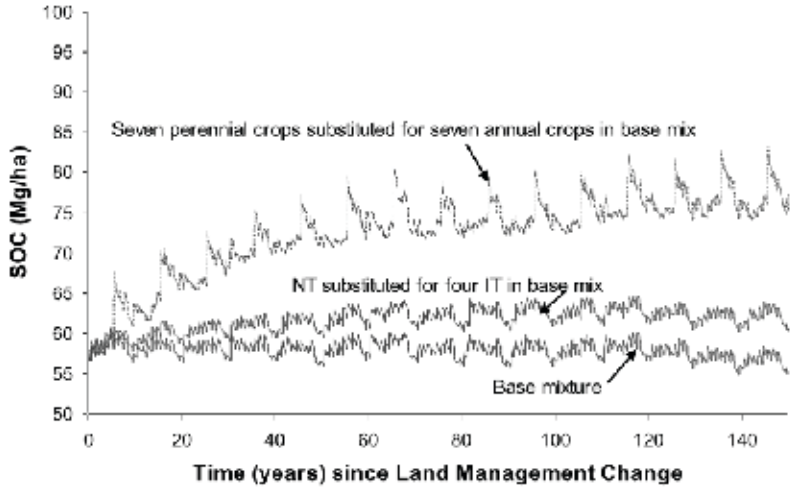
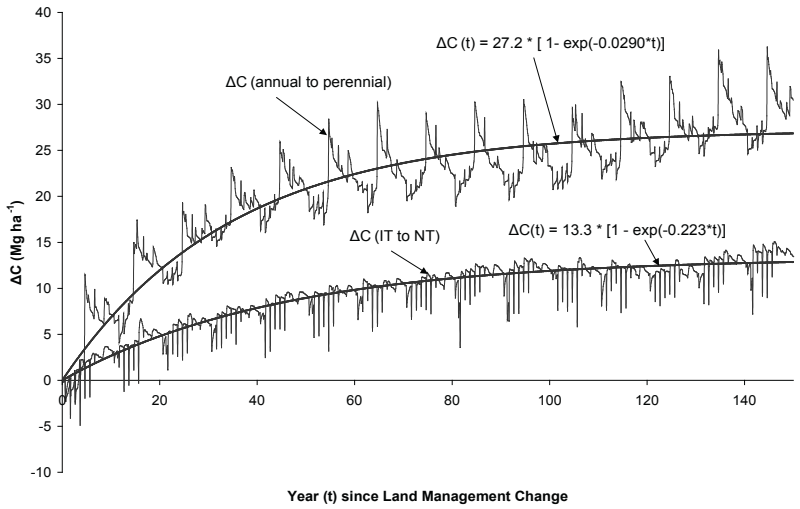


Figure A3–21 Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix



As a separate exercise, NT was substituted for IT 4 years out of 10 in the base mixture (Figure A3–20). The next step was to calculate the $\Delta C_{LMC}(t)$ function by subtracting the simulated SOC values for the base mix values from those imposed by the LMC of interest (Equation A3–57). Finally, the $\Delta C_{LMC}(t)$ was calculated as the proportion of area of farming system divided by the P_{LMC} (Equation A3–58). In this particular case of the time series of ΔC_{LMC}, the respective values of P_{LMC} for the IT to NT reduction and for the addition of perennial crops were 4/10 and 7/10 (Figure A3–24).

SOC dynamics are believed to be governed by first-order kinetics, and thus C change can be expressed as:

Equation A3–60:

$$\Delta C_{LMC}(t) = \Delta C_{LMCmax} \times \left[1 - exp^{(-k \times t)}\right]$$

where:

ΔC_{LMCmax}	=	the maximum SOC change induced by the LMC
k	=	the rate constant
t	=	year

In practice, the exponential equations are fit statistically using methods of least squares. The slope of the natural log transformed exponential equation has units of Mg C/ha per year and is the instantaneous factor value. Since the estimation is based on annual changes, the equation used for estimating the factor for annual change from the previous year (i.e. from year t−1 to year t) is:

Equation A3–61:

$$F_{LMC}(t) = \Delta C_{LMC} max \times \left[exp^{(-k \times [t-1])} - exp^{(-k \times t)}\right]$$

where:

$F_{LMC}(t)$	=	the instantaneous C factor value due to the LMC at a time, t
ΔC_{LMCmax}	=	the maximum SOC change induced by the LMC
k	=	the rate constant, $year^{-1}$
t	=	Year after LMC

Since perfect steady-state conditions are never reached, the exponential equation should theoretically apply forever. In practice, however, the exponential equation was truncated when the $F_{LMC}(t)$ dropped to 25 kg C/ha per year. This rate was below a practical measurement limit (Figure A3–22).

Figure A3–22 Carbon Factors as a Function of Time

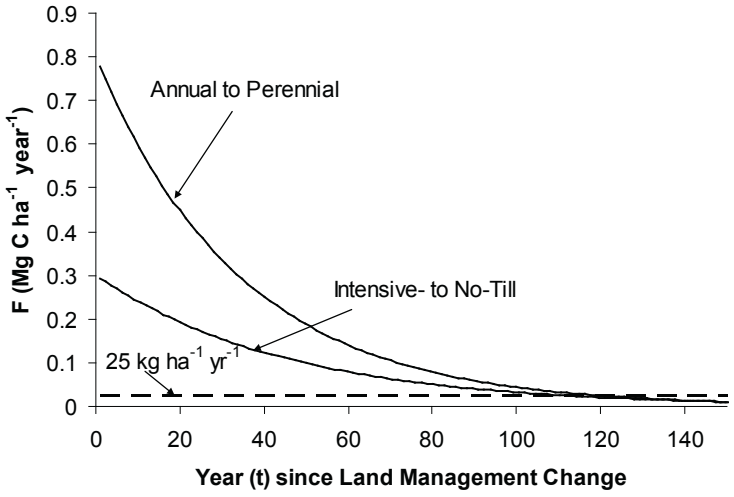


Table A3–58 Effective Linear Coefficients of Soil Organic Carbon for Land Management Change (LMC)[1]

Zone[2]	LMC[3]	k/year	ΔC_{LMCmax} (Mg/ha)	Final Year of Effect after LMC[4]	Mean Annual Linear Coefficient over Duration of Effect of LMC (Mg/ha per year)	Mean Annual Linear Coefficient over First 20 Years after LMC (Mg/ha per year)
East Atlantic	IT to NT	0.0216	3.5	52	0.05	0.06
	IT to RT	0.0251	2.4	36	0.04	0.05
	RT to NT	0.0233	1.1	1	0.03	0
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0217	43.4	167	0.25	0.77
East Central	IT to NT	0.025	5	65	0.06	0.1
	IT to RT	0.0261	1.9	25	0.04	0.04
	RT to NT	0.0255	3.2	46	0.05	0.06
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0247	38.2	147	0.25	0.74
Parkland	IT to NT	0.0286	6.5	70	0.08	0.14
	IT to RT	0.0242	2.8	41	0.04	0.05
	RT to NT	0.0263	3.7	51	0.05	0.07
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0233	29.4	142	0.2	0.55
Semi-arid Prairies	IT to NT	0.0261	4.9	63	0.06	0.1
	IT to RT	0.0188	2.3	30	0.03	0.04
	RT to NT	0.0222	2.5	37	0.04	0.05
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0281	26.1	120	0.21	0.56
West	IT to NT	0.0122	4.8	69	0.04	0.05
	IT to RT	0.0116	0.8	0	0	0
	RT to NT	0.0119	3.9	53	0.03	0.04
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0155	34.4	198	0.17	0.46

Note:
1. Effective Linear Coefficients of SOC were generated using $F_{LMC(t)} = \Delta C_{LMCmax} \times [1 - \exp(-k \times t)]$.
2. Area-weighted summary: East Atlantic is the Atlantic Maritime reporting zone plus the Boreal Shield reporting zone in Newfoundland and Labrador; East Central is the Mixedwood Plains reporting zone plus the Boreal Shield East reporting zone in Ontario and Quebec; Parkland is the Subhumid Prairies, Boreal Shield West and Boreal Plains reporting zones plus those parts of the Montane Cordillera reporting zone with agricultural activity contiguous to agricultural activity within the rest of the Parkland zone; and West is the Pacific Maritime reporting zone plus the Montane Cordillera reporting zone excepting that portion of the latter that is included in the Parkland zone as described above.
3. For LMCs in the opposite direction to that listed, the F_{LMCmax} will be the negative of the value listed.
4. No further C change once the absolute value of the rate of change is less than 25 kg C/ha per year.

Estimating Mean k and ΔC_{LMC}max for Practical Factor Calculations

The ΔC_{LMCmax} and k parameters were determined for all 11 602 soil components of the CanSIS database and three LMCs (changes in tillage practices, summerfallow and annual-perennial crop mix). These soil components represented a wide range of initial SOC states and combinations of base crop mixtures and amounts of substitutions. The parameter values were estimated for each reporting zone as the mean across these soil components, weighted by area of agriculture on each component. The geometric mean was used for k, since its distribution was positively skewed. These means were calculated by three general soil texture classes (sandy, loamy and clayey) and applied to each soil component based on its textural class. Occasionally, k values less than 0 resulted from the fit to ΔC_{LMC}; the k and ΔC_{LMCmax} from these fits were excluded from the reporting zone means.

The dynamics of SOC change in summerfallow have been well studied in Canada. Therefore, rather than using the value for ΔC_{LMC}max from the Century simulations, the ΔC_{LMCmax} value was set so that F was 0.15 Mg C/ha per year (Campbell et al. 2005) at 20 years based on a P_{LMC} of 0.5 (for example a change from 50% fallow to no use of fallow). The k value was derived from the Century simulations as described above.

Generally, rates of SOC losses may be expected to be greater upon an LMC than rates of SOC gain upon the reverse LMC. However, this effect depends greatly on the relative SOC amount at the time of the LMC. Documenting SOC at the time of all LMCs is currently impossible; hence for transparency and simplicity, the reversibility assumption was imposed, which requires that the SOC effect of an LMC in one direction is exactly the negative of the SOC effect of the practice change in the opposite direction.

Soil Carbon Factor Validation

SOC change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). They showed that empirical data comparing SOC change between IT and NT were highly variable, particularly for eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. The mean IT-NT factor for experiments in the Subhumid Prairies reporting zone was over four times that of the Semi-arid Prairies reporting zone. The mean Century model-derived factor for the Semi-arid Prairies reporting zone was similar to the factor derived from the field experiments. However, the Century-derived IT-NT factor for the Subhumid Prairies reporting zone was about 30% lower than the factor derived from the field experiments.

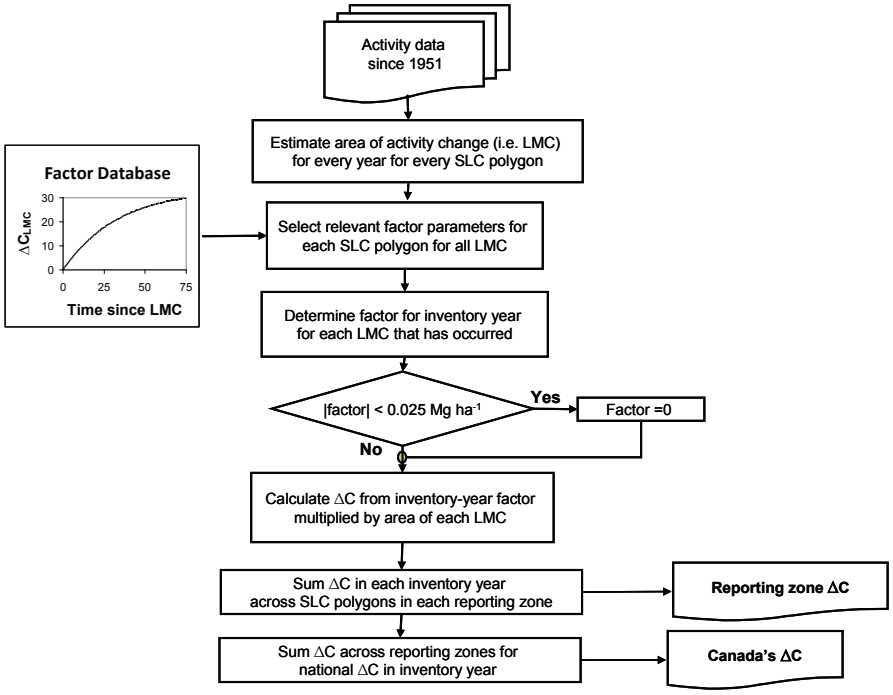
When considering the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, which compared favourably with the range of 0.46–0.56 Mg SOC/ha per year in the modelled factors in the Parkland, Semi-arid Prairies and West reporting zones (Table A3–58). In eastern Canada, only two empirical change factors were available in the East Central reporting zone, but they appeared to be in line with the modelled values (0.60–1.07 Mg SOC/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled).

For conversion of crop fallow to continuous cropping, the rate of C storage was more than double the average rate of 0.15 ± 0.06 Mg/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.

Estimates of Change in Soil Carbon Stocks

SOC changes as a result of LMC were reported for 1990–2015. Because the effect of LMCs declines over time, a vintage or time when change was deemed to have occurred is maintained for each LMC. The C change factor was multiplied by the

Figure A3–23 Method of Using Factors for Land Management Change to Estimate Carbon Change over Large Areas



area of LMC and summed across soil components to produce an estimate of SOC change for the SLC polygon. This is the smallest georeferenced unit of SOC stocks and SOC stock changes calculated using an IPCC Tier 2 approach as follows:

Equation A3–62:

$$\Delta C_{LMC} = \sum_{1951-2015} \sum_{ALLSLC} (\Delta C_{TILL} + \Delta C_{SF} + \Delta C_{CROPPING})$$

where:

ΔC_{LMC}	=	change in SOC stocks due to LMC for a specific year since 1951
ALL SLC	=	all soil landscapes of Canada polygons that contain land management practices in Cropland remaining Cropland
ΔC_{TILL}	=	change in SOC stocks due to change in tillage practices from each SLC, since each particular tillage change
ΔC_{SF}	=	change in SOC stocks due to the change in summerfallow in each SLC
$\Delta C_{CROPPING}$	=	change in soil C stocks due to the change in annual and perennial crops in each SLC

Figure A3–25 provides a schematic of the method for C estimation.

Data Sources

Carbon stock change estimates rely on C factors and a time series of land management data in the *Census of Agriculture*. There are two types of data used for either deriving C factors (modelling) or computing the actual estimates of C stock change. The data mainly used for modelling C factors include SLC, crop-tillage systems derived from the *Census of Agriculture*, and crop yields, climate data and activity data from other surveys and databases. Land management practices from the *Census of Agriculture* are mainly used for estimating annual C stock changes.

Land Information and Activity

The SLC is a national-scale spatial database describing the types of soils associated with landforms, displayed as polygons at an intended scale of representation of 1:1 million. The SLC Version 3.11 was chosen for the LULUCF inventory because of its national scope and standardized structure,

which ensure that all areas of the country are treated in a consistent manner with regard to inventory assessment procedures. In addition, all SLC polygons are "nested" within the 1995 National Ecological Framework, making it possible to scale up or scale down data and estimates, as required.

In all provinces within the agricultural region of Canada, detailed soil survey information with map scales greater than 1:1 million was used to delineate the SLC polygons and compile the associated database files. The SLC Component Soil Names Files and Soil Layer Files provided specific input data, including soil C content, soil texture, pH, bulk density and soil hydraulic properties for modelling C factors with Century. The SLC polygon provides the spatial basis for allocating land management practices, such as tillage practices and cropping systems from the *Census of Agriculture* and Cropland converted from Forest and Grassland, to modelled C factors. The estimated areas of cropland and other land-use practices on an SLC polygon basis were derived from EO-based maps for 1990, 2000 and 2010.

Analysis Units

There are 3404 SLC polygons that have agricultural activities. Since the SLC polygons have several soil landscape components, the finest spatial resolution for analysis of agricultural activities is 13 771 unique combinations of soils, landforms and slope positions within SLC polygons. These unique combinations represent the basic analysis units. The location of land management and soil components is not spatially explicit but rather spatially referenced to SLC polygons.

A procedure was developed to assign agricultural activities to the SLC based on the suitability of each component of a soil polygon. The soil components have different inherent properties that make it more or less likely that they will be used for specific types of agricultural activities. Each soil component within the SLC attribute file has a suitability rating of high, moderate or low in terms of its likelihood of being under annual crop production. In this way, annual crop production is linked to those soils with a high rating. If there was insufficient area with high likelihood of being under annual cropland to be assigned to annual crops production, the remaining annual crop production will be assigned to components with moderate likelihood of being under annual crop production and, if required, to low-ranked components. After the annual crop production area was linked, perennial forages and seeded pasture area were linked to the remaining components in the same manner, starting with components with the highest likelihood of being in annual crops and ending with components with the lowest likelihood of being cropped.

Crop Yields

Crop yields at an ecodistrict level were developed from Statistics Canada surveys. Statistics Canada conducts annual surveys of up to 31 000 farmers, stratified by region, to compile estimates of the area, yield, production and stocks of the principal field crops grown in Canada. Several publications are released at strategic points in the crop year. Yields and levels of production by province are estimated twice, based on expectations to the end of harvest, whereas the November estimate is released after the harvest. The data are released at the Census Agricultural Region level, providing crop yields for approximately 70 spatial units in the country. Census Agricultural Region boundaries were overlaid on SLC boundaries in a GIS, and a yield value for each crop in each soil polygon was assigned based on majority proportion. Data used included 1975–2004 yield data for wheat, barley, oats, corn, soybeans, potatoes and canola. These yields were used to calibrate the Century crop growth submodel.

Climatic Data

There are 958 weather stations in the weather database archived by Agriculture and Agri-Food Canada (AAFC). Long-term normals of monthly maximum and minimum temperatures (°C) and precipitation (mm) from 1951 to 2000 for all ecodistricts were used for modelling C factors. AAFC-archived weather data were provided by Environment and Climate Change Canada's Meteorological Service of Canada.

Earth Observation and the *Census of Agriculture*

Activity data for C estimation in Cropland remaining Cropland category rely mainly on a combination of data from the *Census of Agriculture* and area estimates based on EO analyses. The *Census of Agriculture* is conducted every five years to develop a statistical portrait of Canada's farms and agricultural operators. For confidentiality reasons, the smallest area for which Statistics Canada externally releases data from the *Census of Agriculture* is the Dissemination/Enumeration Area level (of which there are approximately 52 000 in Canada). To provide a biophysical basis upon which to model, data at this level was attributed to the SLC polygons (McConkey et al. 2007a).

In the 2015 NIR, EO-based mapping data were used to provide area estimates of all land-use practices within each of the agricultural SLCs in Canada. Land-use maps based on EO information were generated for 1990, 2000 and 2010 (Huffman et al. 2015). Using SLC polygons as the level of spatial stratification, data were compiled into seven primary land cover categories: cropland, grassland, forest land, settlements, wetlands, water and other land. From 1990 to 2015, annual estimates of land-use areas were generated by interpolating between EO years and extrapolating beyond 2010. Agricultural land-use estimates prior to 1990 were generated using the *Census of Agriculture* and the relative change in cropland and grassland areas between census periods. Land-use estimates for 1981 were generated by calculating the relative change in agricultural land use with the use of data from the 1991 and 1981 censuses and applying this change to the 1990 EO data. Then, moving progressively back through periods between census years, the relative changes were used to generate agricultural land use estimates back to 1951. To minimize spatial variability associated with known issues related to reporting land-use areas based on farm headquarters, the relative change in land-use estimates was calculated at the spatial scale of the ecodistrict and applied to all SLC polygons nested within.

The EO-based cropland attributes were estimated using ratios of cropland area attributes to total cropland area from the *Census of Agriculture*. In the 2017 NIR, to reduce differences between EO and census estimates of provincial crop areas, EO cropland categories (i.e. cropland, pasture, orchards and vineyards) were reconciled using provincial scaling factors. Reconciliations were constrained by the total area of agricultural land within SLC polygons, as interpreted through EO analysis. Data on tillage management practices were taken from the *Census of Agriculture* according to the following categories: (1) IT—tillage that incorporates most of the crop residue into the soil; (2) RT—tillage that retains most of the crop residue on the surface; and (3) NT—no-till seeding or zero-till seeding. For summerfallow, the following tillage categories were used: (1) NT—the area on which chemicals only were used for weed control; (2) IT—the area on which tillage only was used; and (3) RT—the area on which a combination of tillage and chemicals was used. More technical details on the methodological approach used to create the EO-based agricultural activity data are provided in Cerkowniak (2015).

Uncertainty

The derivation of uncertainties about estimates of CO_2 emissions or removals requires estimates of uncertainties for LMC areas and the C factors associated with changes in fallow, tillage and annual/perennial crops (McConkey et al. 2007b). The uncertainty described in this report is based on the 2014 submission methodology and has not yet been updated for the new Earth Observation methodology.

The uncertainty of area of change was determined for ecodistricts. The average area of agricultural land within an ecodistrict is about 140 kha, i.e., sufficiently large that the areas of different management practice were considered independent of those in others, including adjacent ecodistricts. Errors in the areas of management practices in each ecodistrict were assumed to represent inherent uncertainty that was unaffected by the uncertainty of those in other ecodistricts. Further, the ecodistrict area is sufficiently large that a null report of an activity can be assumed to mean that the activity is not occurring within the ecodistrict. Therefore, area uncertainty can be more reliable when considered in relative terms for an ecodistrict than for an SLC polygon.

The uncertainty of the area in a management practice at any time for an average ecodistrict was based on the relative proportion of the area of that management practice in that ecodistrict. The relative uncertainty of the area of management practice expressed as standard deviation of an assumed normal population decreased from 10% of the area to 1.25% of the area as the relative area of that practice increased.

The uncertainties associated with C change factors for fallow, tillage and annual/perennial crops were assumed to arise from two main influences: 1) process uncertainty in C change due to inaccuracies in predicting C change even if the situation of the management practice were to be defined perfectly, and 2) situational uncertainty in C change due to variation in the situation of the management practice.

Process uncertainty includes the effect of uncertainty in the model. This includes the uncertainty in the model predictions from uncertain model parameters and from inaccurate and/or incomplete representation of all relevant processes by the model. Where empirical data are used, process uncertainty includes inadequacies in measurement techniques, analysis error, poor representativeness of measurements, and/or components of C change not measured. To estimate the process error, the variation from measured C change for controlled experiments was used. It was assumed that this represents the inherent uncertainty even when the situation is accurately described. Process uncertainty scaling coefficients for tillage and fallow were derived for Canada from VandenBygaart et al. (2003).

Situational uncertainty derives from the inability to accurately describe each situation. This includes the effect of interactions with past or concurrent changes to land use or land management, variability in the weather or soil properties, variability in crop management, and/or continuity of LMCs. The situational uncertainty scaling coefficients for fallow change, tillage change and annual-perennial crop change were estimated from the observed variability of Century-simulated C change for all soil component-management-climate combinations within the reconciliation unit. There were many combinations of management within which C change was calculated. There was also a range of historical ecodistrict weather that was included in the Century simulations. The situational uncertainty also includes the additional variability of the regional factors introduced by the imposition of reversibility of C change. Average situational uncertainty scaling coefficients were derived for Canada (McConkey et al. 2007b).

Although process and situational uncertainty are expected to interact, given the complexity of the large number of possible interactions between deviations due to process uncertainty and those due to situation uncertainty, it is infeasible to describe their relationship. Hence, it was assumed that the total deviation in total C change was the sum of the deviation from process and situational uncertainty. Details of uncertainty estimate de-velopment are provided in McConkey et al. (2007b). Results of this analysis are provided in Chapter 6.

CO_2 Emissions and Removals from Woody Biomass

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yields. Vineyards are pruned each year, leaving only the trunk and one-year-old stems. Similarly, fruit trees are pruned annually to maintain the desired canopy shape and size. Old plants are replaced on a rotating basis for disease prevention, stock improvement or introduction of new varieties. Typically, Christmas trees are harvested at about 10 years of age. For all three crops, it was assumed that, because of these rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass C within existing farms, as C lost from harvest or replacement would be balanced by gains due to new plant growth. The approach was therefore limited to detecting changes in areas under vineyards, fruit orchards and Christmas tree plantations and estimating the corresponding C stock changes in total biomass.

There are no Canadian studies on the above-ground or below-ground C dynamics of vineyards or fruit trees. However, results from other studies are considered valid inasmuch as varieties, field production techniques and even root stocks are often the same. Canadian literature on Christmas tree plantations is used whenever suitable.

On average, vines are replaced at 28 years of age; the average vine is therefore 14 years old (Mailvaganam 2002). Because of intensive pruning, linear rates of above ground and below-ground biomass accumulation in trunks and roots were set at 0.4 and 0.3 Mg/ha per year, respectively (Nendel and Kersebaum 2004). These were converted to C values using a 50% C content in biomass. Upon a decrease in vineyard areas, an instantaneous loss of 4.9 Mg C/ha is assumed, equal to the average standing biomass for 14-year-old vines (McConkey et al. 2007a).

Because of different standard planting densities, the range of standing biomass per area for apple and peach trees varied narrowly between 36 and 40 Mg/ha (McConkey et al. 2007a). This similarity is expected since, regardless of tree size and planting density, the tree shapes and canopies are manipulated to maximize net photosynthesis per area. An annual rate of C sequestration was calculated over a 10-year growth period at 1.6 Mg C/ha per year. The same rate, multiplied by a root:shoot ratio of 0.40 (Bartelink 1998), was used to estimate C sequestration in below-ground biomass. Instantaneous C loss upon a decrease of orchards was equal to 50% of the total biomass of a 10-year-old tree (22.4 Mg C/ha).

Christmas trees are marketed at about 10 years of age (McConkey et al. 2007a). With a root:shoot ratio of 0.3 (Bartelink 1998; Litton et al. 2003; Xiao and Ceulemans 2004), the total C biomass of a marketable tree plantation is estimated at 11.1 Mg C/ha. Carbon sequestration in biomass of new Christmas tree plantations is calculated for five years at rates of 0.85 and 0.26 Mg C/ha for above-ground and below-ground biomass, respectively. A decrease of plantation area would result in the immediate loss of 5.6 Mg C/ha.

Uncertainty

Poorly growing plants are regularly removed and replaced. Frequently, fruit trees and vineyards are irrigated to maintain desired growth during dry periods. Consequently, the variability in C stock changes should be less than that for other agricultural activities.

For loss of area, all C in woody biomass is assumed to be immediately released. There are no Canadian-specific data on this uncertainty. Therefore, the default uncertainty of ±75% 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 C change uncertainty that contributes to C change uncertainty for a reporting zone.

Cultivation of Organic Soils

Cultivation of histosols for annual crop production usually involves drainage, tillage and fertilization. All these practices increase decomposition of SOC and, thus, release of CO_2 to the atmosphere.

Methodology

The IPCC Tier 1 methodology is based on the rate of C released per unit land area:

Equation A3–63:

$$C = \sum (A_i \times EF)$$

where:

C	=	carbon emissions from cultivation of organic soils (Mg C year^{-1})
A_i	=	area of organic soils that is cultivated for annual crop production in province i, ha
EF	=	C emission factor, Mg C loss/ha per year. The default EF of 5.0 Mg C/ha per year was used (IPCC 2006).

Data Sources

Areas of cultivated histosols at a provincial level are not included in the *Census of Agriculture*. In the absence of these data, consultations with numerous soil and crop specialists across Canada were undertaken. Based on these consultations, the total area of cultivated organic soils in Canada was estimated at 16 kha (Liang et al. 2004).

Uncertainty

The uncertainty associated with emissions from this source is due to the uncertainties associated with the area estimates for the cultivated histosols and of the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols are assessed to be ±50%. The 95% confidence limits of the emission factor provided in the 2006 IPCC Guidelines (IPCC 2006) is ±90%.

A3.5.4.2. Grassland Converted to Cropland

Conversion of native grassland to cropland generally results in losses of SOC and soil organic nitrogen (SON) and in turn leads to emissions of CO_2 and N_2O to the atmosphere. Carbon changes from above-ground or below-ground biomass or dead organic matter upon conversion are generally insignificant based on a recent study on the burning of managed grassland in Canada by Bailey and Liang (2013), 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 yield under crop production (Liang et al. 2005).

A number of studies on changes of SOC and SON in grassland converted to cropland have been carried out on the Brown, Dark Brown and Black soil zones of the Canadian Prairies, and these results are summarized by McConkey et al. (2007a).

Losses of Soil Organic Carbon

The average loss of SOC based on field observations was 22% (McConkey et al. 2007a). Many of the studies involved comparisons within 30 years of breaking of the native grassland, whereas others were 70 or more years from breaking. Since many of these studies did not specify the period since breaking, it is assumed that the 22% SOC loss would refer to about 50–60 years after the land was broken.

The SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils (Figure A3–26) can be estimated with the Century model (Version 4.0). Shortly after breaking, there is an increase in soil organic matter, as below-ground biomass of the grass becomes part of SOC. After a few years, SOC declines below the amount of SOC that existed under grassland. The rate of SOC decline gradually decreases with time. Neglecting the initial SOC increase due to C added from roots, simulated SOC dynamics can be described by the following equation:

Equation A3–64:

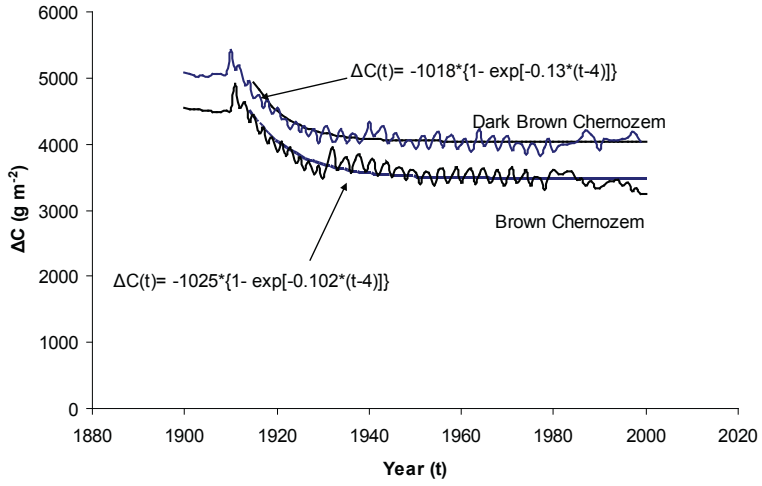
$$\Delta C(t) = \Delta C_{Bmax} \times \left[1 - exp^{(-k[t-t_{lag}])}\right]$$

where:

$\Delta C(t)$	=	change in SOC for the t^{th} year after conversion, Mg C/ha
ΔC_{Bmax}	=	ultimate change in SOC from grassland to cropland, Mg C/ha
k	=	rate constant for describing the decomposition
t	=	time since breaking of grassland, years
t_{lag}	=	time lag before ΔC becomes negative, years

Assuming that the 22% loss at about 50–60 years after initial breaking represents the total loss, the ΔCB_{max} is 0.22/(1−0.22) = 28% of the stabilized SOC under agriculture. Given the uncertainty of actual dynamics, it was assumed that there was no time lag in SOC loss from breaking grassland, so that SOC starts to decline immediately upon breaking. With these assumptions, the general equation for predicting SOC loss from breaking grassland becomes:

Figure A3–24 Century-Simulated SOC Dynamics after Breaking of Grassland to Cropland for the Brown and Dark Brown Chernozemic Soils



Equation A3–65:

$$\Delta C(t) = 0.28 \times SOC_{agric} \times \left[1 - exp^{(-0.12 \times t)}\right]$$

where:

ΔC(t)	=	change in SOC for the t^{th} year after conversion, Mg C/ha
t	=	time since breaking, years
SOC_{agric}	=	0- to 30-cm SOC from the National Soil Database within CanSIS under an agricultural land use (Cropland category), Mg C/ha

Thus, the total losses of SOC in grassland converted to cropland were calculated using an IPCC Tier 2 approach:

Equation A3–66:

$$N_2O_{GLCL} = \sum_{1951-2015} \sum_{ALLSLC} \sum_{t} (\Delta C_{GLCL} \times AREA_{GLCL}) \times 0.06 \times EF_{BASE} \times \frac{44}{28}$$

where:

N_2O_{GLCL}	=	emissions of N_2O in 2015 due to the conversion of grassland to cropland since 1951, kt
ALL SLC	=	all soil polygons that contain grassland conversion to cropland
t	=	time after grassland conversion, years
ΔC_{GLCL}	=	change in SOC for the t^{th} year after grassland conversion, Mg C/ha
$AREA_{GLCL}$	=	area of grassland converted to cropland annually since 1951, ha
EF_{BASE}	=	N_2O emission factor, defined as a function of long-term climate normals (precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (See A3.4.6)
0.06	=	ratio of ON to OC losses
44/28	=	coefficient converting N_2O-N to N_2O

Losses of Soil Organic N and N_2O Emissions

Change in SON is estimated as a fixed proportion of C losses. Where changes in both SON and SOC were determined, the average change in SON was 0.06 kg N lost/kg C lost (McConkey et al. 2007a). Thus, the emissions of N_2O in grassland converted to cropland were calculated using an IPCC Tier 2 approach:

Equation A3–67:

$$N_2O_{GLCL} = \sum_{1951-2015} \sum_{ALLSLC} \sum_{t} (\Delta C_{GLCL} \times AREA_{GLCL}) \times 0.06 \times EF_{BASE} \times \frac{44}{28}$$

where:

N_2O_{GLCL}	=	emissions of N_2O in 2015 due to the conversion of grassland to cropland since 1951, kt
ALL SLC	=	all soil polygons that contain grassland conversion to cropland
t	=	time after grassland conversion, years
ΔC_{GLCL}	=	change in SOC for the t^{th} year after grassland conversion, Mg C/ha
$AREA_{GLCL}$	=	area of grassland converted to cropland annually since 1951, ha
EF_{BASE}	=	N_2O emission factor, defined as a function of long-term climate normals (precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (See A3.4.6)
0.06	=	ratio of ON to OC losses
44/28	=	coefficient converting N_2O-N to N_2O

Data Sources

The area of Grassland remaining Grassland (GLGL) was estimated using a combination of data from the *Census of Agriculture* and EO data. Area estimates of grassland converted to cropland were based on reconciling changes in land area between GLGL and land in cropland management. To avoid issues associated with farm headquarters reporting, data were aggregated to the ecodistrict level prior to the land reconciliation process. Ecodistrict estimates of Grassland to Cropland were then apportioned back to SLC polygons.

Within an SLC, GLGL was allocated to soil components identified as "low" for "likelihood of being cropped." Soil carbon data from the National Soil Database were used to calculate an average SOC content for soils within the SLC polygon.

Uncertainty

The conversion from the agricultural Grassland category to the Cropland category occurs, but the conversion in the other direction does not. The uncertainty of the area of this conversion in a given ecodistrict cannot be larger than the uncertainty of the final area of Cropland or the

initial area of Grassland. Therefore, the uncertainty of the area of conversion was set to the lower of the uncertainty of the area of land in the Cropland or Grassland category. The factor scaling coefficient was assumed to be the same as for annual-perennial crop conversions (McConkey et al. 2007b).

A3.5.4.3. Forest Converted to Cropland

Emissions of CO_2 and N_2O from Soils

Clearing forest to increase agricultural land is a declining but still significant practice in Canada. This section describes the methodology for estimating CO_2 and N_2O emissions associated with the soil disturbance. The method for estimating emissions from biomass upon conversion is presented in Section A3.5.2.5. For SOC change, it is necessary to differentiate between eastern and western Canada.

Eastern Canada

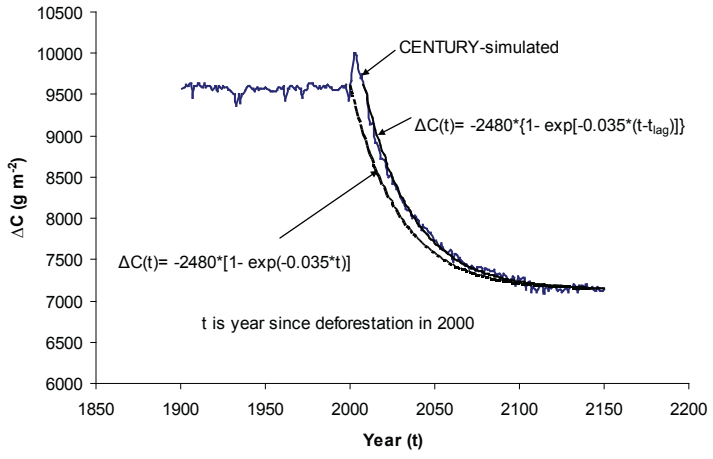
There are many observations that compare SOC for land under forest with SOC for adjacent land under agriculture in eastern Canada. The mean loss of C was 20.3% for a depth of approximately 30 cm (McConkey et al. 2007a). This value is comparable with the soil database in CanSIS (Table A3–59), indicating that, on average, SOC

Table A3–59 Soil Organic C for Forested and Agricultural Land in Eastern and Western Canada from the Canadian Soil Information System Database (0- to 30-cm soil depth)

Soil Texture	Soil Organic Carbon (Mg C/ha)		Difference (%)
	Forested Land[1]	Cropland[1]	
Eastern Canada			
Coarse	85 (26)	68 (42)	-20
Medium	99 (38)	77 (35)	-22
Fine	99 (58)	78 (36)	-21
Western Canada			
Coarse	73 (39)	74 (38)	0
Medium	66 (30)	73 (30)	4
Fine	74 (38)	77 (25)	1

Note:
1. Standard deviation in parentheses.

Figure A3–25 Century-Simulated Soil Organic Carbon Following Conversion of Deciduous Forest to Cropland



for the uppermost 30 cm of soil under agriculture was 20.5% less than that of soil under forest.

Although the SOC for forested land in accounts for C in the litter layer above mineral soil, in practice there is always uncertainty in quantifying the litter layer C and organic C within soil debris (Paul et al. 2002). Soil erosion, which is generally assumed to increase under agriculture, also reduces measured SOC on agricultural land.

The Century model (Version 4.0) was used to estimate the SOC dynamics from forest conversion (Figure A3–27). In the first years after conversion, there is an increase in soil organic matter, as litter and above ground and below-ground DOM become part of SOC. After a few years, SOC falls below the amount that existed before forest conversion. The rate of SOC decline gradually decreases with time.

The following equation was fit to the Century results in Figure A3–25, neglecting the initial SOC increase:

Equation A3–68:

$$\Delta C(t) = \Delta C_{Dmax} \times \left[1 - exp^{(-k \times [t - t_{lag}])}\right]$$

where:

$\Delta C(t)$	=	change in SOC for the t^{th} year a fter conversion, Mg C/ha
ΔC_{Dmax}	=	ultimate change in SOC from forest conversion to agriculture, Mg C/ha
k	=	rate constant for describing the decomposition, $year^{-1}$
t	=	time since land conversion, years
t_{lag}	=	time lag before ΔC becomes negative, years

In the case of simulated SOC after conversion of deciduous forest to cropland (Figure A3–25), 25% of C losses occur within 20 years of forest conversion and 90% within 100 years. Given the uncertainty of actual dynamics, it was assumed that there is no time lag in SOC loss from forest conversion, so that SOC starts to decline immediately upon forest conversion: i.e., the fitted SOC loss (Figure A3–22) is used to estimate SOC loss with time lag set to 0 after fitting.

The mean loss of 20.5% of SOC resulting from forest conversion to cropland for eastern Canada, based on CanSIS information, was assumed to correspond to ≈100 years after forest conversion; the ΔC_{Dmax} is therefore corrected by a factor of 1/0.927, where it is assumed that only 92.7% of the carbon has been lost after 100 years, based on the integration of Equation A3–69, resulting in a ΔC_{Dmax} value of 22.1% of SOC under long-term forest. As the CanSIS soil database has more data on SOC for conditions under long term cropland than on SOC under long-term forest in areas where cropland exists, the maximal SOC losses were calculated relative to stabilized cropland SOC (i.e. loss = 0.221/(1−0.221) × SOC or loss = 0.284 × SOC under agriculture). Therefore, the final equation for estimating SOC loss for forest conversion to cropland in eastern Canada is:

Equation A3–69:

$$\Delta C(t) = 0.284 \times SOC_{agric} \times \left[1 - exp^{(-0.0262 \times t)}\right]$$

where:

$\Delta C(t)$	=	change in SOC for the t^{th} year after conversion, Mg C/ha
SOC_{agric}	=	0- to 30-cm SOC from CanSIS for a cropland soil, Mg C/ha
-0.0262	=	rate constant for describing the decomposition, $year^{-1}$
t	=	time since conversion, years

Thus, the total amount of SOC lost from forest land converted to cropland is estimated using the following equation:

Equation A3–70:

$$\Delta C_{FLCL} = \sum_{1970-2015} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL})$$

where:

ΔC_{FLCL}	=	total SOC loss in 2015 from the conversion of forest land to cropland since 1970, Mg C/ha
t	=	time after the conversion, year
ALL SLC	=	all soil polygons that contain forest land converted to cropland
ΔC_t	=	change in SOC for the t^{th} year after conversion, Mg C/ha (See Equation A3–69)
$AREA_{FLCL}$	=	area of forest land converted to cropland annually since 1970, ha

Note that the SOC loss predicted by Equation A3–70 is in addition to C stock changes in tree biomass and woody DOM that existed in the forest at the time of forest conversion.

Based on the field observations, average N change in eastern Canada was -5.2%, representing 0.4 Mg N/ha (McConkey et al. 2007a). For those comparisons where both N and C losses were determined, the corresponding C loss was 19.9 Mg C/ha, and carbon loss was 50 times N loss. For simplicity, it was assumed that N loss was a constant 2% of C loss. Thus, N_2O emissions from forest land converted to cropland are estimated using the following equation:

Equation A3–71:

$$N_2O_{FLCL} = \sum_{1970-2015} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL}) \times 0.02 \times EF_{BASE} \times \frac{44}{28}$$

where:

N_2O_{FLCL}	=	emissions of N_2O subject to conversion of forest to cropland since 1970, kt
ALL SLC	=	all soil polygons that contain forest land conversion
ΔC_t	=	change in SOC for the t^{th} year after conversion, Mg C/ha per year
$AREA_{FLCL}$	=	area of forest land converted to cropland annually since 1970, ha
0.02	=	conversion of C to N
EF_{BASE}	=	base emission factor, defined as a function of long-term climate normals (precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (See Section A3.4.6)
44/28	=	coefficient converting N_2O-N to N_2O

Western Canada

Much of the current agricultural soil in western Canada was grassland prior to cultivation. Hence, forest conversion has been primarily of forest that adjoins grassland areas. There is also limited conversion of secondary forest that has grown on former grassland since the suppression of wildfires with agricultural development. Historically, forest conversion has been less important in western Canada than in eastern Canada, and fewer comparisons of SOC under forest and agriculture are available in the literature. Ellert and Bettany (1995) reported that there was no difference in SOC between native aspen forest and long term pasture that remained uncultivated since clearing for an Orthic Gray Luvisol near Star City, Saskatchewan.

The CanSIS data provide numerous comparisons of SOC under forest with that under cropland (Table A3–59). On average, these data indicate that there is no loss of SOC from forest conversion. This suggests that, in the long term, the balance between C input and SOC mineralization remains similar under agriculture to what it was under forest. It is important to recognize that the northern fringe of western Canadian agricultural areas, where most forest conversion is now occurring, is marginal for annual crops, and pasture and forage crops are the primary agricultural uses after clearing. In general, loss of C from forest to agriculture is least where agricultural land contains forages and pastures.

For western Canada, no loss of SOC over the long term was assumed from forest conversion to pasture and forage crops. Therefore, the C loss from land conversion in western Canada would be from losses of C in above-ground and below-ground tree biomass and coarse woody DOM that existed in the forest at the time of conversion. Similarly, average organic nitrogen change in western Canada for sites at least 50 years from breaking was +52% (McConkey et al. 2007a), reflecting substantial added N in agricultural systems compared with forests. However, recognizing the uncertainty

about actual soil C–N dynamics upon conversion, forest land converted to cropland was assumed not to be a source of N_2O from the soil pool. N_2O emissions are reported wherever biomass burning occurs during conversion (see Section A3.5.2.1).

Data Sources

The approach used to estimate the area of forest land converted to cropland is described in Section A3.5.2.2. The annual forest conversion by reconciliation unit was disaggregated to SLC polygons on the basis of concurrent changes in the area of cropland within SLC polygons. Only polygons that showed an increase in cropland area for the appropriate time period were allocated to forest conversion, and the amount allocated was equivalent to that polygon's proportion of the total cropland increase within the reconciliation unit.

Uncertainty

The uncertainty of C change in each reporting zone was estimated differently for eastern and western Canada because of differences in C change estimation methods (McConkey et al. 2007b). For western Canada, an uncertainty of C change was estimated, although the mean value of SOC change factor was 0. The assumption was that the uncertainty of SOC change after forest land to cropland conversion in western Canada would follow a similar pattern as that for eastern Canada.

A3.5.5. Grassland

Land in the agricultural Grassland category is defined as "unimproved pasture" used for grazing domestic livestock, but only in geographical areas where grassland would not naturally grow into forest if abandoned, i.e. southern Saskatchewan and Alberta and a small area of southern British Columbia. These grasslands developed under millennia of grazing by large animals, such as bison, and periodic burning. Essentially, the "agricultural Grassland" category consists of extensively managed native range in Canada.

The primary direct human activities on agricultural grassland in Canada are fire suppression, seeding new plant species into the grassland, and adjusting the amount, duration and timing of grazing by domestic livestock. Methodologies for estimating emissions or removals of CO_2 as a result of direct human activities and for estimating CH_4 and N_2O emissions from natural or prescribed fires on agricultural grassland in Canada are presented in the following section.

A3.5.5.1. Grassland Remaining Grassland

The development of the CO_2 estimate method is based on the premise that on long-existing managed grassland, changes in soil C stocks over time occur following changes in soil management that influence the rates of either C additions to or C losses from the soil.

Equation A3–72:

$$SOC = SOC_{REF} \bullet F_{MG} \bullet F_I$$

where:

SOC	=	soil organic carbon stock at any particular time since management and input change, Mg C ha^{-1}
SOC_{REF}	=	the reference soil organic carbon stock, Mg C ha^{-1}
F_{MG}	=	carbon stock change factor for management regime, dimensionless
F_I	=	carbon stock change factor for input of organic matter, dimensionless

The total area of managed grassland is calculated as follows:

Equation A3–73:

$$A_{2015} = GLGL_{1990} - \sum_{1990}^{2015} GLCL$$

where:

A_{2015}	=	the total area of grassland remaining grassland in 2015, ha
$GLGL_{1990}$	=	the area of grassland remaining grassland in 1990, ha
GLCL	=	the area of grassland converted to cropland since 1990, ha

Therefore, the net change in SOC because of management and input changes from grassland remaining grassland can be estimated using the IPCC tier-1 method as follows:

Equation A3–74:

$$\Delta C_{GGMineral} = [(SOC_0 - SOC_{0\text{-}T}) \times A]/T$$

where:

$\Delta C_{GGMineral}$	=	the net change in SOC due to management and input from grassland remaining grassland, Mg C $ha^{-1}yr^{-1}$
SOC_0	=	soil organic carbon stock in the inventory year, Mg C ha^{-1}
$SOC_{0\text{-}T}$	=	soil organic carbon stock T years prior to the inventory year, Mg C ha^{-1}
A	=	area of change in management and input from grassland remaining grassland, ha
T	=	inventory time period, yr (default 20 yr)

If no change in management practices or input occurs, the C stocks are assumed to be at equilibrium, and the change in C stocks is therefore deemed to be zero.

There are a number of studies of the effects of grazing versus no grazing on SOC. Although the productivity of heavily grazed pasture is lower, which may lead to a decline in range conditions, this was not related to declines in SOC (Biondini and Manske 1996). The effect of grazing regime is complex, because of the effects of grazing on plant community and effects on C input to soil from both above-ground and below-ground plant growth (Schuman et al. 2002; Liebig et al. 2005). An additional influence of grazing regime is the increased return of C in fecal matter as stocking rate increases (Baron et al. 2002). Bruce et al. (1999) estimated that there was no opportunity to increase SOC from grazing management improvements on extensively managed rangeland in North America.

The addition of organic amendments and inorganic fertilizer will increase the productivity of native grassland (Smoliak 1965), suggesting that these practices could increase SOC through greater C inputs. However, such practices are basically of academic interest, as the only economically practical management options for semi-arid grasslands are altering grazing regime, burning and introducing new plant species (Liebig et al. 2005).

Grasslands managed for grazing in western Canada in the Brown and Dark Brown soil zones of Alberta, Saskatchewan and British Columbia are occasionally burned by wildfire and by prescribed burning for purposes such as brush management, habitat management, the removal of decadent vegetation and military training exercises. Burning from managed grassland is a net source of CH_4, CO, NO_x and N_2O.

Equation A3–75:

$$EMISSION_{BURN} = \sum (AREA_i \times FUELLOAD_i \times C_{F,i} \times G_{EF}) /1000$$

where:

$EMISSION_{BURN}$	=	emissions of CH_4 or N_2O from prescribed and non-prescribed burning of managed agricultural grassland, kt CH_4 or N_2O
$AREA_i$	=	area of the ith managed agricultural grassland subject to burning, ha
$FUELLOAD_i$	=	average fuel load for the ith managed agricultural grassland subject to burning, Mg DM ha^{-1}
$C_{F,i}$	=	combustion efficiency for the ith managed agricultural grassland subject to burning, fraction, unitless
G_{EF}	=	emission factor of CH_4 (2.7 g CH_4 kg^{-1} dry matter burnt) or N_2O (0.07 g N_2O kg^{-1} dry matter burnt) (IPCC 2006)
1000	=	conversion of mg to kt

Data Sources

As discussed in the section Grassland converted to Cropland, the area of Grassland remaining Grassland (GLGL) was estimated using a combination of data from the *Census of Agriculture* and EO data as described in Section A3.5.4.1. There are no detailed comprehensive activity data over time on management change for Canadian agricultural grassland, except for wild and prescribed fires. 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).

A3.5.6. Wetlands

A3.5.6.1. Peat Extraction

General Approach and Methods

Peat extraction in Canada is for the production of horticultural peat products and related applications; Canada does not produce peat for use as fuel. Since the 1970s, the vacuum harvesting technique has been the dominant method of peat extraction. This technique requires an extensive network of drainage ditches to dry the peat for harvesting by heavy vacuum harvesters. Prior to the implementation of vacuum harvesting, manual block-cutting was used to extract peat blocks with shovels, resulting in topography of high baulks and low trenches. Although these manual methods are no longer used, numerous abandoned block-cut sites remain in the landscape.

Emissions of CO_2, CH_4 and N_2O were estimated for the conversion and management of peatlands for peat extraction using an IPCC Tier 2 method in accordance with guidance from a combination of the 2006 IPCC Guidelines and the 2014 IPCC Wetlands Supplement (IPCC 2014). The approach is based on domestic science and land management practices specific to peat extraction activity in Canada. Emission estimates include on-site CO_2, CH_4 and N_2O emissions, off-site CO_2 emissions from extracted peat and waterborne carbon losses of dissolved organic carbon (DOC) from drained and rewetted sites.

Domestic GHG flux studies at peat extraction sites in Canada were reviewed and measurements compiled to develop country-specific emission factors and parameters (Table A3–60). As the majority of flux measurements were reported for the growing season, annual CO_2 emission factors were developed by adding measured winter values from Strack and Zuback 2013, consistent with drained peatlands having higher winter CO_2 emissions than natural peatlands. Annual CH_4 emission factors were developed assuming that non-growing season fluxes are 15% of annual totals based on natural peatland sites (Saarnio et al. 2007).

Owing to the extraction technology and desired properties of sphagnum peat, preference with respect to site selection is given to open bog (nutrient poor – ombrotrophic) peatlands, which are classified as Other Land under Canada's land categorization framework for the LULUCF Sector. Therefore, only approximately 5% of pre-conversion area meets the definition of Forest Land. Emission estimates are separated into the categories 'Land converted to Peat Extraction' and 'Peat Extraction remaining Peat Extraction'. In calculating emissions from land conversion, a land-use change period of one year is used to represent the land conversion practices of draining and clearing the surface vegetation layer (acrotelm) in preparation for peat extraction. Subsequently, emissions from the ongoing management of peat extraction sites, as well as their decommissioning through abandonment, rehabilitation, or rewetting and restoration, are all reported under 'Peat Extraction remaining Peat Extraction'. The following sections describe the sources of GHG emissions and removals through the peat extraction land management phases.

Biomass Clearing and Drainage

At extraction sites, vegetation removal and drainage results in a loss of CO_2 uptake, enhanced peat decomposition and dissolved organic carbon (DOC) export resulting in increased CO_2 emissions. Emissions of CH_4 decrease substantially from drained fields, but drainage ditches, which occupy 5% of the drained area, become CH_4 hot spots (Waddington and Day 2007). Enhanced peat decomposition also increases N_2O emissions. CO_2

and CH_4 emission factors for drained areas were derived from domestic studies (Table A3–60), but due to a lack of domestic N_2O measurements the default emission factor for peat extraction sites from the 2014 IPCC Wetlands Supplement was used.

Sites that are no longer economical for extraction are decommissioned or abandoned. The altered hydrology and peat properties of these sites hinder natural regeneration, resulting in persistent CO_2 emissions (Waddington et al. 2002). However, revegetation occurs more frequently at abandoned block-cut sites, although total vegetation coverage is low and moss regeneration is limited to wetter trench depressions (Poulin et al. 2005). The CO_2 emission factor for abandoned block-cut areas is lower than for areas drained for vacuum harvesting, while the CH_4 emission factor is higher, which is likely a result of greater revegetation and wetter conditions at block-cut sites.

At some abandoned sites interventions are made to rehabilitate sites to establish another type of environment. Given the lack of flux measurements for these sites, the emission factors for drained areas are generally used for rehabilitated areas. However, the uptake of CO_2 by trees in tree plantations is calculated based on measurements at a tree plantation study (Garcia Bravo 2015). Tree plantations may increase CO_2 sequestration in tree biomass, but this does not offset the large CO_2 emissions from drained peat.

Peat Stockpiling and Product Production

Harvested peat is left in stockpiles before being processed into various peat products. Emissions from peat stockpiles are calculated as an exponential decay for half a year (Cleary et al. 2005). Once it is packaged into products, Canadian peat is transported off-site, largely to the United States, for non-energy uses such as horticulture, where it is assumed to decay in an aerobic environment. Due to the lack of information on decay rates by end use, it is assumed that all peat is emitted in the extraction year. Emissions of CO_2 are calculated based on an estimate of total organic carbon in the peat using a country-specific carbon fraction parameter (Table A3–60) derived from laboratory analysis of pure peat products with moisture contents ranging from 27 to 64% (Hayne et al. 2014).

Rewetting and Restoration

An increasing number of decommissioned sites are rewetted and restored. Rewetting practices increase anaerobic conditions, which reduce peat decay and DOC export, thereby decreasing CO_2 emissions while increasing CH_4 emissions (Strack and Zuback 2013). Since the 1990s, the moss layer transfer technique has been used in Canada for the restoration of peatlands dominated by Sphagnum mosses with the aim of restoring sites to peat-accumulating ecosystems. This technique consists of rewetting and sowing fields with fresh moss spores and spreading a layer of straw mulch to support moss regeneration (Rochefort et al. 2003). Long-term monitoring of restoration sites indicates that rewetting and restoration success varies due to management (e.g. effectiveness of blocking secondary drainage network, timing of restoration procedures and quality of plant material spread) and weather conditions post-restoration (Gonzáles and Rochefort 2014). Domestic GHG research at sites restored for 10 years or less has shown that there is high variability among sites ranging from sources to sinks. Given the range of success among sites and the variability in flux measurements, average emission values are used to best represent the net flux of rewetted and restored sites.

Data Sources

An EO mapping approach based on manual delineation and interpretation of aerial photography, satellite imagery and ancillary data was developed to map the extent of peatland areas disturbed by peat extraction for circa 1990, 2007 and 2013 time periods. Through image interpretation, the total disturbed area was allocated into the following

Table A3–60 Parameters and Emission Factors for Estimating Emissions from Peat Extraction

Emission Factor/Parameter	Unit	Value	Sources
Biomass Clearing			
Forest land biomass cleared	t C ha^{-1}	19.2	Hayne and Verbicki 2011
Other land biomass cleared	t C ha^{-1}	2.8	Hayne and Verbicki 2011
Drainage			
CO_2 from Drained Areas	t CO_2 ha^{-1} yr^{-1}	11.4	Moore et al. 2002 as cited in Cleary 2003; Glatzel et al. 2003; Waddington et al. 2010; Strack and Zuback 2013; Strack et al. 2014
CO_2 -DOC from Drained Areas	t CO_2 ha^{-1} yr^{-1}	0.60	Waddington et al., 2008; Strack and Zuback 2013
CH_4 from Drained Fields	t CH4 ha-1 yr^{-1}	0.008	Moore et al. 2002 as cited in Cleary 2003; Waddington and Day 2007; Strack and Zuback 2013; Strack et al., 2014
CH_4 from Drainage Ditches	t CH_4 ha^{-1} yr^{-1}	0.15	Waddington and Day 2007
N_2O from Drained Areas	t N_2O ha^{-1} yr^{-1}	0.001	IPCC 2014 Wetlands Supplement (Table 2.5, Default value for Boreal & Temperate climate zone)
CO_2 from Abandoned Block-Cut Areas	t CO_2 ha^{-1} yr^{-1}	"8.6"	Waddington and Price 2000; Waddington and Warner 2001; Waddington et al. 2002; McNeil and Waddington 2003
CH_4 from Abandoned Block-Cut Areas	t CH_4 ha^{-1} yr^{-1}	0.012	Waddington and Price 2000
CO_2 Tree Plantation Biomass Uptake	t CO_2 ha^{-1} yr^{-1}	-0.32	Garcia Bravo 2015
Peat Stockpiling & Product Production			
Amount of Stockpiled Peat	t C ha^{-1}	50	Cleary 2003
Exponential decay constant, Stockpiled Peat		0.05	Cleary 2003
Carbon Fraction of Peat Products	t C t air-dry $peat^{-1}$	0.26	Hayne et al. 2014
Rewetting & Restoration			
CO_2 from Restored Areas	t CO_2 ha^{-1} yr^{-1}	7.60	Moore et al. 2002 as cited in Cleary 2003; Petrone et al., 2001; Petrone et al., 2003; Waddington et al. 2010; Strack and Zuback 2013; Strack et al. 2014
CO_2-DOC from Restored Areas	t CO_2 ha^{-1} yr^{-1}	0.13	Waddington et al., 2008; Strack and Zuback 2013
CH_4 from Restored Fields	t CH_4 ha^{-1} yr^{-1}	0.03	Moore et al. 2002 as cited in Cleary 2003; Waddington and Day 2007; S track and Zuback 2013; Strack et al., 2014
CH_4 from Restored Ditches	t CH_4 ha^{-1} yr^{-1}	0.28	Waddington and Day 2007; Strack and Zuback 2013
N_2O from Restored Areas	t N_2O ha^{-1} yr^{-1}	N/A	IPCC 2014 Wetlands Supplement, Default assumption of no N_2O emissions from rewetted/restored areas

four land management subcategories: active extraction areas, abandoned areas, rehabilitated areas and restored areas. Geospatial data developed by the Peatland Ecology Research Group and information provided by industry experts were utilized to aid subcategory allocation. In addition, for a subset of sites, the pre-disturbance land cover class (forest, shrubby or open bog peatland) was determined in order to identify the land category types converted (Forest Land or Other Land).

Annual area estimates were developed using interpolation between mapped time periods and extrapolation after 2013. Annual area estimates for various land management categories were then refined based on secondary data sources.

The two main secondary data sources were industry statistics on peatland areas managed for peat extraction in 2015 compiled by the Canadian Sphagnum Peat Moss Association (CSPMA) and a survey of abandoned peat extraction sites in the provinces of Quebec and New Brunswick (Poulin et al. 2005). Secondary data sources were used to (1) provide a comparative check of total areas converted to peat extraction historically and current production areas and (2) complement limitations in the ability of the mapping approach to identify land management subcategories. National peat production statistics were used to represent the annual amount of extracted peat transported off site (NRCan 2016).

Uncertainty

Given the increased availability and quality of EO imagery and ancillary information over time, it is assumed that there is a decrease in uncertainty in the mapped areas for the later mapping periods. The use of high-resolution satellite imagery for the 2013 time period reduced uncertainty in the overall estimate of the total areas converted for peat extraction. However, there is considerable uncertainty associated with identifying land management subcategories. Uncertainty in the 2015 CSPMA industry statistics is associated with different interpretations of land management category definitions (e.g. restoration) and incomplete coverage of lands not managed by industry association members.

There is a lack of domestic GHG measurements for the various categories of decommissioned sites. Therefore, emission factors may not represent the full range and success rates of applied rehabilitation and restoration techniques. The large variation in moisture content among peat products may contribute substantially to the uncertainty of off-site CO_2 emission estimates from extracted peat.

A3.5.6.2. Flooded Lands

General Approach and Methods

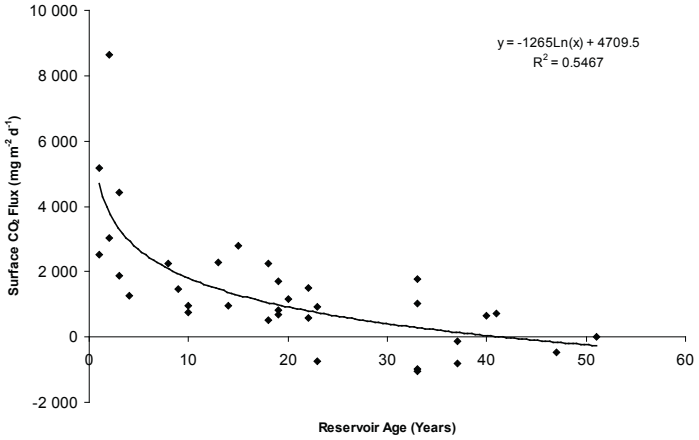
Following the 2006 IPCC Guidelines, emissions from Land converted to Wetlands (creation of flooded lands, namely reservoirs) are estimated for all known reservoirs flooded for 10 years or less. Only CO_2 emissions are reported. An IPCC Tier 2 method was used, whereby country-specific CO_2 emission factors were developed based on measurements, as described below. Details can be found in Blain et al. (2013). It is believed that the default approach, assuming that all biomass carbon would be emitted upon flooding, would overestimate immediate forest conversion emissions from reservoir creation, because the majority of submerged forest biomass does not decay for an extended period of time.

Two complementary estimation methodologies are used to account for GHG fluxes from flooded lands, depending on land conversion practices. When there is evidence of forest clearing and/or burning prior to flooding, immediate and residual emissions from all forest carbon pools are estimated with the CBM-CFS3 (see Section A3.5.2.1). Emissions from forest clearing for infrastructure development are reported under the subcategory Forest Land converted to Settlements. Emissions resulting from the use and disposal of wood products that are harvested before flooding are reported under the category Harvested Wood Products (see Section A3.5.3).

In the absence of evidence of forest clearing, it was assumed that all vegetation was simply flooded, leading to the emission—as CO_2—of a fraction of the submerged carbon from the surface of the reservoir. The proportion of the area flooded that was previously forested was used to attribute these emissions to either the Forest Land converted to Wetlands category or the Other Land converted to Wetlands category.

Since 1993, measurements of CO_2 fluxes have been made above some 57 hydroelectric reservoirs in four provinces: Quebec, Manitoba, British Columbia, and Newfoundland and Labrador (Duchemin 2006). In most studies, the reservoirs were located in watersheds little affected by human activities, with the notable exception of Manitoba. In almost all cases, only diffusive fluxes of CO_2, CH_4 or N_2O (in order of frequency) were measured. Studies on ebullition, degassing emissions and winter emissions are rare and insufficient to support the development of domestic emission factors. Measurements of diffusive fluxes above the surface of reservoirs were compiled for the entire country. Out of these measured reservoirs, a subset of 25 was selected to develop a national emission curve for the 50-year period following impoundment. These measurements were selected based on the availability of documentation

Figure A3–26 Logarithmic Curve Fit for National Reservoir Emission Factors



of measurement procedures and measurement comparability. The emission curve was developed from 25 reservoirs and a total of 33 measurements (Figure A3–26). It is important to note that each of these measurements (data points in Figure A3–26) represents, on average, the integration of between 8 and 28 flux samples per reservoir.

Non-linear regression analysis was used to parameterize the emission curve of the form.

Equation A3–76:

$$CO_{2\ rate\ L\_reservoir} = b_0 + b_1 \times In(t)$$

where:

$CO_{2\ rate\ L\_reservoir}$	=	rate of CO_2 emissions from land converted to wetlands (reservoirs), mg/m^2 per day
b_0, b_1	=	curve parameters, unitless
t	=	time since flooding, years

Total CO_2 emissions from the surface of reservoirs were estimated as the sum of all emissions from reservoirs flooded for 10 years or less:

Equation A3–77:

$$CO_{2\ L\_reservoirs} = \sum (CO_{2\ rate\ L\_reservoir}) \times A_{reservoir} \times Days_{ice\ free} \times 10^{-8})$$

where:

$CO_{2\ L\_reservoirs}$	=	emissions from lands converted to flooded lands (reservoirs), Gg CO_2/year
$CO_{2\ rate\ L\_reservoir}$	=	rate of CO_2 emissions for each reservoir, mg/m^2 per day
$A_{reservoir}$	=	reservoir area, ha
$Days_{ice\ free}$	=	number of days without ice, days

$A_{reservoir}$ was used as the best available estimate of the area converted to managed wetlands (reservoirs), although in reality reservoirs may contain islands, i.e., emergent land areas. "Ice-free period" was defined as the average number of days between the observed freeze date and the breakup date of ice cover on a body of water (Magnuson et al. 2000). In the case of hydroelectric reservoirs, locations were mapped and estimates of the ice-free period were generated from the *Lakes – Ice-Free Period* isoline map of Canada (NRCan 1974).

Emissions were calculated starting on the year of flooding completion. Reservoirs take a minimum of one year to fill following dam completion, unless otherwise confirmed. As CO_2 emissions from the surface of reservoirs are reported only for the 10 years following impoundment, all flooding events since 1980 were used.

Data Sources

The three main data sources used to develop area estimates were: (1) information on forest conversion due to reservoir impoundment in reporting zones 4 and 5 (see Section A3.5.2.2, Forest Conversion); (2) the Canadian Reservoir Database (Duchemin 2002); and (3) official industry numbers, derived from industry correspondence (Eichel 2006; Tremblay[26]).

The Canadian Reservoir Database contains records of 282 hydro reservoirs. Information from provincial and private hydroelectric utilities was accessed to update the database and cross-check the date of reservoir construction and the total reservoir area for all these reservoirs. In some instances, the database reported as new facilities some small, refurbished hydroelectric generation sites in the province of Quebec that entered into production under new ownership. As a result, a separate category was added to the database to document both the original construction and commissioning of a dam and the date when a hydroelectric facility was refurbished without any changes to the reservoir area.

It is important to note that fluctuations in the area of land converted to wetlands (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but reflect the difference between land areas recently (< 10 years ago) converted to reservoirs and older reservoirs (> 10 years), whose areas are thus transferred out of the accounting. The reporting system does not encompass all reservoir areas in Canada, which are monitored separately in the Canadian Reservoir Database.

Uncertainty

A temporal curve better reflects the decreasing trends of emission rates after impoundment than a unique emission factor. Hence, the domestic approach is believed to reduce the uncertainty in estimation factors. However, there are still important remaining sources of uncertainty:

- *Seasonal variability*. Some reservoirs display marked seasonal variability in CO2 fluxes, which are not taken into account in estimate development. Anecdotal evidence suggests that algal bloom in the spring could be associated with this variability, especially in reservoirs subjected to anthropogenic nutrient inputs.
- *Reservoir area*. There are variations in reservoir area due to water level fluctuations during the year.
- *Emission pathways*. The omission of potentially important CO2 emission pathways (e.g. degassing).

A3.5.7. Settlements

This category comprises estimates of removals of CO_2 from land classified as Settlements remaining Settlements (carbon sinks in urban trees) and emissions from land conversion to Settlements (conversion of forest land and of unmanaged grassland to Settlements). The following sections describe the approaches developed to estimate carbon sequestration by urban trees, emissions from the conversion of non-forest land (unmanaged grassland or tundra) to Settlements in the Canadian Arctic and sub-Arctic and estimation of areas of conversion from Cropland to Settlements. Approaches, methods and data sources for estimating emissions from the conversion of forest land to settlements are covered in Section A3.5.2.2.

A3.5.7.1. Settlements Remaining Settlements

General Approach and Methods

In Canada, the management and monitoring of urban trees is done at the level of individual municipalities, and there is no centralized authority or organization with responsibility for compiling national-scale urban tree information. Taking into consideration the lack of specific species class information and the considerable resources it would

26 Tremblay A, Hydro-Québec. 2010. Personal communication dated November 19, 2010, to Dominique Blain, Environment Canada.

require to develop such information, an approach based on urban tree crown (UTC) cover area was developed to estimate CO_2 sequestration by urban trees in Canada. The approach involves the sampling of digital air photos and high-resolution satellite imagery to estimate the proportion of UTC cover in Canada's major urban areas. The growth of urban trees in Canada was estimated using an IPCC Tier 2A approach (IPCC 2006):

Equation A3–78:

$$\Delta C_G = \sum AT \times CRW$$

where:

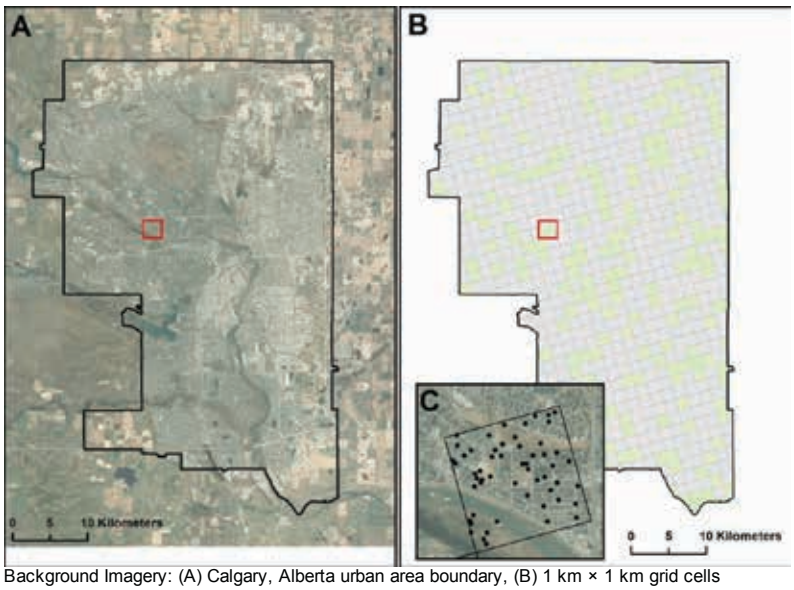
ΔC_G	=	annual carbon accumulation attributed to biomass increment of urban trees in Settlements remaining Settlements, tonnes C yr^{-1}
AT	=	total crown cover area of urban trees, ha
CRW	=	crown cover area-based growth rate for urban trees, tonnes C (ha crown cover)$^{-1}$ yr^{-1}

The total urban area of Canada in 2012 was estimated using the boundaries of Statistics Canada's 2011 populated place digital boundary layer[27], as it was the most nationally consistent delineation of urban areas available. The urban boundaries of 1990 were based on Statistics Canada 1990 polygon layer, but manually edited through visual interpretation of aerial photos and the 1990 GeoCover (MDA 2004 [28]) ortho-rectified image data set, to reduce known over-bounding errors (Statistics Canada 2010). The resulting 1990 urban layer represented a smaller total area (1.53 Mha) than the total urban area identified for 2012. Of the 947 population centres (2.42 Mha) in Canada, 69 (1.53 Mha) were extracted from the Statistics Canada data set that had populations greater than 30 000 individuals. This subset captures all major Canadian cities and represented 62% and 67% of the total urban area in 1990 and 2012, respectively. Furthermore, this subset holds the urban centres that represented approximately

27 Statistics Canada Populated Place spatial data and information available online at: http://www12.statcan.gc.ca/census-recensement/2011/geo/bound-limit/bound-limit-2011-eng.cfm

28 Information on MDA GeoCoveravailable at: http://www.mdafederal.com/geocover/geocoverlc/gclcoverview/. Accessed on November 4, 2016.

Figure A3–27 Sampling Grids and Point Sampling Over Georeferenced Air Photo



Background Imagery: (A) Calgary, Alberta urban area boundary, (B) 1 km × 1 km grid cells representing a 25% sampling rate with randomly selected grid cells shown in green, and (C) close-up of a single grid cell (20 pts/km2 sampling).Orthophoto courtesy of City of Calgary.

79% and 76% of Canada's population in 1990 and 2012, respectively (Statistics Canada 2011; McGovern 2016). While the population centres selected did not completely represent all populated places in Canada, many of the smaller communities that were filtered out are parts of an overall matrix of forest or agricultural land that may be captured under other land categories.

The 67 population centres were spatially allocated to 18 of the 60 reconciliation units (RUs) (see Section A3.5.1). The 18 RUs encompassed 97% and 99% of the total area and population, respectively, of the total of 947 population centres. Estimates of the proportion of UTC cover were developed for each RU using a point-based sampling approach (Pasher et al. 2014). A grid cell approach was used to ensure good spatial distribution of sampling cells (Figure A3–27). Random points at a density of 55 points/km2 on digital air photos or high-resolution satellite imagery were interpreted manually and classed into broad categories of tree crown or non-tree crown.

The same sampling point locations were used for both the 1990 and 2012 UTC assessments, although sampling cells and points which fell outside the 1990 urban boundary were not included to ensure that sampling was restricted to represent urban areas for that time period. A quality control process was implemented which involved random checks by alternative interpreters or reinterpretation. The % UTC for each RU was calculated as the proportion of all points identified as tree canopy out of the total points that were assessed within the RU. The national-scale UTC estimate was 28.5% in 1990 and 27% in 2012.

The total crown cover area of urban trees for each RU was estimated by multiplying the % UTC by the total urban area estimates for the associated RU in 1990 and 2012. Although the urban area boundary has increased by 6% from 1990 to 2012, the national-scale estimate of crown cover changed little, with regional variation in trends. Gains in crown cover area (e.g. tree growth and planting) tended to balance with losses (e.g. tree removal, mortality and urban land-use change).

A CRW value (2.12 t C/ha) was derived from data sets for the United States (Nowak et al. 2013), adjusting for Canada's shorter average growing season (on average 133 days). Net carbon sequestration was estimated as 74% of gross sequestration, accounting for urban tree growth characteristics and tree mortality and decomposition (Nowak et al. 2013). These growth and sequestration factors are applied consistently to all regions of the country and, as a result, estimates of urban tree crown cover area are the main driver of overall removal estimates. Interpolation and extrapolation were used to develop a consistent time series for the 1990–2015 period.

Uncertainty

The uncertainties associated with the estimates of urban area, UTC and carbon sequestration rate all contribute to the overall uncertainty of the estimates of CO_2 removals by urban trees. The result of these combined uncertainties using a Tier 1 error propagation approach provides an estimated total uncertainty of 21% for 1990 and 2012.

The uncertainties associated with 1990 and 2012 urban areas were not quantified by Statistics Canada. An error estimate of 10% was used for the 2012 urban area following the approach used in the 2012 National GHG Inventory report of the United States (U.S. EPA 2013). The error associated with the 1990 urban area estimate was assumed to be slightly higher at 15% than for 2012, based on expert judgement. This approach is similar to the uncertainty estimate for boundary delineation (15%) used for developing forest conversion estimates (Leckie 2011).

The uncertainty associated with UTC estimates was based on the standard error of the sampling approach calculated for each sampling period

(1990/2012). Standard errors for the UTC estimates were low (0.2% for the national UTC estimate) given the very high number of sampling points used.

The uncertainty estimate for the national gross carbon sequestration rate (16%) was developed from sampling error associated with urban tree field data collected in the United States. This uncertainty estimate does not include the estimation error related to using biomass equations, conversion factors and measurement error (Nowak et al. 2013).

A3.5.7.2. Cropland Converted to Settlements

Data Sources

Urban and industrial expansion has been one of the main drivers of Cropland conversion in Canada. Areas of Cropland conversion to Settlements were estimated based on the land-use maps for 1990, 2000 and 2010 developed in Huffman et al. (2015). Areas of conversion for the 1990–2000 and 2000–2010 periods were calculated through spatial analysis for each reporting unit and divided by the number of years in order to develop constant annual conversion rates. Areas of conversion were extrapolated after 2010. The total area of Cropland converted to Settlements for the 1990–2000 and 2000–2010 time periods was 184 kha and 115 kha, respectively, with the majority of change due to urban expansion in reporting zones 7 and 11. This is largely due to urban expansion in the main populated centres, such as Toronto, Hamilton, Oshawa, Montreal and Edmonton.

Uncertainty

Given that the highest conversion rates are caused by urban expansion, an independent assessment was conducted on the areas of conversion by comparing the land cover in each map against visual interpretation of orthorectified Landsat imagery over urban centres. The sampling strategy for this assessment was to perform the analysis on five main census metropolitan areas (CMA[29]), which contribute to 45% of the total area change from Cropland to Settlements. Polygons from the 2011 census were used to define the boundary of each CMA, and over 400 stratified random points were used to verify the land cover class in areas in which there were examples of either change or no-change from Cropland to Settlements, separated by a minimum distance of 1 km, to avoid statistical bias. The minimum mapping unit for the accuracy analysis was defined as a circle with radius of 100 m to prevent errors due to the presence of noise in each classified map. The class in each location was assigned based on the class of the majority of the pixels, to account for changes in land use. An overall accuracy of 80% and 84% was obtained for the areas of change computed from these maps, which concurs with the accuracy assessment carried out in Huffman et al. (2015).

A3.5.7.3. Grassland Converted to Settlements

General Approach and Methods

The Canadian northern regions (Arctic and sub-Arctic) cover nearly half of Canada's land mass and include five land categories (IPCC 2006), excluding Cropland. This assessment covered an area of about 359 million ha and included reporting zones 1, 2, 3 and 17, some small northern areas of reporting zones 4, 8 and 10, as well as reporting zones 13 and 18 north of 60°N latitude. The challenge was to capture land-use change and estimate associated emissions in this vast and remote landscape. An approach was developed specifically for this task and included the following components:

29 This term has been defined by Statistics Canada as the area consisting of one or more neighbouring municipalities with a population of 100000 inhabitants or more.

1. Mapping of non-forest land-use change in Canada's Arctic/sub-Arctic prior to and including 1990 and between 1990 and 2000.
2. Estimation of annual GHG emissions (above-ground biomass only) from non-forest land-use change in Canada's Arctic/sub-Arctic for the 1990–2000 period.

A comprehensive, wall-to-wall analysis over this area was clearly impractical, as this would require on the order of 400 Landsat satellite scenes for each date. Similarly, random sampling would likely not capture enough land-use change events to allow a reliable assessment. Instead, GIS data sets denoting the occurrence of cultural, mining and other human development were used to reduce and optimize the domain of investigation by flagging areas with high probability of occurrence of land use change. These areas of concentrated land-use change potential were targeted for change detection analysis (change vector analysis – Johnson and Kasischke 1998) using 23 Landsat frames from circa 1985, 1990 and 2000. The scenes cover more than 8.7 million ha, 56% of the potential land-use change area identified using the GIS data sets, or 70% of potential land-use change area if seismic survey lines are not included[30]. All 23 frames were located in the western Arctic and sub-Arctic regions.

The Land Use Change Mapping System for Canada's North (Butson and Fraser 2005) can be described as a hybrid change detection method based on two separate techniques: change vector analysis for identifying changed areas and constrained signature extension for labelling those changes (Olthof et al. 2005). A detailed description of how the Land Use Change Mapping System for Canada's North was used for the purpose of capturing non-forest land-use change in Canada's north is available in Fraser et al. (2005). The average rate of land-use change between 1985 and 2000 over the assessed area was 666 ha/year, and 60% of land-use change areas occurred in reporting zone 13. The same annual rate of land-use change was applied for the years 2001–2015.

A series of above-ground biomass maps in 2000 were developed for the main land-use change areas, using relationships between above-ground biomass and remote sensing data constructed from and calibrated with ground measurements (Figure A3–28). These maps were used to determine CO_2 emissions from the clearing of above-ground biomass.

30 Recent, low-impact seismic lines have a narrow swath of approximately 2 m in width, as opposed to conventional ones, which were much larger (~8 m). Low-impact seismic lines were widely adopted over the past decade and considerably reduce the environmental impact of seismic exploration.

Figure A3–28 Study Areas for the Determination of Above-Ground Biomass in Canada's Arctic and Sub-Arctic Region

The dominant land cover types in the two study areas are rock, lichen, low to high shrub, grass and sparse woodland.

Multiple regressions were conducted between natural logarithm (ln) (above-ground biomass) and a combination of reflectance values for all vegetation covers combined (grass, shrub, sparse woodland). The best least-square approximation had an r^2 = 0.72–0.78, dependent on approaches used, a relative mean square error of 75–80%, and a median value of the absolute percentage error of 33–53%. Biomass regressions were applied to the pre-conversion imagery for all land-use change areas to yield an estimate of the biomass cleared. All land-use change activities involved conversion of tundra vegetation to settlements, and all pre-conversion biomass carbon was deemed emitted upon clearing.

Since the 2007 submission, additional imagery was analyzed with the change detection method used for forest conversion area estimation. Reporting zone 4 and part of reporting zone 8 were fully mapped for both forest and non-forest conversion to settlements, adding 55 Mha to the area already mapped. The above-ground biomass of non-forest vegetation was derived from a literature search and estimated at 6 t/ha (or 3 t C/ha). For this region, there was an average rate of non-forest land-use change of 133 ha/year for the 1990–2006 period.

Uncertainty

The uncertainty in land-use change area covered by the 23 Landsat scenes is estimated to be within 20% (Fraser et al. 2005). The biomass equations developed from field measurements in the Dawson City study area were validated on the other study areas of Yellowknife and the Lupin mine. The median values of the absolute percentage error in above-ground biomass estimation for both study areas are 33–53%.

A Monte Carlo simulation method was used to quantify the overall error in carbon emissions caused by uncertainties in land use change area and biomass estimation. At the 95% confidence level, the percentage error varies from 218% if there is only one land-use change site within a reporting zone to 15% if a reporting zone has 75 or more land-use change sites. The error in the total above-ground biomass carbon stock change estimate, if considered as one reporting area, is about 15%. A full discussion of uncertainty can be found in Chen et al. (2005, 2009).

A3.6. Methodology for Waste Sector

The Waste Sector consists of four sources of emissions: solid waste disposal (landfills), biological treatment of solid waste, wastewater treatment and waste incineration. This section of Annex 3 details the accounting methodologies that are used to describe the greenhouse gas (GHG) emission estimates for the following categories from the Waste Sector:

- CH_4 emissions from solid waste disposal (landfills);
- CH_4 and N_2O emissions from biological treatment of solid waste (composting);
- CH_4 and N_2O emissions from wastewater treatment (municipal and industrial); and
- CO_2, CH_4, and N_2O emissions from waste incineration (MSW, hazardous waste and medical waste).

A3.6.1. CH_4 Emissions from Solid Waste Disposal

A3.6.1.1. Methodology

Emissions are estimated from two types of landfills in Canada:

- municipal solid waste (MSW) landfills; and
- wood waste landfills.

The Scholl Canyon model is used to estimate CH_4 generation from all landfills at a provincial level

using the following first-order decay equations (Equation A3–79, Equation A3–80, Equation A3–81, Equation A3–82 and Equation A3–83 (IPCC 2006)):

Equation A3–79: (2006 IPCC Guidelines Eq. 3.1):

$$Q_T = \left[\sum Q_{T,x} - R_T\right] \times (1 - OX_T)$$

where:

Q_T	=	the amount of CH_4 generated in the current year (T), kt CH_4/year
R_T	=	recovered CH_4 in year T, kt CH_4/year
OX_T	=	oxidation factor in year T, fraction
T	=	inventory year

Equation A3–80: (2006 IPCC Guidelines Eq. 3.6)

$$Q_{Tx} = DDOCm\ decomp_T \times F \times 16/12$$

where:

Q_{T_x}	=	amount of CH_4 generated from decomposable material
DDOCm decompT	=	DDOCm decomposed in year T, Gg. The DDOCm being the part of the organic carbon that will degrade under anaerobic condition in landfills.
F	=	fraction of CH_4, by volume, in generated landfill gas (fraction)
16/12	=	molecular weight ratio CH_4/C (ratio)

Equation A3–81: (2006 IPCC Guidelines Eq. 3.5):

$$DDOCm\ decomp_T = DDOCma_{T-1} \times (1 - e^{-k})$$

where:

T	=	inventory year
$DDOCma_{T-1}$		DDOCm accumulated in the solid waste disposal sites (SWDS) at the end of year (*T*-1), Gg
DDOCm $decomp_T$	=	DDOCm decomposed in the SWDS in year *T*, Gg
k	=	reaction constant, k = ln(2)/$t_{1/2}$ (y^{-1})
$t_{1/2}$	=	half-life time (y)

Equation A3–82: (2006 IPCC Guidelines Eq. 3.4):

$$DDOCma_T = DDOCmd_T \times (DDOCma_{T-1} \times e^{-k})$$

where:

T	=	inventory year
DDOCmaT		DDOCm accumulated in the SWDS at the end of year T, Gg
DDOCmaT-1	=	DDOCm accumulated in the SWDS at the end of year (T-1), Gg
DDOCmdT	=	DDOCm deposited into the SWDS in year T, Gg
k	=	reaction constant, k = ln(2)/t1/2 (y-1)
t1/2	=	half-life time (y)

Equation A3–83: (2006 IPCC Guidelines Eq. 3.2):

$$DDOCm = W \times DOC \times DOC_f \times MCF$$

where:

DDOCm	=	mass of decomposable DOC deposited, Gg
W		mass of waste deposited, Gg
DOC	=	degradable organic carbon in the year of deposition, fraction, Gg C/Gg waste
DOCf	=	fraction of DOC that can decompose (fraction)
MCF	=	CH_4 correction factor for aerobic decomposition in the year of deposition (fraction)

The Scholl Canyon model assumes that CH_4 production is highest in the early phase, followed by a slow steady decline in annual production rates. It also assumes that the initial lag time where anaerobic conditions are established is negligible (Figure A3–29).

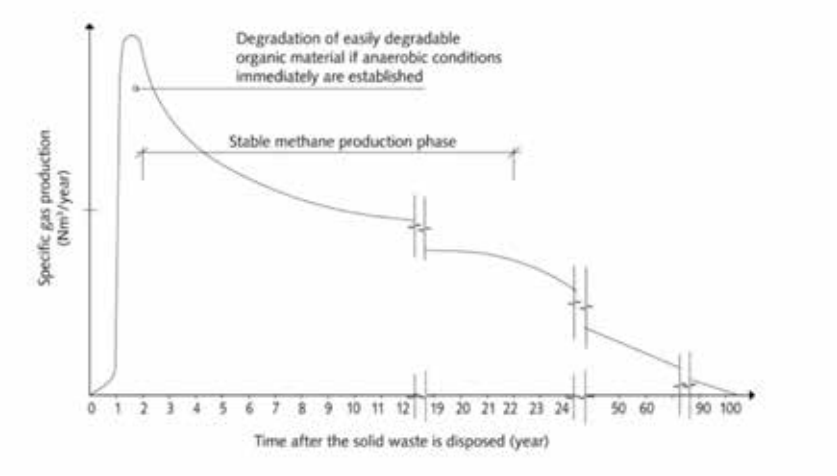
To calculate the net emissions for a specific year and province/territory, the total captured gas quantities (to be flared and or utilized) are subtracted from the generated CH_4 quantities (the sum of $Q_{T,X}$ for every portion of waste landfilled in past "x" years). The CH_4 emitted from the incomplete combustion of the flared portion of captured gas is then added.

Waste Disposed of Each Year (M_x)

MSW Landfills

For the purposes of the inventory, MSW includes residential, institutional, commercial and industrial (ICI), and construction and demolition (C&D)

Figure A3–29 Scholl Canyon Model Representation of Landfill Degradation



Note:
Figure is from IPCC (2002) and is shown as published without modification.

wastes. Two primary sources are used in obtaining landfill data for the GHG inventory. The amount of MSW landfilled in the years 1941 through 1990 was estimated by Levelton (1991). From 1998 to 2015 inclusively, MSW disposal data were obtained from the *Waste Management Industry Survey*, which is conducted by Statistics Canada on a biennial basis (Statistics Canada, 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013, 2015b, 2016a). MSW disposal values for the odd years during that period (1999–2013) were obtained by taking an average of the adjacent even years. Disposal, with respect to the Statistics Canada data, refers to the combination of waste incinerated, exported and landfilled. The annual quantities of waste landfilled are obtained by subtracting incinerated waste and exported waste from the Statistics Canada disposal values for 1998 to 2015. The amount of waste exported is included in the waste disposal values for the Statistics Canada 2000 survey year and subsequent years.[31,32] Waste disposal data compiled by Statistics Canada in the *Waste Management Industry Survey* are the most complete data available, as the survey population includes businesses engaged in the collection and transportation of non-hazardous and hazardous waste, in the operation of disposal facilities and transfer stations, and in the treatment and disposal of waste, as well as local governments and other public waste management bodies. A methodology is used to account for those populations that do not meet the population threshold as detailed in the following extract from the survey text: "…a survey coverage population was developed using information provided by survey respondents as well as from other sources about the municipalities that were served by disposal and recycling facilities. Total populations were calculated for these municipalities using Statistics Canada data. The difference between the total population and the covered population was calculated. A provincial per capita disposal figure was applied to this undercovered population, and this total was added to the survey total to arrive at an adjusted disposal figure. The undercovered portion of the population is small and has been decreasing with each iteration of the survey."

31 Marshall J. 2006. Personal communication (February 2006). Manager of the *Waste Management Industry Survey*: Business and Government Sectors, 2002 Report. Statistics Canada.

32 Marshall J. 2007. Personal communication (email dated February 21, 2006). Manager of the *Waste Management Industry Survey*: Business and Government Sectors, 2004 Report. Statistics Canada.

For all provinces with the exception of Prince Edward Island, MSW disposed quantities for the 1991–1997 time series were interpolated using a polynomial fit to the Levelton (1991) and Statistics Canada (2000, 2003, 2004) disposed MSW values. In lieu of Statistics Canada data for 2015, the amount of MSW disposed of for this year was extrapolated from 2009 to 2015 data using a multiple linear regression (Microsoft Excel LINEST statistical tool for an array) (Equation A3–84).

Equation A3–84:

$$M_x = (C_{13} \times X^{13}) + (C_{12} \times X^{12}) + (C_{11} \times X^{11}) + (C_{10} \times X^{10}) + (C_9 \times X^9) + (C_8 \times X^8) + (C_7 \times X^7) + (C_6 \times X^6) + (C_5 \times X^5) + (C_4 \times X^4) + (C_3 \times X^3) + (C_2 \times X^2) + (C_1 \times X) + C$$

where:

M_X	=	MSW disposed of in year X, t
C_i	=	coefficient of the i^{th} order
X	=	year of interest

Statistics Canada MSW disposal data are unavailable for Prince Edward Island, the Northwest Territories, Nunavut and Yukon. Three sources of disposal data are used to estimate the MSW landfill amounts for 1991–2015. The first set of data was provided by Levelton (1991) for 1971–1990. The second set of disposal data was provided by the Hazardous Waste Branch of Environment Canada for 1992 (Environment Canada 1996b). The third set of disposal data involves multiplying the 1992 percentage of disposed waste for Prince Edward Island, the Northwest Territories, Nunavut and Yukon (Environment Canada 1996b) by the surplus amount of disposed waste provided by Statistics Canada for 1998, 2000, 2002, 2004 and 2006 (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013, 2015b, 2016a). The surplus of waste landfilled for 1998, 2000, 2002, 2004 and 2006 is calculated by subtracting the sum of the provided provincial disposal values from the total Canadian disposal value. Disposal values for the remaining years were obtained by trending historical disposal data with the provincial populations for 1971–2015 (Statistics Canada 2006, 2014, 2015a, 2016b).

Table A3–61 Canadian Exports of Non-Hazardous Wastes

	Non-Hazardous Waste Exported to U.S. (t)			
Year	Ontario	Quebec	BC	Total
1989	100 000	6 978	7 407	114 386
1990	100 000	6 978	7 407	114 386
1991	100 000	6 978	7 407	114 386
1992	1 300 000	90 720	96 297	1 487 017
1993	1 300 000	90 720	96 297	1 487 017
1994	1 000 000	58 735	74 074	1 132 810
1995	1 046 398	26 750	77 511	1 150 660
1996	776 652	22 504	62 522	861 678
1997	770 822	18 257	47 532	836 611
1998	817 071	14 010	32 542	863 623
1999	782 286	73 826	35 235	891 347
2000	1 366 382	91 205	37 928	1 495 516
2001	1 792 287	9 718	49 114	1 851 119
2002	2 083 654	85 438	60 301	2 229 393
2003	2 940 903	85 354	71 487	3 097 743
2004	3 629 172	133 761	82 673	3 845 606
2005	3 728 170	136 236	93 859	3 958 265
2006	3 879 461	224 923	105 046	4 209 429
2007	3 988 280	667 026	118 168	4 773 475
2008	3 644 997	402 614	103 951	4 151 562
2009	3 127 662	389 620	115 428	3 632 711
2010	2 836 269	188 148	150 156	3 174 572
2011	3 374 223	88 153	227 554	3 689 930
2012	2 558 031	499 585	238 705	3 296 321
2013	2 747 859	411 624	234 720	3 394 204
2014	2 747 859	411 624	234 720	3 394 204
2015	2 747 859	411 624	234 720	3 394 204

The estimates of exported solid waste were developed from information solicited directly from the individual U.S. states where the waste was accepted for disposal (Environment Canada 2013a, 2014a; ECCC 2016a), since exporting provinces do not track the quantities of non-hazardous wastes leaving the province to the United States. Information on waste exported from Canada was obtained from the U.S. Congressional Research Service (McCarthy et al. 1990; McCarthy 1993, 1995, 1996, 1997, 1998, 2000, 2001, 2004, 2007; McCarthy and Hardenbergh 2002), the Michigan Department of Environmental Quality (Michigan 1996–2011) and from communications with state officials and representatives of individual landfill facilities in Michigan, Washington, New York, Ohio, Montana, Indiana, Pennsylvania and North Dakota. A summary of the exported waste quantities is provided in

Table A3–62 MSW Landfilled for 1990–2015[4]

Year	NL	P.E.I.	NS	NB	QC[3]	ON[3]	MB	SK	AB	BC[3]	YT	NT & NU	Canada
						tonnes							
1990[1]	366,004	51,293	493,010	462,391	3,692,855	5,857,104	696,174	638,942	1,577,585	1,753,214	16,608	34,493	15,639,672
1991	365,617	61,947	486,496	456,186	3,949,428	6,113,892	760,464	701,608	1,774,996	1,812,682	16,904	34,897	16,535,116
1992	330,777	74,800	480,391	454,946	3,991,984	5,091,187	782,637	718,693	1,858,808	1,772,014	17,200	35,300	15,608,738
1993	367,121	74,963	472,989	453,398	4,116,119	5,315,908	805,084	735,805	1,948,842	1,822,003	17,589	36,098	16,165,919
1994	368,179	77,327	464,463	451,577	4,290,715	5,838,078	827,286	752,500	2,044,313	1,898,953	17,977	36,098	17,067,465
1995	369,483	79,690	454,905	449,521	4,476,279	6,027,235	848,721	768,330	2,144,423	1,952,951	18,366	36,098	17,626,002
1996	371,065	82,054	444,434	447,266	4,644,595	6,545,367	868,855	782,841	2,248,361	2,027,286	18,755	36,098	18,516,976
1997	372,957	84,417	433,166	444,853	4,822,910	6,811,852	887,149	795,571	2,355,305	2,102,720	19,143	36,098	19,166,142
1998[2]	366,280	86,781	457,804	468,571	5,144,770	6,733,410	964,726	848,408	2,527,817	2,198,769	19,532	40,086	19,856,953
1999	382,549	79,635	403,552	441,815	5,306,108	7,327,699	939,619	835,177	2,638,911	2,246,146	18,392	37,746	20,657,347
2000[2]	398,818	71,913	351,812	415,058	5,411,108	7,294,407	914,511	821,946	2,750,004	2,287,008	17,251	35,406	20,769,241
2001	387,706	66,849	350,471	414,332	5,512,702	7,214,659	905,534	808,535	2,820,149	2,338,795	16,291	33,435	20,869,456
2002[2]	376,594	60,722	345,974	413,606	5,453,306	7,396,919	896,556	795,124	2,890,294	2,382,334	15,331	31,464	21,058,224
2003	388,321	65,111	348,329	427,890	5,754,175	6,607,799	912,337	795,029	2,983,803	2,414,235	16,057	32,955	20,746,039
2004[2]	400,048	69,490	351,408	442,173	6,006,198	5,987,923	928,117	794,933	3,077,311	2,447,266	16,784	34,445	20,556,095
2005	414,429	59,544	332,734	476,940	6,177,877	5,827,045	916,195	814,343	3,448,592	2,516,289	15,153	31,099	21,030,238
2006[2]	428,809	49,645	312,391	511,706	6,263,078	5,614,308	904,272	833,753	3,819,872	2,585,747	13,523	27,754	21,364,857
2007	413,997	44,562	313,380	495,584	5,485,854	5,456,751	924,857	868,348	3,983,715	2,526,381	12,685	26,034	20,552,148
2008[2]	399,184	39,381	309,971	479,461	5,414,619	5,749,868	945,441	902,943	4,147,558	2,495,561	11,848	24,315	20,920,149
2009	396,710	49,548	313,627	477,363	5,246,840	6,064,719	982,961	920,106	4,032,525	2,415,528	13,535	27,778	20,941,238
2010[2]	394,235	59,662	315,385	475,265	5,267,279	6,151,608	1,020,481	937,268	3,917,492	2,311,451	15,222	31,241	20,896,589
2011	392,903	61,459	311,368	484,102	5,256,508	5,582,739	1,019,072	947,469	3,915,708	2,211,379	15,550	31,913	20,230,171
2012	391,571	63,366	309,704	492,938	4,734,315	6,366,056	1,017,663	957,670	3,913,924	2,179,395	15,878	32,586	20,475,065
2013	403,365	64,892	310,981	500,527	4,882,639	6,141,560	1,022,093	949,133	4,005,754	2,247,608	16,130	33,104	20,577,783
2014	415,158	66,371	310,837	508,115	4,943,708	6,108,121	1,026,522	940,595	4,097,584	2,313,616	16,382	33,621	20,780,631
2015	410,820	68,533	312,059	513,556	4,777,804	6,021,612	1,036,922	956,864	4,039,328	2,259,197	17,024	35,245	20,448,964

Notes:
1. 1990 data obtained from Levelton (1991).
2. 1998, 2000, 2002, 2004, 2006, 2008 and 2010 data obtained from Statistics Canada disposal data (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013a, 2016a).
3. Exported MSW subtracted from the Statistics Canada disposal data (Environment Canada 2013a).
4. The data represented above were chosen from selected years. MSW landfill data from 1941 to 1990 (Levelton 1991) were used in the multiple linear regression method for estimation of MSW landfilled for 1991–1997.

Table A3–61. Note, in lieu of non-hazardous exported wastes for 2015, the values for this year were assumed to be constant from 2014.

The complete time series (1990–2015) of solid waste landfilled in municipal sites for each province and territory is provided in Table A3–62.

Wood Waste Landfills

The amount of wood waste landfilled in the years 1970 through 1992 is estimated at a national level based on the National Wood Residue Data Base (NRCan 1997). Data for the years 1998 and 2004 are provided in subsequent publications (NRCan 1999, 2005). A linear regression trend analysis is conducted to interpolate the amount of wood residue landfilled in the years 1993–1997 and 1999–2003. An exponential growth function was used to extrapolate wood residue quantities landfilled for the years 2005–2015 so as to reflect the expected exponential reduction in landfilled quantities. These interpolation methods were selected because they are most suitable for the data distribution.

Table A3–63 Wood Waste Generated and Landfilled in Canada for 1990–2015

Year	Wood Waste Disposed of (bone dry tonnes)		Wood Waste Landfilled (bone dry tonnes)		
	Pulp & Paper	Solid Wood Industry	Pulp & Paper	Solid Wood Industry	Total
1990	1 811 062	7 244 248	1 557 513	1 086 637	2 644 151
1991	1 745 204	6 980 815	1 500 875	1 047 122	2 547 998
1992	1 604 087	6 416 346	1 379 514	962 452	2 341 966
1993	1 474 380	5 897 520	1 267 967	884 628	2 152 595
1994	1 355 162	5 420 646	1 165 439	813 097	1 978 536
1995	1 245 583	4 982 332	1 071 201	747 350	1 818 551
1996	1 144 865	4 579 461	984 584	686 919	1 671 503
1997	1 052 291	4 209 165	904 971	631 375	1 536 345
1998	1 080 000	4 320 000	928 800	648 000	1 576 800
1999	888 995	3 555 979	764 536	533 397	1 297 933
2000	817 111	3 268 443	702 715	490 266	1 192 982
2001	751 039	3 004 156	645 894	450 623	1 096 517
2002	690 310	2 761 240	593 667	414 186	1 007 853
2003	634 491	2 537 966	545 663	380 695	926 358
2004	547 561	2 190 244	470 902	328 537	799 439
2005	536 030	2 144 120	460 986	321 618	782 604
2006	492 687	1 970 746	423 710	295 612	719 322
2007	452 848	1 811 392	389 449	271 709	661 158
2008	416 231	1 664 922	357 958	249 738	607 697
2009	382 574	1 530 297	329 014	229 544	558 558
2010	351 639	1 406 557	302 410	210 984	513 393
2011	323 206	1 292 822	277 957	193 923	471 880
2012	297 071	1 188 285	255 481	178 243	433 724
2013	273 050	1 092 200	234 823	163 830	398 653
2014	250 971	1 003 885	215 835	150 583	366 418
2015	230 678	922 710	198 383	138 407	336 789

The breakdown of the amount of wood residue disposed of (defined as residue that is not further used in a product, used as a source of fuel, or converted into a chemical) by the solid wood and the pulp and paper industries is estimated at 80% and 20%, respectively (MWA Consultants Paprican 1998).

The breakdown of the portion of the wood residue directed to landfills from the solid wood and pulp and paper industries is estimated based on the National Wood Residue Data Base (NRCan 1997). To avoid double counting, since emissions from public landfills are already accounted for in the emissions from MSW landfills, the ratio of wood waste landfilled in private versus public landfills, obtained from NRCan (1997), is used to isolate the quantity landfilled in dedicated private wood waste landfills. The allocation of wood waste landfilled in private landfills is estimated at 15% for solid wood operations and 86% for pulp and paper mills for the years 1970–2015. Table A3–63 shows the amount of wood waste disposed of and landfilled for the period 1990–2015.

CH_4 Generation Rate Constant (k)

The CH_4 generation 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 factors: moisture content, nutrient availability, pH and temperature. It is assumed that the landfill temperature is independent of the ambient temperature at depths exceeding 2 m, and the exothermic anaerobic biodegradation of the wastes keeps the methanogens within the optimum mesothermic range (25-40 C). The moisture content is therefore the sole parameter considered, as nutrient availability and pH are relatively minor factors and are too

site specific to include in the model (Maurice and Lagerkvist 2003; Thompson and Tanapat 2005).

MSW Landfills

The k values used to estimate emissions from MSW landfills are based on provincial precipitation data from 1941 to 2016 (Environment Canada 1840-. Historical Precipitation Data). The provincial locations at which the average annual precipitations were calculated were those indicated in the Levelton study where major landfills were located over the 1941 to 1990 period (Levelton 1991), with additional data for British Columbia from a study by Golder Associates Ltd. (2008). From these precipitation values, k values were determined using a relationship prepared by the Research Triangle Institute (RTI) for the U.S. Environmental Protection Agency. 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 inch/year (< 500 mm), between 20 and 40 inch/year (500 to 1000 [average 750] mm) and greater than 40 inch/year (> 1000 mm), respectively. The plot of these decay values and precipitation data showed a linear relationship, Equation A3–85 (RTI 2004). Using the RTI relationship and Environment Canada's average provincial precipitation data for 1941–1975, 1976–1989, 1990–2007 and 2008–2015, average provincial landfill decay rates were calculated for each of the provinces for the four respective time series. These four time intervals were selected to match those used to derive the provincial DOCs and L_0 values in order to better represent the changing conditions over the 1941–2015 time series.

A linear relationship between k values and precipitation was also developed for the province of British Columbia in an independent study (Golder Associates Ltd. 2008). The relationship, based on British Columbia landfill data, is given as $k = 1.3 \times 10^{-4} \times$ precipitation (mm) - 0.019 for precipitation values

Table A3–64 Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites

Region	Annual Precipitation (mm) from ECCC's Historical Weather Data				Calculated Rate Constant k (yr^{-1})			
	1941–1975	1976–1989	1990–2007	2008-present	1941–1975	1976–1989	1990–2007	2008-present
Newfoundland	1314.8	1390.5	1355.7	1386.8	0.075	0.080	0.078	0.080
Prince Edward Island	1051.8	1135.5	1122.6	1128.0	0.056	0.062	0.061	0.062
Nova Scotia	1330.7	1376.6	1334.5	1416.3	0.076	0.079	0.076	0.082
New Brunswick	1102.51	1150.00	1088.58	1145.65	0.060	0.063	0.059	0.063
Quebec	1007.9	1058.9	1085.3	1044.7	0.053	0.057	0.059	0.056
Ontario	834.2	910.8	901.9	885.9	0.041	0.047	0.046	0.045
Manitoba	526.5	493.4	521.2	504.4	0.020	0.017	0.019	0.018
Saskatchewan	383.0	374.7	422.0	430.0	0.010	0.009	0.012	0.013
Alberta	424.2	420.9	417.2	392.2	0.012	0.012	0.012	0.010
British Columbia	871.78	879.74	912.36	802.11	0.044	0.044	0.047	0.039
Yukon	264.2	261.7	271.8	296.0	0.001	0.001	0.002	0.004
Northwest Territories & Nunavut	261.2	273.0	287.0	287.7	0.001	0.002	0.003	0.003
Nunavut	420.1	448.9	372.1	348.3	0.012	0.014	0.009	0.007
NW & NU	340.6	360.9	329.5	318.0	0.007	0.008	0.006	0.005

Table A3–65 Provincial and Territorial MSW Landfill k (yr^{-1})Value Estimates

	Provinces and Territories											
Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	YT	NT & NU
1941–1975	0.075	0.056	0.076	0.06	0.053	0.041	0.020	0.01	0.012	0.044	0.001	0.007
1976–1989	0.080	0.062	0.079	0.063	0.057	0.047	0.017	0.009	0.012	0.044	0.001	0.008
1990–2007	0.078	0.061	0.076	0.059	0.059	0.046	0.019	0.012	0.012	0.047	0.002	0.006
2008–2015	0.080	0.062	0.082	0.063	0.056	0.045	0.018	0.013	0.010	0.039	0.004	0.005

from 279 mm to 2594 mm. Though the slope and constants are different, they do show the validity of a linear relationship to represent the k vs precipitation values, and the difference in the slope between the two equations is acceptable, given the uncertainty values for this source category.

Equation A3–85:

$$k(yr^{-1}) = 7 \times 10^{-5} \times precipitation\ (mm) - 0.0172$$

where:

k	=	reaction constant
yr	=	year of interest

Table A3–64 shows the mean annual precipitation and decay values assigned for each of the provincial landfill sites selected by Levelton (1991) or used in Golder Associates Ltd. (2008).

The k values used to estimate emissions from MSW landfills at a provincial level are derived by taking the average k value estimate for each province for each of the four time series. These values are provided in Table A3–65.

Wood Waste Landfills

Based on the default value recommended by the National Council for Air and Stream Improvement Inc. for estimating the wood products industry's landfill CH_4 emissions, a k value of 0.03/year was assumed to represent the CH_4 generation rate constant for all of the wood waste landfills in Canada (NCASI 2003).

CH_4 Generation Potential (L_0)

MSW Landfills

The CH_4 generation potential (L_0) represents the amount of CH_4 that could theoretically be produced per tonne of waste landfilled. Although not used directly in the present waste model, the L_0 is provided, as it is often used as a point of reference to compare regions and countries (Equation A3–86).

Equation A3–86: (2006 IPCC Guidelines Eq. 3.3/W):

$$L_o = \frac{DDOCm}{W} \times F \times \frac{16}{12} \times 1000\ \frac{kgCH_4}{tCH_4}$$

where:

L_0	=	CH_4 generation potential, kg CH_4/t waste
DDOCm	=	mass of decomposable DOC deposited, Gg
W	=	mass of waste deposited, Gg
F	=	fraction of CH_4 in landfill gas
16/12	=	stoichiometric factor to convert CH_4 to carbon

The methane correction factor (MCF) accounts for the proportion of managed to unmanaged solid waste disposal sites. Unmanaged solid waste disposal sites produce less CH_4, since a larger fraction of waste decomposes aerobically in the top layers of the site. The IPCC default value for MCF for managed landfill sites is chosen to represent the MCF for MSW landfills, since it is assumed that all landfills covered by the data collected are engineered landfills. The IPCC default values for MCF are shown in Table A3–66 (IPCC 2006).

Table A3–66 Solid Waste Disposal Site CH_4 Correction Factors

Type of Site	MCF Default Values
Managed - anaerobic	1.0
Managed - semi-aerobic	0.5
Unmanaged: deep (≥ 5 m waste)	0.8
Unmanaged: shallow (< 5 m waste)	0.4
Uncategorized solid waste disposal sites	0.6

The IPCC (2006) default value of 0.5 for the fraction of CH_4 in landfill gas (F) is used .

DOC_F represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal site. It accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. A default value of 0.6 was selected (IPCC 2006).

DOC represents the amount of organic carbon that is accessible to biochemical decomposition

and is based on the composition of the waste. Waste composition percentages are used to calculate the provincial DOC values according to Equation A3–87 (IPCC 2006) using the default DOC values for paper, garden, food and wood wastes as provided in Table 2.4, Volume 5 (IPCC 2006). Note that although the DOC for textiles has a 2006 IPCC Guidelines default value of 0.24, it can be shown, based on the assumption that the biogenic portion of the textiles was 60% (Note 3 in Table 2.4 of the 2006 IPCC Guidelines), that the biogenic portion of the textiles would have a DOC of 0.4. Textiles were therefore grouped with paper for the first three times series (1941–1975, 1976–1989, 1990–2007).

Equation A3–87:

$$\%DOC(by\ net\ weight) = (0.4 \times A) + (0.2 \times B) + (0.15 \times C) + (0.43 \times D)$$

where:

A	=	% of MSW that is paper and textiles
B	=	% of MSW that is garden or park waste
C	=	% of MSW that is food waste
D	=	% of MSW that is wood or straw

The provincial and territorial DOCs were calculated from waste disposal composition values for four distinct time periods: 1941–1975, 1976–1989, 1990–2007 and 2008–2015.

The DOC values for 2008–2015 were derived from the results of a national waste composition study conducted in 2014 and 2015 that was commissioned by Environment and Climate Change Canada (ECCC 2016b). The study consisted of a combination of on-site landfill audits and a compilation of composition studies that were executed by municipalities and private companies for their landfills over the 2008–2015 period. The purpose of the study was to update the DOC values to properly reflect the more recent provincial and municipal initiatives to divert organic wastes from their landfilled waste streams. Representative provincial waste composition values were presented for each province/territory, waste category and waste stream (residential; institutional, commercial and industrial (ICI); and construction and demolition (C&D)) based on the literature values (where available from sites) and the results of contractor winter and summer on-site audits. The on-site audits were conducted at landfills in British Columbia (Vancouver), the Prairie provinces (Edmonton), Ontario (Hamilton and Brantford), Quebec (Sherbrooke), the Atlantic provinces (St. John's NFL) and the territories (Whitehorse and Dawson City) and covered urban and rural municipalities for summer and winter. Regional values were assumed based on site data for the Prairie provinces, territories and Atlantic provinces. The calculations for the average DOC for this time series were based on Equation A3–88, which is an elaboration of Equation A3–83. This was possible since the waste composition audits from this recent study were more detailed. The default DOC values used are provided in Table A3–67 below.

Equation A3–88:

$$DOC = (40 \times A) + (24 \times B) + (15 \times C) + (43 \times D) + (20 \times E) + (24 \times F) + (39 \times G)$$

where:

A	=	fraction of MSW that is paper/cardboard
B	=	fraction of MSW that is textiles
C	=	fraction of MSW that is food waste
D	=	fraction of MSW that is wood
E	=	fraction of MSW that is garden and park waste
F	=	fraction of MSW that is infant diapers (nappies)
G	=	fraction of MSW that is rubber and leather

Table A3–67 Default DOC Content of Different MSW Component for 2008-2015 (2006 IPCC Guidelines Table 2.4):

MSW component	Default DOC content in % of wet waste
Paper/cardboard	40
Textiles[1]	24
Food waste	15
Wood	43
Garden and park waste	20
Infant diapers (nappies)	24
Rubber and leather	(39)[2]

1. 40% of textiles are assumed to be synthetic (default). Expert judgement by the authors. (2006 IPCC Guidelines)
2. Natural rubbers would likely not degrade under anaerobic condition at SWDS (Tsuchii et al. 1985; Rose and Steinbüchel 2005).

The DOC values for the previous period (1990–2007) were derived from waste composition data obtained from a study based on the 2002 data year (NRCan 2006) using a consistent methodology to estimate the MSW waste composition at disposal for all provinces and territories. These values were assumed to be representative for and remain constant over the period 1990 to 2007. The DOCs were separately developed from residential, ICI and C&D waste type compositions. The quantities for each waste category of residential, ICI and C&D origin were added together to reflect the true composition at disposal at the MSW landfill sites for that time period. The biodegradability of all three waste types is therefore accounted for in the MSW waste composition.

Since waste diversion programs were not significant prior to 1990, a third set of DOCs were developed to represent the waste composition at disposal sites from 1976 to 1989 based on waste composition at generation. This was obtained by adding the NRCan landfill data to the 2004 Statistics Canada recycled waste composition data (Statistics Canada 2007a).

Where gaps due to confidentiality issues were identified in the Statistics Canada report, regional factors (western, central and maritime provinces and northern territories) were used to populate the missing data.

A fourth set of DOCs was developed from a 1967 national study for the period 1941–1975 (Table 1.1-9 in CRC Press 1973), which were derived from national waste compositions provided in the article "World Survey Finds Less Organic Matter"

Table A3–68 Provincial and Territorial Degradable Organic Carbon (DOC) and CH_4 Generation Potential (L_0) Values

Province/Territory	2002 Organic Waste Diversion[1] (%)	1941 to 1975		1976 to 1989		1990 to 2007		2008 to Present	
		DOC (%)	L_0 (kg CH_4/t waste)	DOC (%)	L_0 (kg CH_4/t waste)	DOC (%)	L_0 (kg CH_4/t waste)	DOC (%)	L_0 (kg CH_4/t waste)
Newfoundland	N/A	0.31	122.57	0.19	74.99	0.19	74.85	0.20	79.01
Prince Edward Island	N/A	0.28	112.69	0.17	67.20	0.16	63.54	0.16	63.14
Nova Scotia	29.7	0.27	107.17	0.16	63.13	0.16	63.60	0.15	58.68
New Brunswick	19.8	0.25	99.03	0.17	67.08	0.16	63.81	0.18	70.35
Quebec	13.7	0.39	154.70	0.21	82.83	0.20	81.55	0.21	84.00
Ontario	16.4	0.37	149.96	0.21	83.44	0.21	83.47	0.21	82.20
Manitoba	4.9	0.35	139.42	0.19	77.68	0.19	77.58	0.20	79.49
Saskatchewan	4.3	0.38	151.50	0.22	86.12	0.22	86.40	0.19	75.74
Alberta	16.7	0.29	114.30	0.19	74.56	0.19	74.11	0.22	89.03
British Columbia	23.3	0.28	112.25	0.18	71.58	0.17	66.74	0.18	72.87
Yukon	N/A	0.23	77.88	0.15	50.09	0.17	55.12	0.15	60.62
Northwest Territories	N/A	0.23	77.88	0.15	50.09	0.17	55.12	0.15	61.49
Nunavut	N/A	0.23	93.46	0.15	60.11	0.17	55.12	0.17	67.96

Notes:
Sources: Derived from data obtained from Environment Canada (2016b), NRCan (2006), Statistics Canada (2007a) and CRC Press (1973).
1. Thompson et al. (2006).
N/A = Not available.

(Anon. 1967a), in which the composition of paper and organic matter was given as 70% and 10%, respectively.

Based on waste audits conducted in 1976, 1978 and 1980 (Ontario Ministry of the Environment 1991), the average composition of paper (40%), wood (2.6%), food wastes (22%), textiles (3.4%) and yard waste (3%) for the 1976 to 1989 period were comparable to those from the 2002 generated estimates but differed significantly from the older composition data. Therefore, 1975–1976 was judged to be an appropriate transition point to allow for a realistic change between the significantly different 1967 data set and the data derived from the 2002 waste composition.

Provincial and territorial DOC and L_0 values are summarized in Table A3–68.

The provincial/territorial DOCs given in Table A3–68 are used in the estimation of L_0s and ultimately in the provincial/territorial-specific methane emission generation for the period 1990–2015, inclusively.

The breakdown of organic matter (10%)—obtained from Table 1.1-9: Summary of International Refuse Composition—into food and yard waste was based on the waste composition (10.2% and 8.6%, respectively) given for Montreal, Quebec, in Table 1.1-10: Composition of Household Garbage of CRC Press (1973). The source of data for that table was a separate 1967 article (Anon. 1967b). The information on percentage of wood (2.4%) came from an article by the American Public Works Association (1964) and was presented in Table 1.1-2.8: Composition and Analysis of Average Municipal Refuse (CRC Press 1973).

A provincial profile was developed from the 1967 national average by pro-rating each of its DOC waste categories to match the same provincial profile as for the 1976 to 1989 period.

Wood Waste Landfills

Equation A3–86, as presented in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), is used to calculate the CH_4 generation potential for wood waste landfills. The IPCC MCF default value of 0.8 was selected for unmanaged deep landfill sites (0.8) , as it best represents industry practices. The emissions from this source were reported in CRF Table as category 5.A.2, Unmanaged Solid Waste Disposal Sites , as they are dedicated industrial sector unmanaged deep landfill sites .

The IPCC default value (2006) value of 0.5 is chosen for the fraction of CH_4 in landfill gas (F).

DOC_F represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal sites. It accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. The IPCC Good Practice Guidance (IPCC 2000) provides default values in the order of 0.5–0.6 for waste sites that include lignin. The lower end of this range, 0.5, is used in the calculation of the CH_4 generation potential to better represent the high lignin content in wood waste (IPCC/OECD/IEA 1997).

Equation A3–87 is used to calculate the national wood waste DOC value, assuming a 100% wood composition (IPCC 2006).

Based on these considerations, an L_0 of 115 kg CH_4/t of wood waste is calculated from Equation A3–86.

Captured Landfill Gas

At many large MSW landfill facilities, landfill gas is captured to be flared or utilized, or both. Owing to the relatively high concentration of CH_4 in the landfill gas, the gas can be combusted for electricity or heat generation. To a lesser extent, in recent years, the captured gas is simply collected and vented. If not utilized, the captured landfill gas is flared. For the purposes of the inventory, captured gas includes only the gas that is flared or utilized. In order to calculate the net CH_4 emissions from

landfills, the amount of captured CH_4 is subtracted from the CH_4 generated, as estimated by the Scholl Canyon model. This value is then added to the portion of CH_4 emitted from the flaring operation. GHG emissions associated with the use of landfill gas for energy recovery are accounted for in the Energy Sector. The calculation of net CH_4 emissions is shown in Equation A3–89:

Equation A3–89:

$$CH_{4(NET)} = CH_{4(generated)} - CH_{4(captured)} + CH_{4(emitted-F)}$$

where:

$CH_{4(NET)}$	=	net CH_4 emissions from MSW landfills, t
$CH_{4(generated)}$	=	CH_4 emissions generated from MSW landfills, t
$CH_{4(captured)}$	=	CH_4 emissions captured from MSW landfills, t
$CH_{4(emitted-F)}$	=	CH_4 emissions emitted from flaring of captured MSW landfill gas, t

A flaring emission control efficiency of 99.7% is used to determine the amount of CH_4 emitted. This value is obtained from Table 2.4-3 of Chapter 2.4 of EPA AP 42 (U.S. EPA 1995). The amount of CH_4 emitted from flaring of landfill gas is calculated as follows (Equation A3–90):

Equation A3–90:

$$CH_{4(emitted-F)} = CH_{4(flared)} \times \left(1 - Eff_{(flare-control)}\right)$$

where:

$CH_{4(emitted-F)}$	=	CH_4 emissions emitted from flaring of MSW CH_4 gas, t/year
$CH_{4(flared)}$	=	CH_4 gas flared, t/year
$Eff_{(flare-control)}$	=	flare emission control efficiency, fraction

Table A3–69 Estimated MSW CH_4 Generated, Captured, Flared and Emitted for 1990–2015

Year	CH_4 Generated (kt)	CH_4 Captured (kt)	CH_4 Flared (kt)	CH_4 Emitted from Flare (kt)	CH_4 Emitted (kt)
1990	899.49	192.66	23.61	0.07	706.90
1991	909.88	195.64	27.18	0.08	714.32
1992	922.49	204.78	35.29	0.11	717.81
1993	930.76	209.39	44.46	0.13	721.51
1994	940.58	223.36	56.73	0.17	717.38
1995	953.09	243.44	69.36	0.21	709.86
1996	966.92	264.55	78.67	0.24	702.61
1997	983.21	267.59	80.83	0.24	715.86
1998	1,000.94	271.63	90.80	0.27	729.58
1999	1,019.90	275.68	100.49	0.30	744.52
2000	1,040.90	294.18	117.90	0.35	747.08
2001	1,061.24	312.68	135.20	0.41	748.96
2002	1,080.96	312.53	137.06	0.41	768.84
2003	1,100.28	312.38	139.34	0.42	788.32
2004	1,117.56	310.57	141.10	0.42	807.41
2005	1,133.28	308.75	142.86	0.43	824.96
2006	1,149.13	304.70	130.80	0.39	844.82
2007	1,164.50	331.56	164.90	0.49	833.43
2008	1,120.18	351.18	163.37	0.49	769.50
2009	1,131.98	370.46	185.71	0.56	762.07
2010	1,143.58	417.74	219.52	0.66	726.50
2011	1,154.94	426.58	224.96	0.67	729.04
2012	1,163.55	447.23	231.43	0.69	717.01
2013	1,172.38	449.90	222.31	0.67	723.15
2014	1,181.14	449.90	222.31	0.67	731.91
2015	1,190.11	449.90	222.31	0.67	740.88

The quantities of CH_4 gas collected from 1983 to 1996 were obtained from ad hoc surveys conducted by Environment Canada, [33] while quantities for the years 1997–2003 were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 2003a). CH_4 gas capture data for 2005 were obtained through a study prepared for Environment Canada (Environment Canada 2007). CH_4 gas capture and utilization data for 2006–2007, 2008–2009, 2010–2011 and 2012–2013 were obtained through survey studies (Environment Canada 2009, 2011, 2013b, 2014b). Prior to the 2008 data collection survey, the landfill gas capture data were collected every odd year, and therefore, for the purposes of the national GHG inventory, the landfill gas capture data for the subsequent even years were averaged from the odd years starting from 1997. However, the subsequent biennial surveys collected data for two data years from the facilities; these data were first employed in the 2007 National Inventory Report (NIR) submission estimates. Data for 2014 and 2015 are temporarily constant from 2013, until the more recent information in the 2016 survey is incorporated. Table A3–69 shows the amount of CH_4 captured and flared from 1990 to 2015.[34]

A3.6.2. CH_4 Emissions from Wastewater Treatment

A3.6.2.1. Methodology

Municipal Wastewater Treatment

The IPCC (2006) default method for calculating CH_4 emissions from domestic wastewater handling is not used, because the required data (i.e. volumes of wastewater treated) are not available. Instead, a method similar to the methodology developed for Environment Canada (AECOM Canada 2011) is used to calculate an emission factor. The B_o recommended by AECOM is 0.36 kg CH_4 per kg BOD_5. It was also recommended that the methane conversion factor (MCF) be changed from a percent of population served by anaerobic treatment to the product of a combined MCF (septic systems, facultative lagoons, anaerobic lagoons and direct discharge) and the provincial population served by these systems, i.e. not served by a centralized treatment system. A combined MCF of 0.3 was recommended, as it provides the best representation of the distribution of the Canadian municipal wastewater treatment units.

Therefore, an emission factor of 0.108 was derived from the product of a B_o of 0.36 kg CH_4 per kg BOD_5 and an MCF of 0.3. To provide the EF in units of kg CH_4/capita/yr, the following relation was used, given an organic loading rate of 0.060 kg BOD_5/person/day (2006 IPCC Guidelines default) (Equation A3–91):

Equation A3–91:

$$EF_{CH_4}(kg\ CH_4\ /capita\ per\ year\ ) = (per\ capita\ BOD_5\ loading\ rate) \times (CH_4\ generation\ rate)$$
$$= \left(0.06\frac{kgBOD_5}{capita \times day}\right) \times \left(365\frac{days}{years}\right) \times \left(0.108\frac{kgCH_4}{kgBOD_5}\right) = \left(1.971\frac{kgCH_4}{capita \times year}\right)$$

where:

EF_{CH4}	=	CH_4 emission factor (kg CH_4 per capita per year)
0.06 kg BOD_5/(cap x day)	=	Organic loading rate (kg BOD_5 per capita per day)
365 days/year	=	Conversion factor
0.108 kg CH_4/kg BOD_5	=	CH_4 generation rate

The percentage of wastewater that is treated aerobically for each province is based on the 2006 ratio of rural to urban populations in each province and territory (AECOM Canada 2011). It is assumed that anaerobic primary and secondary wastewater treatment plants, septic tanks and outfalls where the effluent is discharged without treatment and where CH_4 emissions are not captured are predominant in rural areas. Canadian

33 Perkin. Personal communication (letter dated July 1998). National Office of Pollution Prevention, Environment and Climate Change Canada.

34 Where data were not made available from the landfill gas capture facilities, data from previous surveys were employed.

urban municipalities can be assumed to be serviced by aerobic treatment systems and/or anaerobic systems that have full capture of the biogases where they are utilized or flared with near complete combustion.

Emissions are calculated by multiplying the emission factor by the population of the respective province (Statistics Canada 2006, 2014, 2015a, 2016b) and the fraction of wastewater that is anaerobically treated.

Table A_3–70 shows the percentage of wastewater treated anaerobically for 1990–2015. The remaining percentage of wastewater is treated aerobically (primary and secondary wastewater treatment).

Equation A3–92:

$$CH_{4(x)} = EF_{CH_4} \times P_x \times FRAC_{AN(x)}$$

where:

$CH_{4(x)}$	=	CH_4 emissions from wastewater treatment for province x, t/year
EF_{CH4}	=	CH_4 emission factor for wastewater treatment, t/capita per year
P_x	=	population of province x
$FRAC_{AN(x)}$	=	fraction of wastewater treated anaerobically for province x

Industrial Wastewater Treatment – CH_4 & N_2O

Data were collected through surveys of industrial facilities either known or likely to be employing anaerobic units to treat their effluent on-site (Environment Canada 2014d, 2014e; ECCC 2016c). N_2O

Table A3–70 Percentage of Wastewater Treated Anaerobically by Province for the 1990–2015 Time Series

	Fraction of Wastewater Treated Anaerobically (%)												
Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NU	NT	YT
1990	92	56	76	40	43	9	30	44	18	23	100	97	57
1991	92	56	76	40	43	9	30	44	18	23	100	97	57
1992	92	56	76	40	43	9	30	44	18	23	100	97	57
1993	92	56	76	40	43	9	30	44	18	23	100	97	57
1994	92	56	76	40	43	9	30	44	18	23	100	97	57
1995	92	56	76	40	43	9	30	44	18	23	100	97	57
1996	92	56	76	40	43	9	30	44	18	23	100	97	57
1997	92	56	76	40	41	9	30	44	18	23	100	97	57
1998	92	56	76	40	37	9	30	44	18	23	100	97	57
1999	92	56	76	40	32	9	30	44	18	23	100	97	57
2000	92	56	76	40	27	9	30	44	18	23	100	97	57
2001	92	56	76	40	25	9	30	44	18	23	100	97	57
2002	92	56	76	40	25	9	30	44	18	23	100	97	57
2003	92	56	76	40	25	9	30	44	18	23	100	97	57
2004	92	56	76	40	25	9	30	44	18	23	100	97	57
2005	92	56	76	40	25	9	30	44	18	23	100	97	57
2006	92	56	76	40	25	9	30	44	18	23	100	97	57
2007	92	56	76	40	25	9	30	44	18	23	100	97	57
2008	92	56	76	40	25	9	30	44	18	23	100	97	57
2009	92	56	76	40	25	9	30	44	18	23	100	97	57
2010	92	56	76	40	25	9	30	44	18	23	100	97	57
2011	92	56	76	40	25	9	30	44	18	23	100	97	57
2012	92	56	76	40	25	9	30	44	18	23	100	97	57
2013	92	56	76	40	25	9	30	44	18	23	100	97	57
2014	92	56	76	40	25	9	30	44	18	23	100	97	57
2015	92	56	76	40	25	9	30	44	18	23	100	97	57

Source: 1996–2006 data obtained from AECOM (2011). Subsequent and prior years were assumed constant.

emissions from this source are not expected to be significant in view of the relatively few units in operation and given that wastewater from pulp and paper and effluent from potato processing (the two largest industry sectors involved) do not contain large quantities of nitrogenous matter.

A3

Emissions from industrial wastewater handling at a plant-site level are typically difficult to quantify, due to confidentiality issues and the variety of biological treatment units available that focus on biodegradable organics or nitrogen removal or that can serve both functions.

Preliminary inquiries indicated that anaerobic industrial wastewater units were relatively few in Canada. A Tier 3 approach based on information directly collected from individual facilities was deemed more accurate than the default approach.

On the basis of volume of wastewater produced, the prioritized industry sectors were: pulp and paper, chemicals and chemical products, food, beverages, petroleum and coal products, rubber products, plastic products, and total textiles.

In 2006, requests were submitted to the Canadian Chemical Producers' Association (CCPA), Canadian Soft Drink Association (CSDA), Canadian Association of Petroleum Producers (CAPP), Rubber Association of Canada (RAC) and Forest Products Association of Canada (FPAC) to obtain a confirmation for recent years. Of those members who replied, none confirmed the use of an anaerobic system. Nineteen facilities were identified to have anaerobic systems: two in the pulp and paper sector (confirmed by the FPAC),[35] fifteen in the food industry and two in the beverage industry. The following industrial sectors were ruled out based on confirmations from industry representatives that anaerobic treatment was not taking place at facilities in their sectors: chemicals and chemical products,[36] beverages,[37] petroleum and coal products,[38] rubber products,[39] plastic products,[40,41] and total textiles.[42]

Of all the industry sectors, the two pulp and paper facilities treat by far the largest portion of process water.

These facilities directly provided the methane production in volumetric units. These quantities were converted to mass units using the density of methane at 25°C and 1 atm. Fugitive losses from the digesters and the piping system were estimated to be 0.5%, which was an average of the 0.6% for losses in pipelines and leakage at the end user for processing, transmission and distribution of natural gas, and the 0.4% for leakage from residential and commercial sectors. Methane emissions from the inefficiencies of the flare and utilization devices were also accounted for. The methane destruction efficiencies were 0.995 for an enclosed flare and 0.98 for a boiler (Climate Action Reserve 2009). The total emissions were therefore the sum of the piping losses and the quantities of methane circumventing combustion in the flare and boiler.

The emissions for the food industry were similarly calculated. In the absence of production data (i.e. from a cheese manufacturer, potato

35 FPAC. Personal communication (email dated October 4, 2010). Roger Cook, Forest Products Association of Canada, to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division, Environment and Climate Change Canada.

36 CCPA. Personal communication (email dated December 4, 2006). Bruce Caswell, Canadian Chemical Producers' Association, to Paula Critchley, Waste Sector, Greenhouse Gas Division, Environment and Climate Change Canada.

37 CSDA. Personal communication (telephone conversation dated December 2006). Canadian Soft Drink Association and Paula Critchley, Waste Sector, Greenhouse Gas Division, Environment and Climate Change Canada.

38 CAPP. Personal communication (email dated October 24, 2006). Sonia Simard, Canadian Association of Petroleum Producers, to Paula Critchley, Waste Sector, Greenhouse Gas Division

39 RAC. Personal communication (telephone conversation dated December 2006). Rubber Association of Canada, to Paula Critchley, Waste Sector, Greenhouse Gas Division, Environment and Climate Change Canada.

40 CPIA. Personal communication (email dated December 4, 2006). Ray Kelsey, Canadian Plastics Industry Association, to Paula Critchley, Waste Sector, Greenhouse Gas Division, Environment and Climate Change Canada.

41 CPIA. Personal communication (email dated October 6, 2010). Fred Edgecombe, Canadian Plastics Industry Association, to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division, Environment and Climate Change Canada.

42 Lincoln Fabrics. Personal communication (email dated October 4, 2010). Steve Thistle, Plant Manager of Lincoln Fabrics Ltd., to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division, Environment and Climate Change Canada.

Table A3–71 COD Values Used in CH_4 Emission Estimates per Industry Type

Industry Group	IPCC Industry Type	IPCC Degradable Organic Component—COD (g/L)
Food	Vegetables, Fruits & Juices	5
Beverages	Soft Drinks	2
Rubber Products	Organic Chemicals	3
Plastic Products	Plastics and Resins	3.7
Primary Textiles & Textile Products	Textiles (Natural)	0.9
Wood Products	N/A	N/A
Paper & Allied Products	Pulp & Paper (Combined)	9
Primary Metals	N/A	N/A
Fabricated Metals	N/A	N/A
Transportation Equipment	N/A	N/A
Non-Metallic Mineral Products	N/A	N/A
Petroleum & Coal Products	Petroleum Refineries	1
Chemicals & Chemical Products	Organic Chemicals	3

Notes:
Sources: IPCC (2000), except for Industry Group, which is from Environment Canada (1986, 1991, 1996a).

processor and candy bar manufacturer), design parameters (process wastewater volumes, chemical oxygen demand [COD]) were used from the engineering firm that supplied the units to these facilities to generate gas quantities. As it is known that the gas is collected, it was assumed that the losses, i.e. emissions, would consist of piping losses and utilization by a boiler.

Table A3–71 shows the industry sectors included within the Environment Canada surveys (Environment Canada 1986, 1991, 1996a) and the corresponding COD values that are deemed representative of the industry sectors.

A3.6.3. N_2O Emissions from Wastewater Treatment

A3.6.3.1. Methodology

The N_2O emissions from municipal wastewater treatment facilities are estimated based on the amount of nitrogen in sewage and the assumption that 0.01 kg N_2O-N/kg sewage nitrogen will be generated.

To estimate the amount of nitrogen in sewage, it is assumed that protein is 16% nitrogen. Canadian

Table A3–72 Canadian Protein Consumption

Year	Protein Consumption (g/capita per day)
1990	65.26
1991[a]	66.19
1992	66.55
1993	67.20
1994	67.86
1995	68.52
1996[a]	68.59
1997	69.87
1998	70.56
1999	71.25
2000	71.95
2001[a]	72.97
2002	72.79
2003[a]	71.76
2004[a]	72.18
2005[b]	71.12
2006[b]	71.03
2007[b]	71.79
2008[b]	70.25
2009[b]	69.85
2010[b]	69.77
2011[b]	69.43
2012[b]	69.09
2013[b]	68.75
2014[b]	68.41
2015[b]	68.07

Sources :
a. Statistics Canada (2008b), Food Statistics, Catalogue No. 21-020-X: the data have been adjusted for retail, household cooking and plate loss.

b. Statistics Canada (2010b), Food Statistics, Catalogue No. 21-020-X: the data have been adjusted for retail, household cooking and plate loss.

protein consumption data are obtained from the annual food statistics publication (Statistics Canada 2007b, 2008b, 2010b), as shown in Table A3–72. Protein consumption is calculated after retail, household, cooking and plate losses. Data are provided for the years 1991, 1996 and 2001–2009. Protein consumption data for missing years are estimated by applying a multiple linear regression. In the absence of protein consumption data for 2010–2015, a growth function was used to extrapolate protein consumption.

Protein consumption (accounting for food waste at the retail, household cooking and plate level) is employed in this case rather than protein availability because it provides a more realistic and accurate estimate of N_2O emissions from municipal wastewater treatment.

A country-specific study (AECOM 2012) concluded that the use of annual per capita protein available for consumption data could result in an overestimate of wastewater N_2O emissions and recommended the implementation of a consumption-based approach, where protein consumption is calculated from the annual per capita protein available adjusted using USDA[43] food loss statistics.

In Canada, most food loss occurs at the retail and consumer levels; FAO[44] data do not adequately account for these major losses in Canada. Food waste in Canada is typically managed through the solid waste management or on-site composting streams.

A typical wastewater industry value for nitrogen produced by a Canadian individual excluding non-consumed protein is 13 g N/capita/day. Canadian nitrogen loading based on 2009 per capita protein consumption and protein available is 11.2 g N/capita/day and 16.5 g N/capita/day, respectively. The former value is a more accurate estimate of the nitrogen produced by an individual at the household, excluding industrial and non-consumed proteins.

The N_2O emission factor is calculated as follows (Equation A3–93):

Equation A3–93:

$$EF_{N_2O} = PC \times EF_{N_2O-N} \times FRAC_{NPR} \times \frac{44}{28}$$

where:

EF_{N2O}	=	emission factor: kg N_2O/capita per year
PC	=	annual per capita protein consumption, kg/capita per year (Statistics Canada 2007b, 2008b, 2010b)
EF_{N2O-N}	=	emission factor: default 0.01 (0.002–0.12) kg N_2O-N/kg sewage nitrogen produced
$FRAC_{NPR}$	=	fraction of nitrogen in protein: default = 0.16 kg N/kg protein
44/28	=	stoichiometric factor to convert nitrogen to N_2O

Emissions are calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada 2006, 2014, 2015a, 2016b) (Equation A3–94):

Equation A3–94:

$$N_2O_s = EF_{N_2O} \times NR_{PEOPLE}$$

where:

N_2O_s	=	N_2O emissions from human sewage, kg N_2O/year
EF_{N2O}	=	emission factor: kg N_2O/capita per year (Equation A3–93).
NR_{PEOPLE}	=	number of people in country

43 United States Department of Agriculture.

44 Food and Agriculture Organization of the United Nations.

A3.6.4. CH_4 and N_2O Emissions from Municipal Wastewater and Industrial Sludge Handling

Methane emissions from these two sources are assumed to be not occurring. The sludge from municipal wastewater treatment is typically either placed in landfills or applied to soils and is therefore accounted for within the emissions from MSW landfills, or, when land-applied, the application is on the surface, meaning that the degradation is aerobic with no significant CH_4 emissions.

Methodologies for the estimation of N_2O emissions from industrial sludge treatment are not provided in 2006 IPCC Guidelines (IPCC 2006) and, therefore, this category was not estimated.

A3.6.5. CO_2 Emissions from Waste Incineration

A3.6.5.1. Methodology

Municipal Solid Waste Incineration

The IPCC decision tree in Figure 5.5 of IPCC (2000) for CO_2 emissions from waste incineration defines good practice in adapting the methods in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997). Country-specific carbon contents are not available; thus, Box 2 of the decision tree in Figure 5.5 (IPCC 2000) is the chosen methodology for calculation of CO_2 emissions.

The following steps detail the methodology for the estimation of CO_2 emissions from waste incineration:

Calculating the Amount of Waste Incinerated: The amount of waste incinerated each year is based on two primary sources. The amount of MSW incinerated in the year 1992 was estimated based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The amount of MSW incinerated for the years 1999, 2000 and 2001 was estimated based on the study *Municipal Solid Waste Incineration in Canada: An Update on Operations 1999–2001*, performed by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b). A polynomial curve-fitting equation is employed to estimate the amount of MSW incinerated over the period 1991–1998 based on the values provided by A.J. Chandler & Associates Ltd. and Environment Canada. To estimate the coefficients in the polynomial, a multiple linear regression application (Microsoft Excel LINEST statistical tool for an array) is used. A polynomial of the order 13 provides the best fit. This multiple linear regression method of estimation is consistent with the IPCC interpolation method (IPCC 2000). To estimate the amount of MSW incinerated for 2002–2015, a trend extrapolation was performed with the A.J. Chandler & Associates Ltd. and Environment Canada MSW incineration values for all relevant provinces except Quebec and Ontario, for which only the former MSW incineration values (A.J. Chandler & Associates Ltd.) were used. In the province of Ontario, one of the incineration plants closed at the end of 2001. Therefore, the amount of waste incinerated in Ontario for the period 2002–2015 is estimated by trending the A.J. Chandler & Associates Ltd. incineration values for 1999–2001 with population (Statistics Canada 2006, 2014, 2015a, 2016b), assuming that the Ontario incineration plant was closed for this period.

MSW incineration estimates for the period 1990–2015 are shown in Table A3–73.

Developing Emission Factors: Provincial CO_2 emission factors are developed based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The CO_2 emission factors are founded on the assumption that carbon contained in waste undergoes complete oxidation to CO_2.

Table A3–73 Estimated MSW Incinerated by Province for 1990–2015

Year	MSW Incinerated (t)					
	NL	PE.	NS	QC	ON	BC
1990	0	32 000	76 500	619 522	258 700	239 752
1991	0	32 000	58 888	562 929	266 734	252 212
1992	35 500	29 800	56 700	541 100	277 000	257 500
1993	0	32 000	54 601	530 521	255 465	262 988
1994	0	32 000	52 533	509 879	251 775	265 211
1995	0	32 000	50 515	485 993	249 650	265 703
1996	0	32 000	48 549	458 648	249 297	264 755
1997	0	32 000	46 634	427 623	250 925	262 659
1998	0	32 000	44 773	392 695	254 747	259 715
1999	0	32 212	43 650	298 904	258 429	254 800
2000	0	33 000	40 015	303 887	270 811	256 400
2001	0	32 224	40 040	303 910	281 671	246 700
2002	0	32 511	43 220	307 715	165 060	245 247
2003	0	32 540	46 251	310 700	178 747	242 048
2004	0	32 578	48 559	314 041	192 169	237 718
2005	0	32 609	46 802	317 108	204 647	232 220
2006	0	32 593	46 714	320 440	216 690	226 288
2007	0	32 582	43 288	324 499	225 977	219 775
2008	0	32 668	44 260	329 085	236 694	212 057
2009	0	32 763	47 112	334 552	247 106	203 963
2010	0	32 910	51 861	340 281	259 538	196 664
2011	0	33 106	54 795	345 502	271 165	192 276
2012	0	33 207	55 243	350 645	284 378	186 538
2013	0	33 222	52 985	355 313	297 178	181 249
2014	0	33 282	52 246	359 323	308 641	173 877
2015	0	33,330	53,453	362,295	319,442	166,672

Note: Ontario incineration plant closed as of 2001 year-end.

Table A3–74 Quantities of Waste Incinerated in 1992

Waste Types	Waste Quantities Incinerated in 1992											
	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NT & NU	YT
Paper	13 600	10 100	19 940	n.l.	171 610	96 200	n.l.	n.l.	n.l.	92 170	n.l.	n.l.
Plastic	2 650	2 800	5 250	n.l.	42 490	23 200	n.l.	n.l.	n.l.	23 700	n.l.	n.l.
Organics	9 820	9 670	17 710	n.l.	190 480	102 000	n.l.	n.l.	n.l.	65 580	n.l.	n.l.

Source: Environment Canada (1996b), tables 2.3-2.26.

Note: n.l. means that no incineration occurs in that province.

Table A3–75 Estimated MSW Organic Composition and Moisture and Carbon Content

Component	Composition of Total Organics (%)	Moisture Content (%)	Carbon Content (%)
Yard/Garden Waste	41	60.0	47.8
Food Waste	31	70.0	48.0
Wood Waste	16	20.0	49.5
Textiles	10	10.0	55.0
Rubber	2	2.0	69.7
Total Organics	100	50.5	49.3

Sources:
Tchobanoglous et al. (1993), pages 70, 80.
Carbon constants for Textiles and Yard Waste from Peavy et al. (1985).

The provincial breakdown of the type of waste incinerated for 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The quantity of waste incinerated was divided into three categories: paper, plastics and organics. Table A3–74 summarizes these waste quantities.

In accordance with the 2006 IPCC Guidelines (IPCC 2006), only CO_2 emissions resulting from the incineration of carbon in waste of fossil origin (e.g. plastics, certain textiles, rubber, liquid solvents and waste oil) are included in emission estimates. Therefore, it is necessary to estimate the fossil origin portion of the waste in order to develop an emission factor that excludes emissions due to the incineration of biomass. The breakdown in organic composition is estimated by averaging waste composition data from three published documents (Environment Canada 1994a, 1995a, 1995b). Table A3–75 shows the averaged breakdown in organic composition as well as the moisture and carbon content employed to develop the MSW incineration emission estimates.

The amount of fossil fuel-based carbon available in the waste incinerated is determined using typical percent weight carbon content values. Carbon and moisture content values were provided by Tchobanoglous et al. (1993) and Peavy et al. (1985). The carbon content for plastic is 80%, an average of the 75–85% range provided by the Good Practice Guidance (IPCC 2000), based upon a recommendation from a 2011 ERT centralized review. The amount of carbon per tonne of waste is estimated by subtracting the moisture content from the mass of fossil origin waste and multiplying by the carbon content value of the waste type. The fossil origin portion of the organic waste is determined by multiplying the organic waste by the percent fossil origin composition as follows (Equation A3–95):

Equation A3–95:

$$Waste\ Type_{Fossil-Origin} = M_{Total} \times \left(1 - \%\ Organic_{Comp}\right)$$

where:

$WasteType_{Fossil-Origin}$	=	amount of fossil fuel–based waste incinerated, t
M_{Total}	=	amount of waste incinerated, t (1992 data provided by Environment Canada [1996b])
$\%Organic_{Comp}$	=	% organic composition per waste type (Environment Canada 1994a, 1995a, 1995b)

The amount of fossil fuel-based carbon is 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. The derivation of the CO_2 emission factor is shown in the following equations (Equation A3–96 and Equation A3–97):

Equation A3–96:

$$C_{Avail(y)} = \left(Waste\ Type_{\ Fossil-Origin}\right) \times (1 - \%\ Moisture) \times \%\ C_{Waste\ Type}$$

where:

$C_{Avail(y)}$	=	available carbon per waste type for province y, t
$WasteType_{Fossil-Origin}$	=	amount of fossil fuel-based waste incinerated, t (1992 data provided by Environment Canada [1996b])
% Moisture	=	% moisture content per waste type (Tchobanoglous et al. 1993)
$\%\ C_{WasteType}$	=	% carbon content per waste type (dry basis) (Tchobanoglous et al. 1993)

Equation A3–97:

$$EF_{CO_2-1992_{(y)}} = \left(\frac{\sum C_{Avail(y)}}{M_{Inc(y)}}\right) \times \frac{44}{12}$$

where:

$EF_{CO2-1992(y)}$	=	1992 CO_2 emission factor for incineration for province y, t CO_2/t waste incinerated
$C_{Avail(y)}$	=	available carbon per waste type for province y, t (See Equation A3–95)
$M_{Inc\,(y)}$	=	total mass waste incinerated in 1992 for province y, t
44/12	=	stoichimetric factor to convert carbon to CO_2

Calculating CO_2 Emissions: Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors (Equation A3–98).

Equation A3–98:

$$CO_{2(x)} = EF_{CO_2-1992} \times \left(M_{Inc(x)/province}\right)$$

where:

$CO_{2(x)}$	=	CO_2 emissions from waste incineration in year x, t/province per year
$EF_{CO2-1992}$	=	1992 provincial CO_2 emission factor for incineration, t CO_2/t incinerated
$M_{Inc(x)/province}$	=	mass waste incinerated per province in year x, t/year

Table A3–76 Activity Data and Emissions from Hazardous Waste Incineration for 1990–2015

Year	Quantitiy of Hazardous Waste Incinerated	Estimated GHG Emissions		
	tonnes	kt CO_2	kt CH_4	kt N_2O
1990	100,762	166.3	0.017	0.319
1991	109,111	180.0	0.019	0.345
1992	117,879	194.5	0.020	0.373
1993	125,109	206.4	0.021	0.396
1994	142,050	234.4	0.024	0.449
1995	164,727	271.8	0.028	0.521
1996	146,125	241.1	0.025	0.462
1997	132,348	218.4	0.022	0.419
1998	155,511	256.6	0.026	0.492
1999	140,820	232.4	0.024	0.446
2000	168,379	277.8	0.029	0.533
2001	179,525	296.2	0.030	0.568
2002	184,845	305.0	0.031	0.585
2003	144,036	237.7	0.024	0.456
2004	161,891	267.1	0.027	0.512
2005	157,788	260.4	0.027	0.499
2006	147,775	243.8	0.025	0.468
2007	134,878	222.6	0.023	0.427
2008	147,494	243.4	0.025	0.467
2009	134,122	221.3	0.023	0.424
2010	138,031	227.8	0.023	0.437
2011	130,503	215.3	0.022	0.413
2012	85,153	140.5	0.144	0.269
2013	89,604	147.9	0.015	0.284
2014	89,604	147.9	0.015	0.284
2015	89,604	147.9	0.015	0.284

Hazardous Waste Incineration

CO_2 emissions were estimated from activity data provided directly by facilities engaged in hazardous waste incineration in Canada through successive surveys conducted in 2006, 2008, 2010, 2012 and 2014 (Environment Canada 2010, 2013c, 2014c). The 2014 and 2015 waste quantities incinerated were assumed constant from 2013, since the 2016 waste incineration survey results were not completed in time for the 2017 submission. The waste quantities and emissions are presented at a national level in Table A3–76.

These amounts of incinerated waste include contaminated substrates such as soils, wood, metal and other material, and therefore are conservative. The hazardous waste quantities may also include inorganic wastes such as aqueous solutions containing heavy metals, or wastes such as water-based urethanes, as opposed to solvent-based urethane wastes that have high fossil fuel carbon content.

The IPCC Good Practice Guidance defaults were used for the CO_2 estimation: carbon content (50%) and fossil carbon as % of total carbon (90%). In the absence of IPCC default values for N_2O and CH_4 emission factors, EFs were derived from one hazardous waste incineration facility that had provided total emissions based on direct measurements of N_2O and CH_4 emissions for the year 2007. The site burned 177 tons of hazardous waste (HW) and emitted 0.03 tons CH_4 and 0.56 tons N_2O in 2007. The emission factors were then calculated as 0.0001695 t CH_4/t HW and 0.003164 t N_2O/t HW.

Clinical Waste Incineration

The types of clinical waste incinerated in Canada include cytotoxic waste, human or animal anatomical waste and pharmaceutical waste (Stericycle 2014). The IPCC 2006 Tier 1 method (IPCC 2006) for CO_2 emissions was used (Equation A3–99).

Table A3–77 Activity Data and Emissions from Clinical Waste Incineration for 1990-2015

Year	Quantity of Clinical Waste Incinerated	Estimated GHG Emissions		
	tonnes	t CO_2	t N_2O	t CH_4
1990	3,985	2,279.5	0.158	0.226
1991	4,000	2,287.9	0.159	0.226
1992	4,012	2,294.9	0.160	0.227
1993	5,587	3,195.5	0.161	0.306
1994	5,604	3,205.5	0.162	0.307
1995	6,694	3,828.8	0.164	0.362
1996	10,844	6,202.6	0.165	0.569
1997	10,583	6,053.6	0.165	0.556
1998	10,313	5,899.1	0.165	0.543
1999	10,063	5,756.2	0.166	0.531
2000	9,755	5,579.6	0.169	0.516
2001	9,435	5,396.8	0.153	0.497
2002	9,309	5,324.7	0.134	0.487
2003	9,278	5,306.9	0.114	0.483
2004	9,867	5,644.0	0.095	0.509
2005	10,600	6,063.2	0.083	0.544
2006	9,288	5,312.7	0.076	0.477
2007	8,421	4,816.9	0.073	0.433
2008	8,420	4,816.3	0.067	0.432
2009	7,294	4,172.4	0.040	0.371
2010	6,729	3,849.1	0.033	0.342
2011	7,813	4,469.2	0.027	0.395
2012	7,817	4,471.5	0.027	0.395
2013	7,822	4,474.0	0.028	0.395
2014	7,826	4,476.3	0.028	0.396
2015	7,826	4,476.3	0.028	0.396

Equation A3–99:

$$CO_2\ Emissions = \sum_i (SW_i \cdot dm_i \cdot CF_i \cdot FCF_i \cdot OF_i) \cdot 44/12$$

where:

CO_2 Emissions	=	CO_2 emissions in inventory year, Gg/yr
SW_i	=	total amount of solid waste of type i (wet weight) incinerated
dm_i	=	dry matter content in the waste (wet weight) incinerated, (fraction)
CF_i	=	fraction of carbon in the dry matter (total carbon content), (fraction)
FCF_i	=	fraction of fossil carbon in the total carbon, (fraction)
OF_i	=	oxidation factor, (fraction)
44/12	=	conversion factor from C to CO2
i	=	type of waste incinerated (MSW, sewage sludge, hazardous waste, clinical waste, etc.)

The dry matter content was found using the water content default value of 0.35 for clinical waste from the 2006 IPCC Guidelines, Volume 5, Chapter 2, Table 2.6 (IPCC 2006). The default values of 60% for total carbon (% of dry weight) and 40% for fossil carbon as % of total carbon and the default oxidation factor of 100% for clinical waste from the 2006 IPCC Guidelines, Volume 5, Chapter 5, Table 5.2 (IPCC 2006) were used. The waste quantities and emissions are presented at a national level in Table A3–75. The 2014 and 2015 waste quantities incinerated were assumed constant from 2013, since the 2016 waste incineration survey results were not completed in time for the 2017 submission. Note that there will be a significant correction for 2015 values in the 2018 submission when the results from the 2016 waste incineration survey are incorporated, as the Stericycle waste facility in Moncton, N.B., was destroyed by fire in March 2015 and the incinerator located in Wainwright, Alberta, closed in April 2015.

For clinical waste incineration, linear interpolation was used between data points and extrapolated based on provincial totals of clinical waste. For values outside of data point ranges, the extrapolation was based on population data.

There are currently believed to be 3 centralized (and commercial) clinical waste incinerators, 33 hospital-based incinerators and 8 clinical incinerators operated by the Government of Canada. The Canadian provinces of British Columbia, and Quebec and the Winnipeg region of Manitoba exported their clinical waste to other jurisdictions (other Canadian provinces or to the United States) for the duration of the time series, whereas Saskatchewan had substantial exports to Alberta.

The activity data were identified as from either continuous or batch-type incineration; no semi-continuously operated incinerators were identified.

A3.6.5.2. Data Sources

The amount of MSW incinerated in the year 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The amount of MSW incinerated for the years 1999, 2000, and 2001 was estimated by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

The amount of fossil fuel-based carbon available in the waste incinerated is determined using typical percent weight carbon constants. Carbon constants and moisture contents were provided by Tchobanoglous et al. (1993) and Peavy et al. (1985).

Hazardous incineration activity data were obtained directly from facilities. Surveys were conducted by Environment Canada in 2006, 2008, 2010 (Environment Canada 2010), 2012 (Environment Canada 2013c) and 2014 (Environment Canada 2014c).

The amounts of clinical waste incinerated were estimated from activity data provided directly by facilities in 2006, 2008, 2010 (Environment Canada 2010), 2012 (Environment Canada 2013c) and 2014 (Environment Canada 2014c). The 2014 and 2015 waste quantities incinerated were assumed constant from 2013, since the 2016 waste incineration survey results were not completed in time for the 2017 submission. Clinical waste incineration survey coverage was supplemented by progress reports prepared by the Canadian Council of Ministers of the Environment on issues related to dioxins, furans and mercury emissions, as clinical waste incineration was formerly a major source of these pollutants (CCME 2006, 2007 and 2010), as well as by a report on solid waste incineration in Canada prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

A3.6.6. N_2O Emissions from Waste Incineration

A3.6.6.1. Methodology

Municipal Solid Waste Incineration

Emissions of N_2O from MSW incineration are estimated using the assumption that the IPCC five-stoker facility factors are most representative. The average N_2O emission factor over the range given as IPCC default values for MSW five-stoker facilities is 0.148 kg/t waste incinerated (IPCC/OECD/IEA 1997). To estimate emissions, the calculated factor is multiplied by the amount of waste incinerated by each province (Equation A3–100). The national emission values are then determined as the summation of these emissions for all provinces.

Equation A3–100:

$$N_2O_{MSW} = M_{MSW} \times EF_{N_2O-MSW}$$

where:

N_2O_{MSW}	=	N_2O emissions from municipal solid waste incineration, t/year
M_{MSW}	=	mass of municipal solid waste incinerated, t/year
$EF_{N2O-MSW}$	=	MSW N_2O emission factor (0.148 kg N_2O/t MSW incinerated / 1000 kg/t)

Sewage Sludge Incineration

Emissions of N_2O from sewage sludge incineration are estimated using the IPCC default emission factor for fluidized beds, 0.8 kg/t of dried sewage sludge incinerated (IPCC 2000). The emission factor in the IPCC 2000 is specific to fluidized bed technology which is more representative for Canada. No mention is made of the technology used for the values in the 2006 IPCC Guidelines. Therefore, Canada believes that the emission factor in IPCC 2000 is more accurate for the Canadian context. To estimate emissions, the calculated factor is multiplied by the amount of waste incinerated by each province (Equation A3–101). The

national emission values are then determined as the summation of these emissions for all provinces.

Equation A3–101:

$$N_2O_{SS} = M_{SS} \times EF_{N_2O-SS}$$

where:

N_2O_{SS}	=	N_2O emissions from sewage sludge incineration, t/year
M_{SS}	=	mass of dried sewage sludge incinerated, t/year
EF_{N2O-SS}	=	sewage sludge N_2O emission factor (0.8 kg N_2O/t dried sludge incinerated / 1000 kg/t)

Hazardous Waste Incineration

Refer to Section A3.6.5.1.

Clinical Waste Incineration

The IPCC 2006 Tier 1 method (IPCC 2006) for N_2^0 emissions was used (Equation A3–102).

Equation A3–102:

$$N_2O\ Emissions = \sum_i (IW_i \cdot EF_i) \cdot 10^{-6}$$

where:

N_20 Emissions	=	N_20 emissions in inventory year, Gg/yr
IW_i	=	amount of incinerated waste of type i, Gg/yr
EF_i	=	N_20 emission factor (kg N_20/Gg of waste) for waste of type i
10^{-6}	=	conversion factor from kilogram to gigagram
i	=	type of waste incinerated (MSW, sewage sludge, hazardous waste, clinical waste, etc.)

The activity data were identified as from either continuous or batch-type incineration; no semi-continuously operated incinerators identified. The stoker-type emission factors were found to be more representative of the clinical waste incinerators in Canada. The CH_4 emissions for a given site were therefore calculated using the stoker default emission factors for continuous incineration (50 g N_20/t waste incinerated) and batch-type incineration (60 g N_20/t waste incinerated) in IPCC 2006, Volume 5, Chapter 5, Table 5.6 (IPCC 2006). MSW default emission factors were used in accordance with the IPCC Good Practice Guidance (IPCC 2000) as no clinical-waste-specific values are provided.

Data Sources

Data sources for MSW incineration are described in Section A3.6.5.2.

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. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

Hazardous incineration activity data were obtained directly from facilities. Surveys were conducted by Environment Canada in 2006, 2008, 2010 (Environment Canada 2010), 2012 (Environment Canada 2013c) and 2014 (Environment Canada 2014c).

For clinical waste incineration, refer to Section A3.6.5.2

A3.6.7. CH_4 Emissions from Waste Incineration

A3.6.7.1. Methodology

MSW Incineration

CH_4 emissions from the incineration of MSW are assumed to be negligible, as supported by the findings of a recent study commissioned by Environment Canada (CRA 2011). However, waste incineration of the biosolids resulting from municipal wastewater treatment does produce CH_4 emis-

sions. The IPCC does not provide a methodology for CH_4 emissions from waste incineration, but recommends that national experts use existing published methods (IPCC 2000).

Emissions of CH_4 are estimated based on emission factors obtained from the U.S. Environmental Protection Agency (U.S. EPA 1995). The emission factors are 1.6 t/kt of total dried solids for fluidized bed sewage incinerators and 3.2 t/kt of dried solids for multiple hearth incinerators, both equipped with venturi scrubbers. It is assumed that all incinerators are of the fluidized bed type.

CH_4 emissions from sewage sludge incineration 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. 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 (Environment Canada 1994b). Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b). To estimate the amount of sewage sludge incinerated in the years 2002–2015, a linear regression analysis was completed using the MSW incineration values from the study by A.J. Chandler & Associates Ltd. and Compass Environmental Inc.

Table A3–78 Estimated Sewage Sludge Incinerated for 1990–2015

	Sewage Sludge Incinerated (t, dry basis)				
Year	QC	ON	SK	BC	National Total
1990	49,200	222,795	1,840	0	273,835
1991	59,400	222,795	1,840	0	284,035
1992	79,800	222,795	1,840	0	304,435
1993	64,833	129,125	71	0	194,029
1994	100,181	93,072	59	0	193,311
1995	101,356	113,985	152	0	215,493
1996	93,276	112,697	70	0	206,043
1997	15,424	0	0	4,885	20,310
1998	18,341	0	0	4,951	23,292
1999	17,901	0	0	0	17,901
2000	17,804	0	0	0	17,804
2001	18,174	0	0	0	18,174
2002	19,017	0	0	0	19,017
2003	19,514	0	0	0	19,514
2004	20,010	0	0	0	20,010
2005	20,506	0	0	0	20,506
2006	21,002	0	0	0	21,002
2007	21,499	0	0	0	21,499
2008	21,995	0	0	0	21,995
2009	22,491	0	0	0	22,491
2010	22,987	0	0	0	22,987
2011	23,484	0	0	0	23,484
2012	23,980	0	0	0	23,980
2013	24,476	0	0	0	24,476
2014	24,972	0	0	0	24,972
2015	25,469	0	0	0	25,469

Note:
A large step change is observed in the quantities of sewage sludge incinerated in Ontario for the period 1996–1997. This is a result of two pilot projects that were approved in the mid-1990s for non-incineration waste disposal of sewage sludge. The first project involved the spreading of treated sewage sludge on farmers' fields outside of Toronto, and the second project involved the transportation of sewage sludge spreading on mine tailings. Both projects proved to have difficulties, owing to odour problems and the large quantities of waste that were to be spread on farmers' fields. From 1996 to 2000, Toronto sludge was stored during periods when excess quantities of waste were unable to be applied on land. In 2001, a new contract commenced that involved the spreading of biosolids on Ontario farmers' fields, with excess biosolids being shipped to U.S. landfill sites.

Sewage Sludge Incineration

In view of the relatively small number of facilities that incinerate sewage sludge in Canada, we believe that all relevant facilities were contacted, and we expect that the activity data collected from all three sources of information are complete. As such, our approach to estimating the amount of sewage sludge incinerated is consistent over the time series.

Sewage sludge incineration estimates for the period 1990–2015 are shown in Table A3–78.

CH_4 emissions are calculated as follows (Equation A3–103):

Equation A3–103:

$$CH_{4(s)} = S_{Inc} \times EF_{CH_4-FB}$$

where:

$CH_{4(s)}$	=	CH_4 emissions from waste incineration, t/year
S_{Inc}	=	sewage sludge incinerated, dry t/year
EF_{CH4-FB}	=	CH_4 emission factor for fluidized bed incinerators: 1.6 t CH_4/kt sewage sludge incinerated / 1000 kg/t

Hazardous Waste Incineration

Refer to Section A3.6.5.1.

Clinical Waste Incineration

The IPCC 2006 Tier 1 method (IPCC 2006) for CH_4 emissions was used (Equation A3–104).

Equation A3–104:

$$CH_4\ Emissions = \sum_i (IW_i \cdot EF_i) \cdot 10^{-6}$$

where:

CH_4 emissions	=	CH_4 emissions in inventory year, Gg/yr
IW_i	=	amount of solid waste of type i incinerated, Gg/yr
EF_i	=	aggregate CH_4 emission factor, kg CH_4/Gg of waste
10^{-6}	=	conversion factor from kilogram to gigagram
i	=	type of waste incinerated (MSW, sewage sludge, hazardous waste, clinical waste, etc.)

The activity data were identified as from either continuous or batch-type incineration; no semi-continuously operated incinerators were identified. The stoker-type emission factors were found to be more representative of the clinical waste incinerators in Canada. The CH_4 emissions for a given site were therefore calculated using the stoker default emission factors for continuous (0.2 kg/Gg waste incinerated) and batch-type incineration (60 kg/Gg waste incinerated) in IPCC 2006, Volume 5, Chapter 5, Table 5.3 (IPCC 2006). MSW default emission factors were used in accordance with the IPCC Good Practice Guidance (IPCC 2000) as no clinical-waste-specific values are provided.

A3.6.7.2. Data Sources

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. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

Hazardous incineration activity data were obtained directly from facilities. Surveys were conducted by Environment Canada in 2006, 2008, 2010 (Environment Canada 2010), 2012 (Environment Canada 2013c) and 2014 (Environment Canada 2014c).

For clinical waste incineration refer to Section A3.6.5.2.

Annex 4

COMPARISON OF SECTORAL AND REFERENCE APPROACHES AND THE NATIONAL ENERGY BALANCE

This annex covers the energy and the CO_2 emission results from the reference approach (RA), a comparison of the results from the RA with those estimated by the sectoral approach (SA), and a summary of the national energy balance, which is the main energy data source for both the RA and the SA.

A4.1. Comparison of Reference Approach with Sectoral Approach

Results from the RA were compared with the SA as a check of energy consumed and CO_2 emissions from the combustion of fossil fuels. The check

Table A4–1 Comparison of Adjusted Reference Approach and Sectoral Approach for Canada

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Overall Energy Comparison													
Reference Approach (PJ)	7171	7013	7233	7278	7520	7714	8029	8277	8360	8741	9032	8888	9027
Sectoral Approach (PJ)	6474	6314	6564	6576	6801	6963	7178	7335	7426	7740	8092	7992	8108
Percent Difference without Adjustment (%)	10.8	11.1	10.2	10.7	10.6	10.8	11.9	12.8	12.6	12.9	11.6	11.2	11.3
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	6388	6209	6415	6443	6682	6846	7009	7207	7280	7601	7973	7767	7885
Percent Difference with Adjustment - 100% x (RA-SA)/SA	**-1.32**	**-1.66**	**-2.27**	**-2.01**	**-1.75**	**-1.68**	**-2.36**	**-1.73**	**-1.96**	**-1.79**	**-1.47**	**-2.82**	**-2.74**
Adjusted Non-Energy Fossil Fuels and Feedstocks													
Non-Energy Use of Gaseous Fuels (PJ)	163	181	172	193	200	198	241	260	255	267	243	205	152
Non-Energy Use of Liquid Fuels (PJ)	518	507	530	529	533	560	671	702	714	761	702	809	883
Non-Energy Use of Solid Fuels (PJ)	102	116	115	113	105	110	108	107	110	112	115	106	106
Overall Emission Comparison													
Reference Approach (Gg CO_2)	419155	407942	418782	417056	431226	442043	451435	466903	474420	491685	515023	503640	507685
Sectoral Approach (Gg CO_2)	417655	407878	421592	418663	431555	442289	454916	467809	474697	490893	512580	507487	510567
Percentage Difference (%)	**0.36**	**0.02**	**-0.67**	**-0.38**	**-0.08**	**-0.06**	**-0.77**	**-0.19**	**-0.06**	**0.16**	**0.48**	**-0.76**	**-0.56**
Liquid Fuels													
Reference Approach (Gg CO_2)	207386	193996	194832	197375	203695	206596	207326	217058	221797	225300	229688	227272	227826
Sectoral Approach (Gg CO_2)	205904	194088	197511	198398	203188	205744	210764	218169	222145	223890	226330	230178	229322
Percentage Difference (%)	**0.72**	**-0.05**	**-1.36**	**-0.52**	**0.25**	**0.41**	**-1.63**	**-0.51**	**-0.16**	**0.63**	**1.48**	**-1.26**	**-0.65**
Solid Fuels													
Reference Approach (Gg CO_2)	86241	89641	91786	83524	87673	88743	91376	98558	103457	103145	111301	109793	106145
Sectoral Approach (Gg CO_2)	86726	90096	92545	84790	89251	90634	92436	99354	104564	104639	113006	111315	108161
Percentage Difference (%)	**-0.56**	**-0.50**	**-0.82**	**-1.49**	**-1.77**	**-2.09**	**-1.15**	**-0.80**	**-1.06**	**-1.43**	**-1.51**	**-1.37**	**-1.86**
Gaseous Fuels													
Reference Approach (Gg CO_2)	125406	124248	132072	135985	139508	146423	152447	151148	148953	163031	173789	166338	173343
Sectoral Approach (Gg CO_2)	124903	123636	131444	135302	138767	145630	151429	150146	147774	162156	173000	165758	172714
Percentage Difference (%)	**0.40**	**0.49**	**0.48**	**0.50**	**0.53**	**0.54**	**0.67**	**0.67**	**0.80**	**0.54**	**0.46**	**0.35**	**0.36**

Table A4-1Comparison of Adjusted Reference Approach and Sectoral Approach for Canada

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Overall Energy Comparison													
Reference Approach (PJ)	9237	9277	9040	8984	9395	9124	8649	8934	9135	9317	9474	9587	9519
Sectoral Approach (PJ)	8334	8267	8179	8067	8457	8238	7867	8070	8206	8277	8507	8600	8558
Percent Difference without Adjustment (%)	10.8	12.2	10.5	11.4	11.1	10.8	10.0	10.7	11.3	12.6	11.4	11.5	11.2
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	8052	8004	7920	7781	8201	8016	7600	7785	7921	8013	8270	8492	8424
Percent Difference with Adjustment - 100% x (RA-SA)/SA	**-3.38**	**-3.18**	**-3.17**	**-3.54**	**-3.04**	**-2.69**	**-3.39**	**-3.53**	**-3.47**	**-3.19**	**-2.79**	**-1.26**	**-1.57**
Adjusted Non-Energy Fossil Fuels and Feedstocks													
Non-Energy Use of Gaseous Fuels (PJ)	159	171	158	162	161	128	142	142	162	165	150	126	138
Non-Energy Use of Liquid Fuels (PJ)	919	991	860	928	924	878	830	921	946	1038	966	877	886
Non-Energy Use of Solid Fuels (PJ)	107	111	102	112	110	101	77	86	106	100	88	92	71
Overall Emission Comparison													
Reference Approach (Gg CO_2)	518336	515780	511324	501604	527947	512756	483308	493938	496104	498577	511104	522023	516461
Sectoral Approach (Gg CO_2)	525840	522969	516946	508071	532117	515781	489471	501322	504312	505871	517452	518657	515139
Percentage Difference (%)	**-1.43**	**-1.37**	**-1.09**	**-1.27**	**-0.78**	**-0.59**	**-1.26**	**-1.47**	**-1.63**	**-1.44**	**-1.23**	**0.65**	**0.26**
Liquid Fuels													
Reference Approach (Gg CO_2)	239259	247785	243644	237813	247749	241875	235290	238368	238469	242773	241715	245786	243019
Sectoral Approach (Gg CO_2)	244135	252551	249501	246087	253777	245316	239896	246563	246375	247822	247497	241736	241259
Percentage Difference (%)	**-2.00**	**-1.89**	**-2.35**	**-3.36**	**-2.38**	**-1.40**	**-1.92**	**-3.32**	**-3.21**	**-2.04**	**-2.34**	**1.68**	**0.73**
Solid Fuels													
Reference Approach (Gg CO_2)	104015	97296	100700	98550	103399	96361	79990	83735	73625	68323	67794	64742	64719
Sectoral Approach (Gg CO_2)	107244	100279	101024	97420	102113	96512	82083	83420	74488	68789	68977	66100	65742
Percentage Difference (%)	**-3.01**	**-2.97**	**-0.32**	**1.16**	**1.26**	**-0.16**	**-2.55**	**0.38**	**-1.16**	**-0.68**	**-1.72**	**-2.05**	**-1.56**
Gaseous Fuels													
Reference Approach (Gg CO_2)	174699	170300	166697	164955	176406	174129	167720	171505	183707	187125	201289	211191	208417
Sectoral Approach (Gg CO_2)	174098	169741	166137	164279	175834	173562	167184	171008	183145	188903	200673	210515	207832
Percentage Difference (%)	**0.35**	**0.33**	**0.34**	**0.41**	**0.33**	**0.33**	**0.32**	**0.29**	**0.31**	**-0.94**	**0.31**	**0.32**	**0.28**

was performed for all years from 1990 to 2015 and is an integral part of reporting to the United Nations Framework Convention on Climate Change (UNFCCC).

Direct comparison of energy results in the RA and SA shows significant discrepancies, since the SA total does not include some of the non-energy use of fossil fuels and feedstocks. Comparison of the RA and SA shows a 10.0 to 12.9% variation in energy. This is corrected by excluding the non-combustion energy of certain feedstocks and fossil fuels to ensure that the RA and the SA are comparing similar sources. When the RA energy amounts include adjustments for non-energy use of feedstocks and fossil fuels, the difference between the SA and adjusted RA varies from -3.54 to -1.26%. Figure A4–1 shows a comparison of the original and adjusted RA and SA.

No adjustments were necessary for the emissions estimate in the RA since online CRF Reporting software, supplied by the UNFCCC, correctly removes non-energy and feedstock associated emissions and allocates them to industrial processes. Comparison of the RA and SA emission estimates, as seen in Table A4–1, shows an overall -1.63 to 0.65% variation.

A4.2. Reference Approach Methodology

The RA follows the 2006 Intergovernmental Panel on Climate Change (IPCC) Guideline's designated method with the use of country-specific energy conversion factors (in higher heating value [HHV]/gross calorific value [GCV]) and emission factors. In Canada, as in the United States, HHV is used to record the energy content of fuels. Fuel quantities from the most recent Report on *Energy Supply–Demand in Canada* (RESD) (Statistics Canada 1990–) and the *Energy Statistics Handbook* (Statistics Canada 2010) are entered in their physical units, with the exception of international bunkers. A discussion of the data for international bunkers is presented in the following sections: 3.1.4, International Bunker Fuels; A3.1.4.2.3, Civil Aviation; and A3.1.4.2.4, Navigation. For primary fuels (crude oil, ethane, natural gas liquids, coal and natural gas), the stock change data have been adjusted to account for inter-product transfers, stock variation and other adjustments,

Table A4–2 Reference Approach Energy Conversion and Emission Factors for Canada

Fuel Types			Energy Conversion Factor, GCV			Carbon Emission Factor - 2015 Value (t C/TJ GCV)	Reference	Oxidation Factors	Comments
			2015 Value	Unit	Reference				
Liquid	**Primary Fuels**	Crude Oil	39.17	TJ/ML	See Comments	19.26	Refer to Comments	1.0	Weighted energy conversion and emission factor are based on country-specific data.
		Ethane	17.22	TJ/ML	4	15.46	2	1.0	Total available ethane is consumed as a feedstock in industrial processes.
		Orimulsion	NA	–	–	NA	–	1.0	
		Natural Gas Liquids	29.11	TJ/ML	–	16.36	–	1.0	Propane and butane from natural gas liquids.
	Secondary Fuels	Bitumen	44.46	TJ/ML	4	21.11	3	1.0	Use of asphalt
		Gas/Diesel Oil	38.3	TJ/ML	4	19.16	2	1.0	Use of diesel fuel oil
		Gasoline	35	TJ/ML	4	17.84	2	1.0	
		Jet Kerosene	37.4	TJ/ML	4	18.67	2	1.0	Use of aviation turbo fuel.
		Liquefied Petroleum Gases (LPG)	25.35	TJ/GL	4	16.33	2	1.0	Propane and butane from petroleum refineries
		Lubricants	39.16	TJ/ML	4	19.66	3	1.0	
		Naphtha	35.17	TJ/ML	4	19.33	3	1.0	
		Other Kerosene	37.68	TJ/ML	4	18.53	2	1.0	
		Other Oil	38.8	TJ/ML	4	19.15	2	1.0	Use of light fuel oil
		Petroleum Coke – Refinery and Upgrader	44.20	TJ/ML	4	22.84	4	1.0	Country-specific weighted emission factors based on available emission factors for refining and upgrading (of oil sands to synthetic crude oil).
		Refinery Feedstocks	35.17	TJ/ML	4	19.33	3	1.0	Use of petrochemical feedstock in industrial processes
		Residual Fuel Oil	42.5	TJ/ML	4	20.26	2	1.0	Use of heavy fuel oil.
		Shale Oil	NA	–	–	NA	–	–	
		Still Gas – Refinery and Upgrader Fuel Gas	39.56	TJ/ML	4	14.69	4	1.0	Country-specific weighted emission factor based on factors from refinery and from upgrading (of crude from oil sands to synthetic crude oil) activities.
	Other Liquid Fuels	Aviation Gasoline	33.52	TJ/ML	4	19.25	3	1.0	
		Other Product Feedstocks	39.82	TJ/ML	4	19.84	3	1.0	

Table A4-2 Reference Approach Energy Conversion and Emission Factors for Canada (cont'd)

Fuel Types			Energy Conversion Factor, GCV			Carbon Emission Factor - 2015 Value (t C/TJ GCV)	Reference	Oxidation Factors	Comments
			2015 Value	Unit	Reference				
Solid	**Primary Fuels**	Anthracite	27.7	TJ/kt	4	23.45	3	0.988	
		Other Bituminous Coal	28.37	TJ/kt	4	21.00	5	0.988	Use of Canadian bituminous coal
		Sub-bituminous Coal	18.45	TJ/kt	4	26.14	5	0.994	
		Lignite	16.29	TJ/kt	4	23.59	5	0.995	
		Oil Shale	NA	–	–	NA	–	–	
		Peat	NA	–	–	NA	–	–	
	Secondary Fuels	Coke	28.83	TJ/kt	4	30.02	2	1.0	Previously reported as Coking Coal.
		BKB & Patent Fuel	NA	–	–	NA	–	–	
		Coke Oven Gas	19.14	TJ/GL	4	12.52	2	–	
	Other Solid Fuels	Foreign Bituminous Coal	29.82	TJ/kt	4	23.71	5	1.0	
Gaseous	**Primary Fuels**	Natural Gas	39.64	TJ/GL	4	13.60	2	1.0	Country-specific weighted emission factor based on proportion of marketable and non-marketable natural gas.
Biomass		Solid Biomass	18	TJ/kt	4	18.41	3	1.0	1) Consists of industrial and residential biomass consumption.
		Liquid Biomass	16.02	TJ/kt	4	18.84	3	1.0	1) Consists of spent pulping liquor, ethanol and biodiesel.
		Gas Biomass	39.82	TJ/Gl	1	13.54	1	1.0	1) Consists of methane from landfill gas.

References: (1) IPCC/OECD/IEA (1997); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada, #57-003 (2014 data); (5) Environment Canada, 2016.
NA = Not applicable; BKB = Charcoal briquettes; NGL = natural gas liquids; LPG = liquified petroleum gas.

all of which are reported separately in the RESD and all of which directly impact fuel availability. This adjusted stock change number is used to determine apparent consumption. Similarly, the stock change data for secondary fuels takes into consideration inter-product transfers, international bunkers, stock variation and other adjustments. In cases where imports or exports are reported as "C" (confidential) in the reference approach, stock change has been modified to allow the calculation of the correct apparent consumption.

Once the apparent consumption is determined, country-specific energy conversion factors and carbon emission factors are used to calculate the carbon content and emissions. Energy conversion factors are taken from the following sources: RESD (Statistics Canada 1990–), *Canada's Greenhouse Gas Emissions: Estimates for 1990* (Jaques 1992), the *1998 Fossil Fuel and Derivative Factors* (McCann 2000) and Measurement Canada, an Industry Canada agency. For the majority of fossil fuels, the applied emission factors and oxidation factors are from McCann (2000), Jaques (1992) and the 2006 IPCC Guidelines.

Figure A4–2 presents the applied emission factor, energy conversion factor and oxidation value in the RA. Energy conversion factors are taken directly from the RESD, with the exception of bituminous coal, lignite, crude oil, heavy fuel oil, natural gas, petroleum coke and still gas, where weighted factors have been developed to account for the quantity and variation of energy content at the point of consumption such as commercial usage or self-generated usage. For example, for provinces with natural gas production, there are two emission factors for natural gas: market-

able natural gas, which is sold to consumers, and non-marketable natural gas, which is consumed directly by the producers of natural gas.

A4.3. National Energy Balance

This section provides a general background on the national energy balance and its data quality framework. In Canada, the Environment, Energy and Transportation Statistics Division (EETSD) of Statistics Canada is responsible for the collection, compilation and dissemination of energy data under the authority of the *Statistics Act*.[1] The national energy balance is provided in the RESD and can be found on Statistics Canada's website.[2] The RESD is the primary source of activity data used to estimate GHG emissions for the Energy Sector. The non-energy and feedstock information from the RESD is also used by the Industrial Processes and Product Use Sector. The RESD is an accounting of energy forms in Canada from import and export activities through to production and domestic consumption (refer to Figure A4–1 for a sample of an energy flow diagram). It consists of information on crude oil, natural gas, coal, refined petroleum product (RPPs), electricity, steam, non-energy use of fossil fuels, feedstock and other secondary energy forms for all Canadian industrial sectors and other energy use, such as the transportation, residential and commercial sectors.

Energy and fossil fuel data are collected using a mix of annual and monthly surveys, along with census data from industry, federal agencies (such as the National Energy Board [NEB]), provincial energy departments and agencies (such as the Alberta Energy Regulator [AER] and the Alberta Utilities Commissions [AUC]), and the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC). Refer to Figure A4–2, Canadian Energy Flow, for a sample of the energy and fossil fuel data input. The oil and gas information as provided by the AER is highly accurate, since it is tied to oil and gas exploitation permits and to federal and provincial royalty schemes.

1 Statistics Canada. Statistics Act. http://laws-lois.justice.gc.ca/eng/acts/S-19/.

2 Statistics Canada. Report on Energy Supply and Demand in Canada (Annual). Catalogue No. 57-003-X http://www.statcan.gc.ca/pub/57-003-x/2017002/tablesectlist-listetableauxsect-eng.htm.

Figure A4–1 Sample of an Energy Balance Flow Diagram for Canada (RESD)

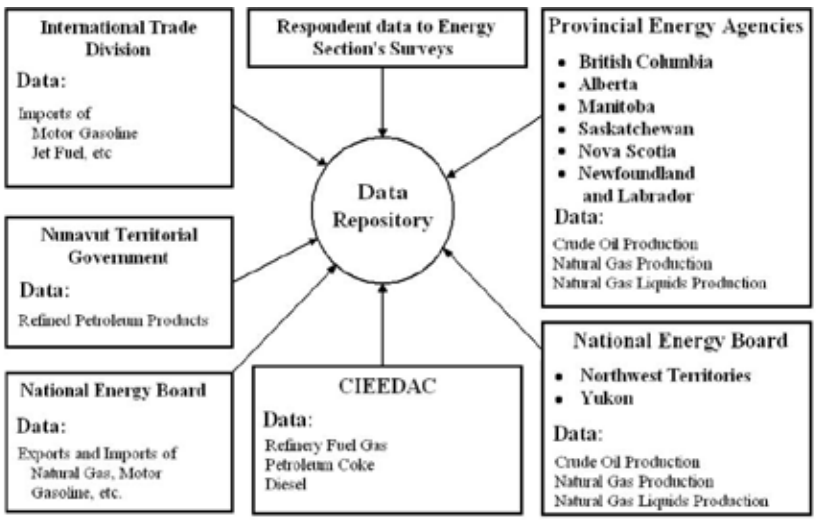
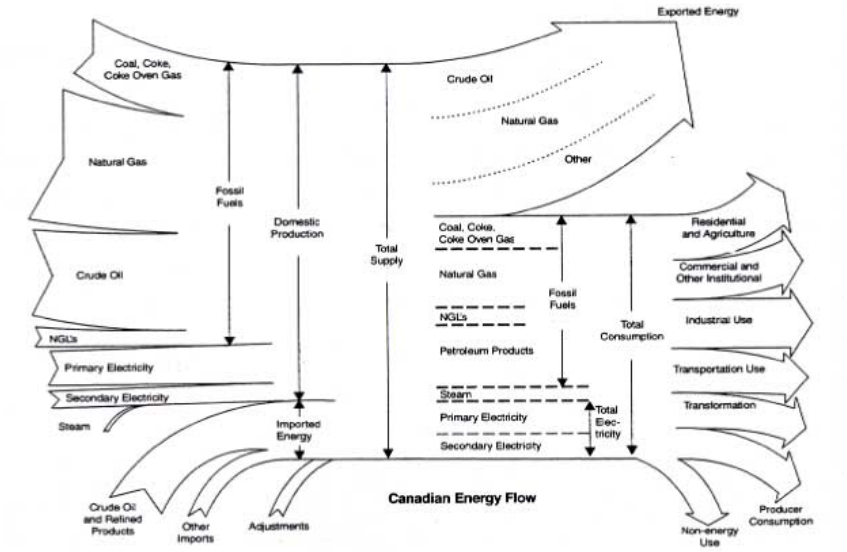


Figure A4–2 Fossil Fuel and Energy Data Input



The RESD is used by various federal departments for energy efficiency programs, policy development, energy and emission forecasting, and reporting to the UNFCCC. As such, EETSD's quality management system for the RESD includes an internal and external stakeholder review process. Its quality assurance framework and methodological reports are documented and made available through Statistics Canada's Integrated Meta Database.[3] EETSD has also established partnerships with various federal government departments, provincial energy ministries, industrial associations and centres of excellence to assist with their quality assurance process.

The following quality criteria are essential to the development of the RESD as set out by Statistics Canada: relevance, accuracy and reliability, timeliness and punctuality, accessibility and clarity, coherence and comparability, and interpretability and metadata.

There are also other internal data quality checks of the information collected through provincial energy departments and various supply, disposition and consumption surveys. For example, the quantity of crude oil shipped as reported by the producer is verified against report receipts from pipeline companies, and the information as reported by pipelines is verified against refinery receipts. EETSD also applies both a top-down approach through the supply and disposition surveys and a bottom-up approach through the Industrial Consumption of Energy (ICE) survey to verify the quality of the data for manufacturing industries. The ICE survey collects fuel consumption data directly from manufacturing industries following the North American Industry Classification System. In addition, an annual Survey of Secondary Distributors of Refined Petroleum Products (SSD) was implemented to collect data on sale volumes for use in reallocating volumes of heavy fuel oil, light fuel oil, diesel and gasoline to the appropriate consuming sectors due to the deregulation of the sale of these products from primary producers (refineries) to include

3 Statistics Canada. Quality Assurance Framework. http://www.statcan.gc.ca/pub/12-539-x/manage-gestion/4058322-eng.htm.

secondary resellers/distributers. Prior to this improvement, the volume of fuel sold by refineries to secondary distributors were all misallocated to the commercial sector. The deregulation of the sale of these four fuels started around the year 2000. A consistent approach was applied to the historical dataset to address the misallocated fuel volumes between 2000 and 2008 since the SSD only started collecting sale volumes in from 2009 onward.

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Also, as part of EETSD's quality framework, an annual "work-in-progress" review has been established with Environment Canada and Natural Resources Canada to review the ICE estimates and the RESD prior to their official release. Industrial stakeholders also participate in the review of ICE data through the Canadian Industry Program for Energy Conservation group. CIEEDAC also participates in the review of refinery data and the industrial energy statistics.

Annex 5

Assessment of Completeness

Overall, this inventory report serves as a comprehensive assessment of anthropogenic greenhouse gas (GHG) emissions and removals in Canada. However, emissions for some categories are not estimated (NE) or have been included elsewhere (IE) with other categories for reasons explained in Table A5–1 and Table A5–2. These tables are consistent with Table 9 (Completeness – Information on Notation Keys) of the Common Reporting Format (CRF) tables available online here: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php.

Table A5–1 Summary of GHG Sources and Sinks Not Estimated (NE)[1]

GHG	Sector	Source/sink category	Explanation
CH_4	Agriculture	3.1 Livestock/3.A Enteric Fermentation/3.A.4 Other livestock/Other (please specify)/Fur-bearing Animals	No default emission factors available for Fox and Mink
CH_4	Agriculture	3.1 Livestock/3.A Enteric Fermentation/3.A.4 Other livestock/Other (please specify)/Rabbit	No default emission factors available for Rabbit
CH_4	Agriculture	3.1 Livestock/3.A Enteric Fermentation/3.A.4 Other livestock/Poultry	No default emission factor available for Poultry
CH_4	Agriculture	3.D Agricultural Soils	Methane emissions from agricultural soils are not estimated because no methodology is available in the 2006 IPCC Guidelines
CH_4	Energy	1.B Fugitive Emissions from Fuels/1.B.1 Solid Fuels/1.B.1.b Solid Fuel Transformation	Unknown emission rates and activity data.
CH_4	Industrial Processes and Product Use	2.B Chemical Industry/2.B.1 Ammonia Production	CH_4 emissions assumed negligible.
CH_4	Industrial Processes and Product Use	2.B Chemical Industry/2.B.8 Petrochemical and Carbon Black Production/2.B.8.d Ethylene Oxide	Source category not estimated. Under consideration for future submissions.
CH_4	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/Asphalt roofing	Country-specific information currently unavailable; CH_4 emissions are assumed to be negligible based on 2006 IPCC GL Volume 3, Chapter 5
CH_4	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/Road paving with asphalt	CH_4 Emissions from road paving with asphalt are not estimated. Currently, there are no country-specific information on this. Based on the 2006 IPCC Guidelines (Volume 3, Chapter 4), CH_4 emissions from this category are assumed to be negligible.
CH_4	LULUCF	4.A Forest Land/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/Total Organic Soils/Drained Organic Soils	No suitable activity data for this estimation.
CH_4	LULUCF	4.B Cropland/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/Total Mineral Soils/Rewetted Mineral Soils	There is no guidance in 2006 IPCC guidelines to report CH_4 emissions from rewetted mineral soils in Cropland.
CH_4	LULUCF	4.B Cropland/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/Total Organic Soils/Drained Organic Soils	There is no guidance in 2006 IPCC guidelines to report CH_4 emissions from drained organic soils in Cropland.
CH_4	LULUCF	4.B Cropland/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/Total Organic Soils/Rewetted Organic Soils	There is no guidance in 2006 IPCC guidelines to report CH_4 emissions from rewetted organic soils in Cropland.
CH_4	LULUCF	4.D Wetlands/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/Other Wetlands (please specify)	No suitable activity data for this estimation. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CH_4	Waste	5.B Biological Treatment of Solid Waste/5.B.2 Anaerobic Digestion at Biogas Facilities/5.B.2.a Municipal Solid Waste	NE notation: Emissions from anaerobic digestion at biogas facilities have not been assessed.

Table A5-1 Summary of GHG Sources and Sinks Not Estimated (NE) (cont'd)

GHG	Sector	Source/sink category	Explanation
CH_4	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.1 Biogenic/5.C.2.1.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories.There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada
CH_4	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.2 Non-biogenic/5.C.2.2.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories.There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada
CO_2	Energy	1.B Fugitive Emissions from Fuels/1.B.1 Solid Fuels/1.B.1.b Solid Fuel Transformation	Unknown emission rates and activity data.
CO_2	Industrial Processes and Product Use	2.A Mineral Industry/2.A.4 Other Process Uses of Carbonates/2.A.4.a Ceramics	Under consideration for future submissions
CO_2	Industrial Processes and Product Use	2.B Chemical Industry/2.B.8 Petrochemical and Carbon Black Production/2.B.8.d Ethylene Oxide	Source category not estimated. Under consideration for future submissions.
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/Asphalt roofing	Country-specific information currently unavailable; CO_2 emissions are assumed to be negligible based on 2006 IPCC GL Volume 3, Chapter 5
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/Road paving with asphalt	CO_2 Emissions from road paving with asphalt are not estimated. Currently, there are no country-specific information on this. Based on the 2006 IPCC Guidelines (Volume 3, Chapter 4), CO_2 emissions from this category are assumed to be negligible.
CO_2	LULUCF	4.A Forest Land/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/ Total Organic Soils/Drained Organic Soils	No suitable activity data for this estimation.
CO_2	LULUCF	4.B Cropland/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/ Total Mineral Soils/Rewetted Mineral Soils	No suitable activity data for this estimation. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CO_2	LULUCF	4.B Cropland/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/ Total Organic Soils/Rewetted Organic Soils	No suitable activity data for this estimation. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CO_2	LULUCF	4.D Wetlands/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/ Other Wetlands (please specify)	No suitable activity data for this estimation. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CO_2	LULUCF	4.G Harvested Wood Products/Approach B/Information Item/HWP in SWDS	Work is ongoing to incorporate the effects of wood and paper waste in solid waste disposal sites
CO_2	LULUCF	4.G Harvested Wood Products/Approach B/Information Item/HWP in SWDS	"Work is ongoing to incorporate the effects of wood and paper waste in solid waste disposal sites
CO_2	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.1 Biogenic/5.C.2.1.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories.There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada
CO_2	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.2 Non-biogenic/5.C.2.2.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories.There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada
N_2O	Agriculture	3.D Agricultural Soils/3.D.1 Direct N_2O Emissions From Managed Soils/3.D.1.2 Organic N Fertilizers/3.D.1.2.b Sewage Sludge Applied to Soils	The amount of N in Sewage Sludge Applied to Soils is not available.
N_2O	Agriculture	3.D Agricultural Soils/3.D.1 Direct N_2O Emissions From Managed Soils/3.D.1.2 Organic N Fertilizers/3.D.1.2.c Other Organic Fertilizers Applied to Soils	The amount of N in Other Organic Fertilizers Applied to Soils is not available.
N_2O	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/Asphalt roofing	Country-specific information currently unavailable
N_2O	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/Road paving with asphalt	Country-specific information currently unavailable

Table A5-1 Summary of GHG Sources and Sinks Not Estimated (NE) (cont'd)

GHG	Sector	Source/sink category	Explanation
N_2O	LULUCF		N_2O emissions from indirect sources of non-agricultural and non-LULUCF origin are not estimated
N_2O	LULUCF	"4.A Forest Land 4.A Forest Land/4.A.1 Forest Land Remaining Forest Land/4(III) Direct N_2O Emissions from N Mineralization/Immobilization"	Management-induced changes in soil organic carbon are not available because of limited activity data over the entire time series
N_2O	LULUCF	4.A Forest Land/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/ Total Organic Soils/Drained Organic Soils	No suitable activity data for this estimation.
N_2O	LULUCF	4.A Forest Land/4.A.2 Land Converted to Forest Land/4(III) Direct N_2O Emissions from N Mineralization/Immobilization/4.A.2.1 Cropland converted to forest land	Management-induced changes in soil organic carbon are not available because of limited activity data over the entire time series
N_2O	LULUCF	"4.C Grassland 4.C Grassland/4.C.1 Grassland Remaining Grassland/4(III) Direct N_2O Emissions from N Mineralization/Immobilization"	Management-induced changes in soil organic carbon from GLGL are not available because of limited management activity data over the entire time series
N_2O	LULUCF	4.D Wetlands/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/ Other Wetlands (please specify)	No suitable activity data for this estimation. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
N_2O	LULUCF	"4.E Settlements 4.E Settlements/4.E.1 Settlements Remaining Settlements/4(III) Direct N_2O Emissions from N Mineralization/Immobilization"	Emissions of N_2O from urban trees are not reported as the net carbon stock change in soils was not estimated due to lack of data.
N_2O	LULUCF	4.E Settlements/4.E.2 Land Converted to Settlements/4(III) Direct N_2O Emissions from N Mineralization/Immobilization/4.E.2.1 Forest land converted to settlements	Emissions of N_2O from are not estimated due to lack of data.
N_2O	LULUCF	4.E Settlements/4.E.2 Land Converted to Settlements/4(III) Direct N_2O Emissions from N Mineralization/Immobilization/4.E.2.3 Grassland converted to settlements	Emissions of N_2O from are not estimated due to lack of data
N_2O	Waste	5.B Biological Treatment of Solid Waste/5.B.2 Anaerobic Digestion at Biogas Facilities/5.B.2.a Municipal Solid Waste	NE notation: Emissions from anaerobic digestion at biogas facilities have not been assessed.
N_2O	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.1 Biogenic/5.C.2.1.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories.There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada
N_2O	Waste	5.C Incineration and Open Burning of Waste/5.C.2 Open Burning of Waste/5.C.2.2 Non-biogenic/5.C.2.2.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories.There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada
N_2O	Waste	5.D Wastewater Treatment and Discharge/5.D.2 Industrial Wastewater	There is no methodology provided in the 2006 GL for N2O emissions from industrial wastewater where there is primary discharge.

Note:
1. "Not Estimated" includes sources and sinks which are considered in the 2006 IPCC Guidelines (IPCC 2006) but are not considered in this inventory.

Table A5–2 Summary of GHG Sources and Sinks Included Elsewhere (IE)[1]

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels 1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels/Gaseous Fuels"	1.A.1.c.i Manufacture of solid fuels	1.A.2.g.iii Mining (excluding fuels) and quarrying	Only aggregated data were available.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels/Liquid Fuels 1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels"	1.A.1.c.i Manufacture of solid fuels	1.A.2.g.iii Mining (excluding fuels) and quarrying	Only aggregated data were available.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Gaseous Fuels"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated activity data were available
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Liquid Fuels"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated data were available
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Solid Fuels"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated activity data were available
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Biomass 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated data were available
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars/Gaseous Fuels"	1.A.3.b.i Cars	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars/Liquefied Petroleum Gases (LPG)"	1.A.3.b.i Cars	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/Propane.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks/Gaseous Fuels"	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.

Table A5-2 Summary of GHG Sources and Sinks Included Elsewhere (IE) (cont'd)

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks/ Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks"	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses/Gaseous Fuels"	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses/Liquefied Petroleum Gases (LPG)"	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles/ Gaseous Fuels 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles"	1.A.3.b.iv Motorcycles	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles/ Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles"	1.A.3.b.iv Motorcycles	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Gas/Diesel Oil"	1.A.4.c.iii Agriculture/Forestry/ Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Gasoline"	1.A.4.c.iii Agriculture/Forestry/ Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Biomass 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing"	1.A.4.c.iii Agriculture/Forestry/ Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Other Liquid Fuels (please specify) 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing"	1.A.4.c.iii Agriculture/Forestry/ Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.

Table A5-2 Summary of GHG Sources and Sinks Included Elsewhere (IE) (cont'd)

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CH_4	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Residual Fuel Oil 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing"	1.A.4.c.iii Agriculture/Forestry/Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
CH_4	1.AA Fuel Combustion - Sectoral approach/Information item/Biomass	1.AA Info Items	5.C.1.2.a Municipal Solid Waste	Only aggregated data available
CH_4	1.AA Fuel Combustion - Sectoral approach/Information item/Fossil fuels	1.AA Info Items	5.C.1.2.a Municipal Solid Waste	Only aggregated data available
CH_4	1.B Fugitive Emissions from Fuels/1.B.1 Solid Fuels/1.B.1.a Coal Mining and Handling/1.B.1.a.1 Underground Mines/1.B.1.a.1.ii Post-Mining Activities	1.B.1.a. ii. Underground Mines - Mining Activities	1.B.1.a. ii. Underground Mines - Mining Activities	Only aggregated emission factors were available.
CH_4	1.B Fugitive Emissions from Fuels/1.B.1 Solid Fuels/1.B.1.a Coal Mining and Handling/1.B.1.a.2 Surface Mines/1.B.1.a.2.ii Post-Mining Activities	1.B.1.A.ii. Surface Mines- Post Mining Activities	1.B.1.A.ii Surface Mines- Mining Activities	Only aggregated emission factors were available.
CH_4	1.B Fugitive Emissions from Fuels/1.B.2 Oil and Natural Gas and Other Emissions from Energy Production/1.B.2.a Oil/1.B.2.a.1 Exploration	1.B.2.a.1 Oil - Exploration	1.B.2.a.2 Oil - Production	Only aggregated activity data were available.
CH_4	1.B Fugitive Emissions from Fuels/1.B.2 Oil and Natural Gas and Other Emissions from Energy Production/1.B.2.a Oil/1.B.2.a.5 Distribution of Oil Products	1.B.2.a.5 Oil - Distribution of Oil Products	1.B.2.a.4 Oil - Transport	Only aggregated data were available.
CH_4	1.B Fugitive Emissions from Fuels/1.B.2 Oil and Natural Gas and Other Emissions from Energy Production/1.B.2.b Natural Gas/1.B.2.b.1 Exploration	1.B.2.b.1 Natural Gas - Exploration	1.B.2.b.2 Natural Gas - Production	Only aggregated data were available.
CH_4	1.D Memo Items/1.D.2 Multilateral Operations	1.D.2 Multilateral Operations	1.A.3.a Domestic Aviation and 1.A.3.d Domestic Navigation	Canada is unable to disaggregate the fuel sold for Multilateral Operations from that sold for commercial or Military Aviation and Navigation. As such, these emissions, if occuring, will be reported in either Domestic Aviation or Domestic Navigation.
CH_4	2.B Chemical Industry/2.B.10 Other (please specify)/Carbon Black Production - N_20 Emissions	2.B.8.f	2.B.8.f	Refer to 2.B.8.f. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.B Chemical Industry/2.B.10 Other (please specify)/Ethylene Production - N_20 Emissions			Refer to 2.B.8.b. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.B Chemical Industry/2.B.10 Other (please specify)/Methanol Production - N_20 Emissions	2.B.8.a	2.B.8.a	CRF does not allow the input of N_{20} emissions under 2.B.8.a, thus this additional node was required.
CH_4	2.C Metal Industry/2.C.1 Iron and Steel Production/2.C.1.a Steel	2.C.1.a	2.C.1.b Pig Iron	Disaggregated data currently not available.
CH_4	2.C Metal Industry/2.C.1 Iron and Steel Production/2.C.1.c Direct Reduced Iron	2.C.1.c	1.A.2.a	Disaggregated data currently not available.
CH_4	2.C Metal Industry/2.C.1 Iron and Steel Production/2.C.1.d Sinter	2.C.1.d	1.A.2.a	Disaggregated data currently not available.
CH_4	2.C Metal Industry/2.C.1 Iron and Steel Production/2.C.1.e Pellet	2.C.1.e	1.A.2.a	Disaggregated data currently not available.
CH_4	2.C Metal Industry/2.C.2 Ferroalloys Production	2.C.2	2.C.1.b	Disaggregated data currently not available.
CH_4	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/Solvent use	$2D_3$ Other and Undifferentiated	$2D_3$ Other and Undifferentiated	$2D_3$ Other and Undifferentiated
CH_4	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/Solvent use	$2D_3$ Other and Undifferentiated	$2D_3$ Other and Undifferentiated	Disaggregate data are unavailable.
CH_4	4.A Forest Land/4.A.1 Forest Land Remaining Forest Land/4(V) Biomass Burning/Controlled Burning/Organic Soils	Organic Soils	Mineral Soils	AD does not allow the disaggregation of activity into organic and mineral soils

Table A5-2 Summary of GHG Sources and Sinks Included Elsewhere (IE) (cont'd)

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CH_4	4.A Forest Land/4.A.1 Forest Land R emaining Forest Land/4(V) Biomass Burning/Wildfires/Organic Soils	Organic Soils	Mineral Soils	AD does not allow the disaggregation of activity into organic and mineral soils
CH_4	4.B Cropland/4.B.1 Cropland Remaining Cropland/4(V) Biomass Burning/Controlled Burning/Mineral Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture Sector.	Agriculture Sector.	Field burning of agricultural crop residues is reported in the Agriculture Sector
CH_4	4.B Cropland/4.B.1 Cropland Remaining Cropland/4(V) Biomass Burning/Controlled Burning/Organic Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture Sector.	Agriculture Sector.	Field burning of agricultural crop residues is reported in the Agriculture Sector
CH_4	4.B Cropland/4.B.2 Land Converted to Cropland/4(V) Biomass Burning/Controlled Burning/Organic Soils	Organic Soils	Mineral Soils	AD does not allow the disaggregation of activity into organic and mineral soils
CH_4	4.C Grassland/4.C.1 Grassland Remaining Grassland/4(V) Biomass Burning/Con-trolled Burning/Organic Soils	Organic Soils	Mineral Soils	Prescribed burning on organic soils under GLGL is reported in mineral soils
CH_4	4.C Grassland/4.C.1 Grassland Remaining Grassland/4(V) Biomass Burning/Wildfires/ Organic Soils	Mineral Soils	Mineral Soils	Wildfires on organic soils in GLGL is reported in mineral soils
CH_4	4.D Wetlands/4.D.2 Land Converted to Wetlands/4(V) Biomass Burning/Controlled Burning/Organic Soils	Organic Soils	Reported under Mineral soils.	AD does not allow the disaggregation of activity into organic and mineral soils
CH_4	4.E Settlements/4(V) Biomass Burning/ Organic Soils	4(V) Biomass Burning - Organic soils	4(V) Biomass Burning - Mineral soils	Reported under Mineral soils. AD does not allow the disaggregation of activity into organic and mineral soils
CH_4	4.E Settlements/4.E.2 Land Converted to Settlements	4.E.2 Land Converted to Settlements	4(V) Biomass Burning - Mineral soils	Emissions of CH_4 are reported in Table 4(V) Biomass Burning
CO_2	3.G Liming/3.G.2 Dolomite $CaMg(CO_3)2$	3.G.1 Limestone $CaCO_3$	3.G.1 Limestone $CaCO_3$	Dolomite is included in Limestone
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels 1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels/Gaseous Fuels"	1.A.1.c.i Manufacture of solid fuels	1.A.2.g.iii Mining (excluding fuels) and quarrying	Only aggregated data were available.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels/Liquid Fuels 1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels"	1.A.1.c.i Manufacture of solid fuels	1.A.2.g.iii Mining (excluding fuels) and quarrying	Only aggregated data were available.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Gaseous Fuels"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated activity data were available
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Liquid Fuels"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated activity data were available
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Solid Fuels"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated activity data were available

Table A5-2 Summary of GHG Sources and Sinks Included Elsewhere (IE) (cont'd)

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Biomass 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated activity data were available
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars/Gaseous Fuels"	1.A.3.b.i Cars	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars/Liquefied Petroleum Gases (LPG)"	1.A.3.b.i Cars	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks/ Gaseous Fuels"	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks/ Liquefied Petroleum Gases (LPG)"	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses/Gaseous Fuels"	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses/Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses"	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles/ Gaseous Fuels 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles"	1.A.3.b.iv Motorcycles	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles/ Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles"	1.A.3.b.iv Motorcycles	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane.

Table A5-2 Summary of GHG Sources and Sinks Included Elsewhere (IE) (cont'd)

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Gas/Diesel Oil"	1.A.4.c.iii Agriculture/Forestry/Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Gasoline"	1.A.4.c.iii Agriculture/Forestry/Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Biomass 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing"	1.A.4.c.iii Agriculture/Forestry/Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Other Liquid Fuels (please specify) 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing"	1.A.4.c.iii Agriculture/Forestry/Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
CO_2	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Residual Fuel Oil 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing"	1.A.4.c.iii Agriculture/Forestry/Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
CO_2	1.AA Fuel Combustion - Sectoral approach/Information item/Biomass	1.AA Info Items	5.C.1.2.a Municipal Solid Waste	Only aggregated data available
CO_2	1.AA Fuel Combustion - Sectoral approach/Information item/Fossil fuels	1.AA Info Items	5.C.1.2.a Municipal Solid Waste	Only aggregated data available
CO_2	1.B Fugitive Emissions from Fuels/1.B.2 Oil and Natural Gas and Other Emissions from Energy Production/1.B.2.a Oil/1.B.2.a.1 Exploration	1.B.2.a.1 Oil - Exploration	1.B.2.a.2 Oil - Production	Only aggregated data were available.
CO_2	1.B Fugitive Emissions from Fuels/1.B.2 Oil and Natural Gas and Other Emissions from Energy Production/1.B.2.a Oil/1.B.2.a.5 Distribution of Oil Products	1.B.2.a.5 Oil - Distribution of Oil Products	1.B.2.a.3 Oil - Transport	Only aggregated data were available.
CO_2	1.B Fugitive Emissions from Fuels/1.B.2 Oil and Natural Gas and Other Emissions from Energy Production/1.B.2.b Natural Gas/1.B.2.b.1 Exploration	1.B.2.b.1 Natural Gas - Exploration	1.B.2.b.2 Natural Gas - Production	Only aggregated data were available.
CO_2	1.D Memo Items/1.D.2 Multilateral Operations	1.D.2 Multilateral Operations	1.A.3.a Domestic Aviation and 1.A.3.d Domestic Navigation	Canada is unable to disaggregate the fuel sold for Multilateral Operations from that sold for commercial or Military Aviation and Navigation. As such, these emissions, if occuring, will be reported in either Domestic Aviation or Domestic Navigation.
CO_2	2.B Chemical Industry/2.B.10 Other (please specify)/Carbon Black Production - N_20 Emissions	2.B.8.f	2.B.8.f	Refer to 2.B.8.f. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry/2.B.10 Other (please specify)/Ethylene Production - N_20 Emissions			Refer to 2.B.8.b. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.

Table A5-2 Summary of GHG Sources and Sinks Included Elsewhere (IE) (cont'd)

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CO_2	2.B Chemical Industry/2.B.10 Other (please specify)/Methanol Production - N_20 Emissions	2.B.8.a	2.B.8.a	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added
CO_2	2.B Chemical Industry/2.B.6 Titanium Dioxide Production	2.B.6	2.D.3 Other - Other and Undifferentiated	Disaggregated data currently not available
CO_2	2.B Chemical Industry/2.B.8 Petrochemical and Carbon Black Production/2.B.8.f Carbon Black	2.B.8.f	2.D.3 Other - Other and Undifferentiated	Disaggregated data currently not available
CO_2	2.B Chemical Industry/2.B.8 Petrochemical and Carbon Black Production/2.B.8.g Other/Other (please specify)/Styrene	2.B.8.g Other	2.D.3 Other - Other and Undifferentiated	Disaggregated data currently not available
CO_2	2.C Metal Industry/2.C.1 Iron and Steel Production/2.C.1.c Direct Reduced Iron	2.C.1.c	1.A.2.a	Disaggregated data currently not available.
CO_2	2.C Metal Industry/2.C.1 Iron and Steel Production/2.C.1.d Sinter	2.C.1.d	1.A.2.a, 2.D.3	Disaggregated data currently not available.
CO_2	2.C Metal Industry/2.C.1 Iron and Steel Production/2.C.1.e Pellet	2.C.1.e	1.A.2.a, 2.D.3	Disaggregated data currently not available.
CO_2	2.C Metal Industry/2.C.2 Ferroalloys Production	2.C.2	2.C.1.a and 2.C.1.b	Emissions from Ferroalloy Production are included in Steel Production (2C1a) since it is a direct production of specialty steels from iron ore via EAF process using reductants. However, the reductant portion is not disaggregated in Statistics Canada's Report on Energy Supply and Demand (RESD) so emissions from the use of reductants are allocated to Pig Iron Production (2C1b).
CO_2	2.C Metal Industry/2.C.5 Lead Production	2.C.5	2.D.3	Disaggregated data currently not available.
CO_2	2.C Metal Industry/2.C.6 Zinc Production	2.C.6	2.D.3	Disaggregated data currently not available.
CO_2	2.D Non-energy Products from Fuels and Solvent Use/2.D.1 Lubricant Use	2.D.1	2.D.3	Disaggregated data currently not available.
CO_2	2.D Non-energy Products from Fuels and Solvent Use/2.D.2 Paraffin Wax Use	2.D.1	2.D.3	Disaggregated data currently not available.
CO_2	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/ Solvent use	$2D_3$ Other and Undifferentiated	$2D_3$ Other and Undifferentiated	Disaggregated data are currently unavailable.
CO_2	4.A Forest Land/4.A.1 Forest Land Remaining Forest Land/4(V) Biomass Burning/ Controlled Burning/Organic Soils	Organic Soils	Mineral Soils	AD does not allow the disaggregation of activity into organic and mineral soils
CO_2	4.A Forest Land/4.A.1 Forest Land Remaining Forest Land/4(V) Biomass Burning/ Wildfires/Organic Soils	Organic Soils	Mineral Soils	AD does not allow the disaggregation of activity into organic and mineral soils
CO_2	4.B Cropland/4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils/ Total Organic Soils/Drained Organic Soils	If data are available, under the specific LULUCF category, where emissions actually occur	Reported in Agriculture Sector	AD does not allow the disaggregation of activity into the specific LULUCF category.
CO_2	4.B Cropland/4.B.1 Cropland Remaining Cropland/4(V) Biomass Burning/Controlled Burning/Mineral Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture Sector.	Agriculture Sector.	Field burning of agricultural crop residues is reported in the Agriculture Sector
CO_2	4.B Cropland/4.B.1 Cropland Remaining Cropland/4(V) Biomass Burning/Controlled Burning/Organic Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture Sector.	Agriculture Sector.	Field burning of agricultural crop residues is reported in the Agriculture Sector
CO_2	4.B Cropland/4.B.2 Land Converted to Cropland/4(V) Biomass Burning/Controlled Burning/Organic Soils	Organic Soils	Mineral Soils	AD does not allow the disaggregation of activity into organic and mineral soils
CO_2	4.D Wetlands/4.D.2 Land Converted to Wetlands/4(V) Biomass Burning/Controlled Burning/Organic Soils	Mineral Soils	Reported under mineral soils	AD does not allow the disaggregation of activity into organic and mineral soils
CO_2	4.E Settlements/4(V) Biomass Burning/ Organic Soils	4(V) Biomass Burning - Organic soils	4(V) Biomass Burning - Mineral soils	Reported under Mineral soils. AD does not allow the disaggregation of activity into organic and mineral soils

Table A5-2 Summary of GHG Sources and Sinks Included Elsewhere (IE) (cont'd)

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CO_2	4.G Harvested Wood Products/Approach B/Approach B_2/Total HWP from Domestic Harvest/HWP Produced and Consumed Domestically/Other (please specify)/C inputs and annual change	By commodity	By commodity	This child node is not a commodity and was created only for the purpose of reporting the C inputs and annual change in stock for HWP produced and consumed domestically, because AD does not allow the disaggregation by commodity.
N_2O	3.D Agricultural Soils/3.D.1 Direct N_2O Emissions From Managed Soils/3.D.1.7 Other	Not present in the IPCC 2006 Guidelines	3.D.1.1 Inorganic N Fertilizers/3.D.1.2.a Animal Manure Applied to Soils/3.D.1.4 Crop Residues	Canada reports three country-specific sources/removals of N_2O (conservation tillage, summerfallow and irrigation), but because of limitation of current CRF Reporter Software, the net impact of these country-specific source/sink categories on emissions/removals needs to be reported under 3.D.1.1, 3.D.1.2.a, and 3.D.1.4 of Agricultural Soils.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels 1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels/Gaseous Fuels"	1.A.1.c.i Manufacture of solid fuels	1.A.2.g.iii Mining (excluding fuels) and quarrying	Only aggregated data were available.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels/Liquid Fuels 1.AA Fuel Combustion - Sectoral approach/1.A.1 Energy Industries/1.A.1.c Manufacture of Solid Fuels and Other Energy Industries/1.A.1.c.i Manufacture of solid fuels"	1.A.1.c.i Manufacture of solid fuels	1.A.2.g.iii Mining (excluding fuels) and quarrying	Only aggregated data were available.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Gaseous Fuels"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated activity data were available
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Liquid Fuels"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated data were available
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Solid Fuels"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated activity data were available
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco/Biomass 1.AA Fuel Combustion - Sectoral approach/1.A.2 Manufacturing Industries and Construction/1.A.2.e Food Processing, Beverages and Tobacco"	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other - Other Manufacturing	Only aggregated data were available
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars/Gaseous Fuels"	1.A.3.b.i Cars	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.

Table A5-2 Summary of GHG Sources and Sinks Included Elsewhere (IE) (cont'd)

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.i Cars/Liquefied Petroleum Gases (LPG)"	1.A.3.b.i Cars	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	"Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane. "
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks/ Gaseous Fuels"	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.ii Light duty trucks/ Liquefied Petroleum Gases (LPG)"	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses/Gaseous Fuels"	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses/Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iii Heavy duty trucks and buses"	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles/ Gaseous Fuels 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles"	1.A.3.b.iv Motorcycles	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels	Canada is not currently able to disaggregate Gaseous Fuel (Natural Gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Gaseous Fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Gaseous Fuels.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles/ Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion - Sectoral approach/1.A.3 Transport/1.A.3.b Road Transportation/1.A.3.b.iv Motorcycles"	1.A.3.b.iv Motorcycles	1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane	Canada is not currently able to disaggregate Propane emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road Propane emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles/Other Liquid Fuels/ Propane.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Gas/Diesel Oil"	1.A.4.c.iii Agriculture/Forestry/ Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Gasoline"	1.A.4.c.iii Agriculture/Forestry/ Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.

Table A5-2 Summary of GHG Sources and Sinks Included Elsewhere (IE) (cont'd)

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Biomass 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing"	1.A.4.c.iii Agriculture/Forestry/Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Other Liquid Fuels (please specify) 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing"	1.A.4.c.iii Agriculture/Forestry/Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
N_2O	"1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing/Residual Fuel Oil 1.AA Fuel Combustion - Sectoral approach/1.A.4 Other Sectors/1.A.4.c Agriculture/Forestry/Fishing/1.A.4.c.iii Fishing"	1.A.4.c.iii Agriculture/Forestry/Fishing/Fishing	1.A.3.d Domestic Navigation	Canada is not currently able to disaggregate fishing from domestic navigation. All fishing emissions are thus included under Domestic Navigation 1.A.3.d.
N_2O	1.AA Fuel Combustion - Sectoral approach/Information item/Biomass	1.AA Info Items	5.C.1.2.a Municipal Solid Waste	Only aggregated data available
N_2O	1.AA Fuel Combustion - Sectoral approach/Information item/Fossil fuels	1.AA Info Items	5.C.1.2.a Municipal Solid Waste	Only aggregated data available
N_2O	1.D Memo Items/1.D.2 Multilateral Operations	1.D.2 Multilateral Operations	1.A.3.a Domestic Aviation and 1.A.3.d Domestic Navigation	Canada is unable to disaggregate the fuel sold for Multilateral Operations from that sold for commercial or Military Aviation and Navigation. As such, these emissions, if occuring, will be reported in either Domestic Aviation or Domestic Navigation.
N_2O	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/Other (please specify)/Other and Undifferentiated	2.B.8	2.B.10	Only aggregated CO_2 emissions are included under 2.D.3.
N_2O	2.D Non-energy Products from Fuels and Solvent Use/2.D.3 Other (please specify)/Solvent use	$2D_3$ Other and Undifferentiated	$2D_3$ Other and Undifferentiated	Disaggregate data are unavailable.
N_2O	4(IV) Indirect N_2O Emissions from Managed Soils/Atmospheric Deposition	Agricultural Soils	Agricultural Soils	N_2O emissions from volatized N of Managed Soils is reported in the Agriculture Sector
N_2O	4(IV) Indirect N_2O Emissions from Managed Soils/Nitrogen Leaching and Run-off	Agricultural Soils	Agricultural Soils	Indirect N_2O emissions from Leaching and Runoff of N from fertilizers and other N sources is reported in the Agriculture Sector.
N_2O	4.A Forest Land/4.A.1 Forest Land Remaining Forest Land/4(I) Direct N_2O Emissions from N Inputs to Managed Soils/Inorganic N Fertilizers	f data are available, under the specific LULUCF category, where emissions actually occur	Reported in Agriculture Sector	AD does not allow the disaggregation of activity into the specific LULUCF category
N_2O	4.A Forest Land/4.A.1 Forest Land Remaining Forest Land/4(I) Direct N_2O Emissions from N Inputs to Managed Soils/Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur	Reported in Agriculture Sector	AD does not allow the disaggregation of activity into the specific LULUCF category
N_2O	4.A Forest Land/4.A.1 Forest Land Remaining Forest Land/4(V) Biomass Burning/Controlled Burning/Organic Soils	Organic Soils	Mineral Soils	AD does not allow the disaggregation of activity into organic and mineral soils
N_2O	4.A Forest Land/4.A.1 Forest Land Remaining Forest Land/4(V) Biomass Burning/Wildfires/Organic Soils	Organic Soils	Mineral Soils	AD does not allow the disaggregation of activity into organic and mineral soils
N_2O	4.A Forest Land/4.A.2 Land Converted to Forest Land/4(I) Direct N_2O Emissions from N Inputs to Managed Soils/Inorganic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur	Reported in Agriculture Sector	AD does not allow the disaggregation of activity into the specific LULUCF category
N_2O	4.A Forest Land/4.A.2 Land Converted to Forest Land/4(I) Direct N_2O Emissions from N Inputs to Managed Soils/Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur	Reported in Agriculture Sector	AD does not allow the disaggregation of activity into the specific LULUCF category

Table A5-2 Summary of GHG Sources and Sinks Included Elsewhere (IE) (cont'd)

GHG	Source/sink category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
N_2O	4.B Cropland/4.B.1 Cropland Remaining Cropland/4(V) Biomass Burning/Controlled Burning/Mineral Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture Sector.	Agriculture Sector.	Feild burning of agricultural crop residues is reported in the Agriculture Sector
N_2O	4.B Cropland/4.B.1 Cropland Remaining Cropland/4(V) Biomass Burning/Controlled Burning/Organic Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture Sector.	Agriculture Sector.	AD does not allow the disaggregation of activity into organic and mineral soils
N_2O	4.B Cropland/4.B.2 Land Converted to Cropland/4(V) Biomass Burning/Controlled Burning/Organic Soils	Organic Soils	Mineral Soils	AD does not allow the disaggregation of activity into organic and mineral soils
N_2O	4.C Grassland/4.C.1 Grassland Remaining Grassland/4(V) Biomass Burning/Controlled Burning/Organic Soils	Mineral Soils	Mineral Soils	Prescribed burning in organic soils under GLGL is reported in mineral soils
N_2O	4.C Grassland/4.C.1 Grassland Remaining Grassland/4(V) Biomass Burning/Wildfires/Organic Soils	Mineral Soils	Mineral Soils	Wildfires on organic soils in GLGL is reported in mineral soils
N_2O	"4.D Wetlands/4.D.1 Wetlands Remaining Wetlands/4(III) Direct N_2O Emissions from N Mineralization/Immobilization 4.D Wetlands"	Table 4(III) Direct N_2O Emissions from N Mineralization/ Immobilization	Table 4(II)	Emissions of N_2O from peat extraction remaining peat extraction are reported in Table 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils.
N_2O	4.D Wetlands/4.D.2 Land Converted to Wetlands/4(III) Direct N_2O Emissions from N Mineralization/Immobilization/4.D.2.1 Forest land converted to wetlands	Table 4(III) Direct N_2O Emissions from N Mineralization/ Immobilization	Reported in Table 4(II)	Emissions of N_2O from land converted to peat extraction are reported in Table 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils.
N_2O	4.D Wetlands/4.D.2 Land Converted to Wetlands/4(III) Direct N_2O Emissions from N Mineralization/Immobilization/4.D.2.5 Other land converted to wetlands	Table 4(III) Direct N_2O Emissions from N Mineralization/ Immobilization	Reported in Table 4(II)	Emissions of N_2O from land converted to peat extraction are reported in Table 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils.
N_2O	4.D Wetlands/4.D.2 Land Converted to Wetlands/4(V) Biomass Burning/Controlled Burning/Organic Soils	Organic Soils	Mineral Soils	AD does not allow the disaggregation of activity into organic and mineral soils
N_2O	4.E Settlements/4(V) Biomass Burning/ Organic Soils	4(V) Biomass Burning - Organic soils	4(V) Biomass Burning - Mineral soils	Reported under Mineral soils. AD does not allow the disaggregation of activity into organic and mineral soils
N_2O	4.E Settlements/4.E.1 Settlements Remaining Settlements/4(I) Direct N_2O Emissions from N Inputs to Managed Soils/ Inorganic N Fertilizers	Under Agriculture if data is not available to differentiate	Reported in Agriculture Sector	AD does not allow the disaggregation of activity into this category
N_2O	4.E Settlements/4.E.1 Settlements Remaining Settlements/4(I) Direct N_2O Emissions from N Inputs to Managed Soils/ Organic N Fertilizers	Under Agriculture if data is not available to differentiate	Reported in Agriculture Sector	AD does not allow the disaggregation of activity into this category
N_2O	4.E Settlements/4.E.2 Land Converted to Settlements/4(I) Direct N_2O Emissions from N Inputs to Managed Soils/Inorganic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur	Reported in Agriculture Sector	AD does not allow the disaggregation of activity into the specific LULUCF category
N_2O	4.E Settlements/4.E.2 Land Converted to Settlements/4(I) Direct N_2O Emissions from N Inputs to Managed Soils/Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur	Reported in Agriculture Sector	AD does not allow the disaggregation of activity into the specific LULUCF c ategory
SF_6	2.G Other Product Manufacture and Use/2.G.1 Electrical Equipment/SF_6	2.G.1	2.G.1	Aggregated SF_6 emissions from stocks includes SF_6 use (to top up equipment), equipment disposal and equipment failure; these emissions currently cannot be disaggregated.

Note:
1. "Included Elsewhere" includes sources and sinks in this inventory that are allocated to a sector other than that indicated by the 2006 IPCC Guidelines (IPCC 2006)

Annex 6

Emission Factors

This annex summarizes the development and selection of emission factors for use in estimating greenhouse gas (GHG) emissions. Additional details on sector-specific methodologies for the use of these factors are presented in Annex 3.

A6.1. Fuel Combustion

A6.1.1. Natural Gas and Natural Gas Liquids

A6.1.1.1. Carbon Dioxide (CO_2)

CO_2 emission factors for fossil fuel combustion depend primarily on fuel properties such as carbon content, density and heating value and, to a lesser extent, on the combustion technology.

For natural gas, there are two principal fuel types combusted in Canada: marketable fuel (processed for commercial sale) and non-marketable fuel (unprocessed, for internal use). There are regional variations in marketable and non-marketable natural gas use, with nine regions consuming marketable fuel and seven regions consuming non-marketable fuel. Provincial and territorial emission factors (Table A6–1) have been developed based on data from chemical analysis of representative natural gas samples (McCann 2000). Both imported and domestic natural gas were included, where applicable, in the mix of gas samples used for chemical analysis. Non marketable natural gas emission factors are higher than those of marketable fuels as a result of their raw nature; in addition to methane, non-marketable natural gas may include ethane, propane and butane in the fuel mix.

CO_2 emission factors (Table A6–3) for natural gas liquids (NGL), such as ethane, propane and butane, were developed based on chemical analysis data for marketable fuels (McCann 2000).

A6.1.1.2. Methane (CH4)

Emissions of CH_4 from fuel combustion are technology-dependent. Sectoral emission factors (Table A6–2 and Table A6–3) have been developed based on technologies typically used in Canada. The factors were developed based on a broad review of emission factors for combustion technologies (SGA Energy 2000). The emission factor for producer consumption of natural gas was developed based on a technology split for the upstream oil and gas industry (CAPP 1999) and technology-specific emission factors from the U.S. EPA report AP 42 (U.S. EPA 1996a).

A6.1.1.3. Nitrous Oxide (N_2O)

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors (Table A6–2 and Table A6–3) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

Table A6–1 CO_2 Emission Factors for Natural Gas

Province	Emission Factor[1] (g/m³)	
	Marketable[2]	Non-marketable[3]
Newfoundland and Labrador	1 901	2 494
Nova Scotia	1 901	2 494
New Brunswick	1 901	NO
Quebec	1 887	NO
Ontario	1 888	NO
Manitoba	1 886	NO
Saskatchewan	1 829	2 441
Alberta	1 928	2 392
British Columbia	1 926	2 162
Yukon	1 901	2 401
Northwest Territories	2 466	2 466

Notes:

NO = Not occurring

1. McCann (2000)
2. The term "marketable" applies to fuel consumed by the Electric Utilities, Manufacturing Industries, Residential/Commercial and Transport subsectors.
3. The term "non-marketable" applies to raw gas consumption, mainly by natural gas producers.

Table A6–2 CH_4 and N_2O Emission Factors for Natural Gas

Source	Emission Factor (g/m³)[1]	
	CH_4	N_2O
Electric Utilities	0.490	0.049
Industrial	0.037	0.033
Producer Consumption (Non-marketable)	6.4[2]	0.060
Pipelines	1.900	0.050
Cement	0.037	0.034
Manufacturing Industries	0.037	0.033
Residential, Construction, Commercial/ Institutional, Agriculture	0.037	0.035

Notes:

1. SGA Energy (2000)
2. Adapted from U.S. EPA (1996b) and CAPP (1999)

Table A6–3 Emission Factors for Natural Gas Liquids

Source	Emission Factor (g/L)		
	CO_2	CH_4	N_2O
Propane			
Residential	1 515[1]	0.027[2]	0.108[2]
All Other Uses	1 515[1]	0.024[2]	0.108[2]
Ethane	986[1]	0.024[2]	0.108[2]
Butane	1 747[1]	0.024[2]	0.108[2]

Notes:

1. McCann (2000)
2. SGA Energy (2000)

A6.1.2. Refined Petroleum Products

A6.1.2.1. CO_2

CO_2 emission factors for fossil fuel combustion are dependent primarily on fuel properties and, to a lesser extent, on the combustion technology.

Emission factors have been developed for each major class of refined petroleum products (RPP) based on their heating value, carbon content and destiny (McCann 2000), to ensure consistency with the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC 2006).

The composition of petroleum coke is process-specific. Factors have been developed for both refinery (catalytic cracker) derived cokes and coke used in upgrading facilities. These factors (Table A6–5) have been developed using data provided by industry to the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC) in their *Review of Energy Consumption* reports on the refining and upgrading industry (CIEEDAC 2003, 2010). The bulk of the coke consumed by refineries is catalytic cracker-derived, and the emission factor is an average of petroleum coke and catalytic cracker coke emission factors.

Emission factors for still gas (Table A6–5) from refining operations and upgrading facilities were also derived from data provided by industry and reported by CIEEDAC (2003, 2010).

A6.1.2.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors were developed (Table A6–4) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

The emission factor for petroleum coke was assumed to be the same for both catalytic cracker-derived cokes and coke used in upgrading facilities.

The emission factor for still gas from upgraders (Table A6–4) was based on the 2006 IPCC default emission factor and was adapted using energy conversion factors published by Statistics Canada (2014). The still gas emission factors for refineries and other industries (Table A6–7)were based on the 2006 IPCC default emission factor, which was calculated on an annual basis using energy conversion factors provided by Statistics Canada (2014).

Table A6–4 Emission Factors for Refined Petroleum Products

Source	Emission Factor (g/L)		
	CO_2[1]	CH_4[2]	N_2O[2]
Light Fuel Oil			
Electric Utilities	2 753	0.18	0.031
Industrial	2 753	0.006	0.031
Producer Consumption	2 670	0.006	0.031
Residential	2 753	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 753	0.026	0.031
Heavy Fuel Oil			
Electric Utilities	3 156	0.034	0.064
Industrial	3 156	0.12	0.064
Producer Consumption	3 190	0.12	0.064
Residential, Forestry, Construction, Public Administration and Commercial/Institutional	3 156	0.057	0.064
Kerosene			
Electric Utilities	2 560[3]	0.006	0.031
Industrial	2 560[3]	0.006	0.031
Producer Consumption	2 560[3]	0.006	0.031
Residential	2 560[3]	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 560[3]	0.026	0.031
Diesel - Refineries and Others	2 690	0.133	0.4
Diesel - Upgraders[4]	2 690	0.147	1.10
Petroleum Coke	(see Table A6–5)	0.12	(see Table A_6–56)
Still Gas - Refineries and Others	(see Table A6–5)	(see Table A6–8)	0.00002
Still Gas - Upgraders	(see Table A6–5)	0.0389	0.00002
Motor Gasoline	2 316	0.100[5]	0.02[5]

Notes:
1. Adapted from McCann (2000)
2. SGA Energy (2000); except Diesel - Upgraders and Motor Gasoline
3. Assumed McCann (2000) aviation turbo-fuel emission factor
4. Assumed Off-road Diesel emission factors (see Table A_6–12) since fuel is consumed in oil sands mining trucks.
5. Adapted from IPCC (2006)

N/A = Not available

Table A6–5 CO_2 Emission Factors for Petroleum Coke and Still Gas

	Emission Factor													
	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Petroleum Coke	g/L													
Upgrading Facilities[1]	3 556	3 551	3 481	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3,494	3,494	3,494
Refineries & Others[2]	3 766	3 787	3 711	3 814	3 817	3 820	3 817	3 816	3,826	3,814	3,814	3,826	3,814	3,826
Still Gas	g/m^3													
Upgrading Facilities[1]	2 310	2 090	2 120	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2,140	2,140	2,140
Refineries & Others[2]	1,740	1,800	1 683	1 719	1 753	1 760	1 705	1 723	1,840	1,830	2,075	2,099	2,099	2,123

Notes:

1. CIEEDAC (2003)

Table A6–6 CO_2 EN_2O Emission Factors for Petroleum Coke

	Emission Factor												
	1990	1991	1992	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001-2015
Petroleum Cake													
Upgrading Facilities[1,2]	21.9	22.1	22.3	22.3	22.5	22.7	22.7	22.7	23.0	23.5	23.7	24.2	24.0
Refineries & Others[1,2]	24.6	24.8	25.0	25.0	25.2	25.5	25.5	25.4	25.8	27.0	27.1	27.6	27.5

Notes:

1. Adapted from IPCC (2006)
2. Energy content from Statistics Canada Cat. No. 57-003 (2014)

Table A6–7 CH_4 Emission Factors for Still Gas (Refineries and Others)

	Emission Factor[1]													
	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Still Gas							g/m3							
Refineries & Others[1,2]	32.6	33.5	33.8	32.0	32.0	32.2	31.6	32.0	32.1	32.6	30.5	31.0	31.0	31.0

Notes:

1. Adapted from IPCC (2006)
2. Energy content from Statistics Canada Cat. No. 57-003 (2014)

A6.1.2.3. N_2O

Emissions of N_2O from fuel combustion are technologydependent. Emission factors for RPPs, with the exception of petroleum coke, have been developed (Table A6–4) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

Table A6–8 CO_2 Emission Factors for Coal

Province	Coal Type	Source	Emission Factor (kg CO_2/tonne)[1,2,3,4,5]			Moisture (wt %)
			Mean	Uncertainty (95% CI)		
				Low	High	
Newfoundland & Labrador, P.E.I., Quebec, Nova Scotia (Prior to 2000)	Canadian Bituminous[2]	Nova Scotia	2315	-33%	22%	3.2
Newfoundland & Labrador, P.E.I., Quebec, Nova Scotia (2000 onward)	Canadian Bituminous[3]	Alberta	2185	-26%	26%	7.7
New Brunswick	Canadian Bituminous[2]	New Brunswick	2305	-14%	14%	3.2
Ontario, Alberta, Saskatchewan, B.C.	Canadian Bituminous[2]	Alberta	2185	-26%	26%	7.7
Atlantic5	Foreign Bituminous[2]	Non-U.S.	2540	-7%	7%	8.3
Ontario, Quebec	Foreign Bituminous[3]	U.S. (Pennsylvania)	2662	-7%	7%	N/A
All Provinces & Territories, except Saskatchewan	Lignite3	Saskatchewan	1214	-2%	2%	24
Saskatchewan	Lignite3	Saskatchewan	1458	-13%	13%	36
Ontario, Manitoba, Atlantic	Sub-bituminous[2]	Foreign	1425	-8%	8%	24
Alberta, Saskatchewan, B.C.	Sub-bituminous[3]	Alberta	1770	-7%	8%	21
All Provinces & Territories	Anthracite	--	2382	-6%	6%	N/A

Notes:

1. Factors presented on a "wet basis." Moisture content shown is that for the "weighted average" emission factor.
2. Carbon content, Radovan et al. (2012), oxidation factor, Environment and Climate Change Canada, 2016.
3. Carbon content and oxidation factor, Environment and Climate Change Canada, 2016.
4. 95 % Confidence Intervals, which were determined through statistical analysis of Canadian coal data.
5. Atlantic refers to the Maritime provinces and Newfoundland & Labrador.

N/A = not available

Emission factors for petroleum coke (Table A6–6) were based on 2006 IPCC default emission factors and were calculated on an annual basis using energy conversion factors provided by Statistics Canada (2014).

A6.1.3. Coal and Coal Products

A6.1.3.1. CO_2

CO_2 emission factors for coal combustion depend largely on the properties of the fuel and, to a lesser extent, on the combustion technology. Coal emission factors (Table A6–8) were developed for each province on the basis of the rank of the coal and the region of supply. Emission factors were based on data from chemical analysis of coal samples for electric utilities, which account for the vast majority of coal consumption.

Some factors for Canadian bituminous coal presented in Table A6–8 were developed based on a statistical analysis, by ECCC (Radovan, et al, 2012), of over 3000 analytical samples for a variety of coal types and producing/consuming regions. The analysis and uncertainty calculations were conducted using the @Risk software package. The coal emission factors are presented with uncertainty estimates, since the supply and quality of coal can vary over time. The average coal carbon and moisture content for each coal type was used to develop CO_2 emission factors. An additional study to determine country-specific coal oxidation factors and further investigate the carbon content of coal burned at electric generation facilities was conducted for ECCC by GHD Limited in 2016 (ECCC, 2016).

Based on an anlysis of this study, updated factors and uncertainty estimates for many coal-types have been determined (ECCC, 2016). Factors for anthracite imported from the United States are from Annex 2 of the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008 (U.S. EPA 2010). All coal emission factors in Table A6–8 now incorporate Canada-specific oxidation factors (ECCC 2016).

Coke and coke oven gas emission factors are presented in Table A6–9. The coke emission factor was developed from an iron and steel industry study completed in 2014 (CRA 2014). It is representative of coke use in the cement, non-ferrous metal and other manufacturing industries. The coke oven gas emission-factor value is from McCann (2000) and represents use in the iron and steel industry.

Table A6–9 CO_2 Emission Factors for Coal Products

Coal Product - Fuel Type	Emission Factor
Coke Oven Gas[1]	687 g/m^3
Coke[2]	3 173 g/kg

Notes:
1. McCann (2000)
2. CRA (2014)

A6.1.3.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors for sectors (Table A6–10) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

A6.1.3.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for sectors (Table A6–10) have been developed based on technologies typically used in Canada. The emission factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

Table A6–10 CH_4 and N_2O Emission Factors for Coals[1]

Source	Emission Factor	
	CH_4	N_2O
	g/kg	
Coal		
Electric Utilities	0.02	0.03
Industry and Heat & Steam Plants	0.03	0.02
Residential, Public Administration	4.00	0.02
Coke	0.03	0.02
	g/m^3	
Coke Oven Gas	0.04	0.04

Note:
1. SGA Energy (2000)

A6.1.4. Other Fuels

A6.1.4.1. CO_2

Alternative fuels such as tires, refuse, and waste oil and solvents are used in the cement industry to offset combustion of purchased fuels like coal, oil or natural gas. CO_2 emissions associated with the stationary combustion of waste fuels are included in the National Inventory Report where data are available. Fuel use data reported by the cement industry, using CO_2 accounting and reporting standards developed by the World Business Council for Sustainable Development (WBSCD 2005), were used to generate the emission factors in Table A6–11.

Table A6–11 Emission Factors for Alternative Fuels

Source/Fuel	GHG	Emission Factor (kg/GJ)											
		1990 - 1994	1995 - 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010 - 2015
Cement Industry Waste Fuel	CO_2[1]	78.8	77.6	78.6	80.6	82.6	81.5	81.2	83.8	87.7	86.3	79.2	80.1
	CH_4[2]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	N_2O[2]	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004

Notes:

1. Adapted from WBSCD (2005)
2. Adapted from IPCC (2006)

A6.1.4.2. CH_4

CH_4 emission factors for alternative fuels were adapted from the 2006 IPCC Guidelines (IPCC 2006).

A6.1.4.3. N_2O

N_2O emission factors for alternative fuels were adapted from the 2006 IPCC Guidelines (IPCC 2006).

A6.1.5. Mobile Combustion

A6.1.5.1. CO_2

CO_2 emission factors for mobile combustion are dependent on fuel properties and are generally the same as those used for stationary combustion fuels.

A6.1.5.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Mode-specific CH_4 emission factors have been developed based on technologies typically used in Canada, and are summarized in Table A6–12. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies (SGA Energy 2000). A number of on-road CH_4 emission factors were subsequently refined with updated Canadian and U.S. emissions test results (Environment Canada 2006, 2009; Graham et al. 2008).

Over 50 aircraft-specific aviation turbo fuel CH_4 emission factors from the 2006 IPCC Guidelines (IPCC 2006) are used in the Tier 3 civil aviation model (Aviation Greenhouse Gas Emission Model - AGEM). Table A6–12 displays a national overall average implied emission factor, for conciseness (refer to Section A3.4.2.3 for more information on AGEM).

A6.1.5.3. N_2O

EEmissions of N_2O from fuel combustion are technology-dependent. Mode-specific N_2O emission factors have been developed based on technologies typically used in Canada. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies (SGA Energy 2000). Similar to the CH_4 emission factors of Section A6.1.5.2, a number of on-road N_2O emission factors were subsequently refined with updated Canadian and U.S. emissions test results (Environment Canada 2006, 2009; Graham et al. 2008, 2009).

In particular, the updated test data highlighted the effect of high-sulphur gasoline on N_2O emission factors. Vehicles fuelled with high-sulphur gasoline for the majority of their useful lives generally emitted higher levels of N_2O than those run on low sulphur gasoline (Environment Canada 2009).

Table A6–12 Emission Factors for Energy Mobile Combustion Sources

Mode†	Emission Factor (g/L fuel)		
	CO_2	CH_4	N_2O
Road Transport			
Gasoline Vehicles			
Light-duty Gasoline Vehicles (LDGVs)			
Tier 2	2 316[1]	0.14[3]	0.022[4]
Tier 1	2 316[1]	0.23[5]	0.47[5]
Tier 0	2 316[1]	0.32[6]	0.66[7]
Oxidation Catalyst	2 316[1]	0.52[8]	0.20[6]
Non-catalytic Controlled	2 316[1]	0.46[8]	0.028[6]
Light-duty Gasoline Trucks (LDGTs)			
Tier 2	2 316[1]	0.14[3]	0.022[4]
Tier 1	2 316[1]	0.24[5]	0.58[5]
Tier 0	2 316[1]	0.21[8]	0.66[7]
Oxidation Catalyst	2 316[1]	0.43[8]	0.20[6]
Non-catalytic Controlled	2 316[1]	0.56[6]	0.028[6]
Heavy-duty Gasoline Vehicles (HDGVs)			
Three-way Catalyst	2 316[1]	0.068[8]	0.20[8]
Non-catalytic Controlled	2 316[1]	0.29[6]	0.047[6]
Uncontrolled	2 316[1]	0.49[6]	0.084[6]
Motorcycles			
Non-catalytic Controlled	2 316[1]	0.77[3]	0.041[3]
Uncontrolled	2 316[1]	2.3[6]	0.048[6]
Diesel Vehicles			
Light-duty Diesel Vehicles (LDDVs)			
Advanced Control*	2 690[2]	0.051[6]	0.22[6]
Moderate Control	2 690[2]	0.068[6]	0.21[6]
Uncontrolled	2 690[2]	0.10[6]	0.16[6]
Light-duty Diesel Trucks (LDDTs)			
Advanced Control*	2 690[2]	0.068[6]	0.22[6]
Moderate Control	2 690[2]	0.068[6]	0.21[6]
Uncontrolled	2 690[2]	0.085[6]	0.16[6]
Heavy-duty Diesel Vehicles (HDDVs)			
Advanced Control	2 690[2]	0.11[9]	0.151[9]
Moderate Control	2 690[2]	0.14[6]	0.082[6]
Uncontrolled	2 690[2]	0.15[6]	0.075[6]
Natural Gas Vehicles	1.9[2]	9E-03[6]	6E-05[6]
Propane Vehicles	1 515[2]	0.64[6]	0.028[6]
Off-road			
Off-road Gasoline	2 316[1]	2.7[6]	0.050[6]
Off-road Diesel	2 690[2]	0.15[12]	1.0[12]
Railways			
Diesel Train	2 690[2]	0.15[12]	1.0[12]
Marine			
Gasoline	2 316[1]	0.23[12]	0.067[12]
Diesel	2 690[2]	0.25[12]	0.073[12]
Light Fuel Oil	2 753[2]	0.25[12]	0.073[12]
Heavy Fuel Oil	3 156[2]	0.28[12]	0.080[12]
Kerosene	2 560[15]	0.006[16]	0.031[16]
Aviation			
Aviation Gasoline	2 365[10]	2.2[10]	0.23[10]
Aviation Turbo Fuel	2 560[2]	0.029[11]	0.071[12]
Other Gaseous Fuels			
Natural Gas	1.9[2]	9E-03[6]	6E-05[6]
Propane	1 515[2]	0.64[6]	0.028[6]
Renewable Fuels			
Ethanol	1 509[13]	**	**
Biodiesel	2 474[13, 14]	***	***

Notes:

† In the context of Transportation Modes, Tiers 0–2 refer to increasingly stringent U.S. EPA emission standards, enabled through advancements in emission control technologies. It should not be confused with IPCC GHG estimation methodologies. EPA Tiers apply to on-road vehicles under the following model year breakdown, with some overlap due to technology penetration (refer to Figure A3-2 of Annex 3 for more details): Tier 0: 1980-1995; Tier 1: 1994-2003; Tier 2: 2004-2013.

1. Adapted from McCann (2000)
2. McCann (2000)
3. Adapted from Environment Canada ERMD Report 04-44 (2006)
4. Adapted from Environment Canada ERMD Report 04-44 (2006) and Graham et al. (2009)
5. Adapted from Environment Canada ERMS Report 07-14A (2009)
6. SGA Energy (2000)
7. Adapted from Barton & Simpson (1994)
8. ICF Consulting (2004)
9. Graham et al. (2008)
10. Jaques (1992)
11. National overall average emission factor based on 2006 IPCC Guidelines (IPCC 2006). Refer to Section A3.4.2.3 of Annex 3.1 for further information.
12. IPCC (2006)
13. Refer to Section 3.5.1 of Chapter 3 for further information.
14. BioMer (2005)
15. Assumed McCann (2000) aviation turbo-fuel emission factor
16. SGA Energy (2000); except Diesel - Upgraders and Motor Gasoline

* Advanced control diesel emission factors are used for Tier 2 diesel vehicle populations.
** Gasoline CH_4 and N_2O emission factors (by mode and technology) are used for ethanol.
*** Diesel CH_4 and N_2O emission factors (by mode and technology) are used for biodiesel.

A6.2. Industrial Processes

A6.2.1. Mineral Products

To estimate emissions from the production and use of mineral products, emission factors are listed in Table A6–13.

A6.2.2. Chemical Industry

Table A6–14, Table A6–15, Table A6–16, and Table A6-17, present the emission factors used for categories included under the Chemical Industry subsector, as well as the sources from which these factors were obtained.

Table A6–13 Carbon Dioxide (CO_2) Emission Factors for Mineral Products

Category	Mineral Product	Emission Factor (g CO_2/kg of mineral product)
Cement Production	Clinker	532[1]
Lime Production	TOC	11.5[2]
	High-Calcium Lime	751[3]
Limestone and Dolomite Use	Dolomitic lime	889[3]
	Limestone	418[4]
	Dolomite	468[4]
Soda Ash Use	Soda Ash	415[4]
Magnesite Use	Magnesite	522[4]

Notes:
1. Cement Association of Canada (2016). This is an annual emission factor and ranges between 522.0 and 532.7 g CO_2/ kg clinker. This EF is multiplied by the CKD correction factor, 1.012 to account for clinker that is lost or removed from the process. Excluding the correction factor, the 2015 EF is 526 g CO_2/kg clinker.
2. Cement Association of Canada (2016).
3. Developed based on information provided by Kenefick (2008). Personal communication (email to Shen A, Environment Canada, dated October 7, 2008). Canadian Lime Institute (CLI).
4. AMEC (2006).

Table A6–14 Emission Factors for Ammonia Production

	Activity Data	Fuel Factor m^3natural gas/tonne of NH_3	Emission Factor CO_2/ m^3 of natural gas	Emission Recovery Factor g CO_2 / kg of urea
Ammonia Production	Feedstock use of natural gas to manufacture ammonia	Facility-specific fuel factors are used and these are confidential. See Annex 3.3 for details.	Marketable natural gas emission factors found in Table A6–1 are used.	728

Table A6–15 N_2O Emission Factors for Nitric Acid and Adipic Acid Production

Category	Process Description	N_2O Emission Factor (kg/t)
Nitric Acid Production	Dual-pressure plants with extended absorption "Type 1"	9.4[1]
	Dual-pressure plants with extended absorption "Type 2"	12[1]
	High-pressure plants with non-selective catalytic reduction	0.66[1]
	High-pressure plants with selective catalytic reduction	8.5[2]
Adipic Acid Production	Oxidation reaction of cyclohexanone and cyclohexanol mixture without N_2O abatement	300[2]

Notes:
1. Collis G. 1992. Personal communication (letter from Collis G to Jaques A., Greenhouse Gas Division, dated March 23, 1992). Canadian Fertilizer Institute
2. IPCC (2000)

Table A6–16 Emission Factors for Petrochemical Products

Petrochemical Product	Emission Factor	Type
Silicon Carbide	11.6 kg CH_4 / t (tonne) product	IPCC default[1]
Calcium Carbide	4.8 kg CH_4 / t product	Derived from IPCC data[2]
Carbon Black	1.29 kg CH_4 / t product	Sector-wide weighted average[3]
	0.032 kg N_2O / t product	Sector-wide weighted average[3]
	0.040 kg CO_2 / t product	Sector-wide weighted average[3]
Ethylene	0.039 kg CH_4 / t product	Sector-wide weighted average[3]
	0.0055 kg N_2O / t product	2014 Sector-wide weighted average[3]
	0.411 t CO_2 / t product	Sector-wide weighted average[4]
Ethylene Dichloride	0.4 kg CH_4 / t product	IPCC default[1]
Styrene	4 kg CH_4 / t product	IPCC default[1]
Methanol	0.031 kg CH_4 / t product	Sector-wide weighted average[3]
	0.010 kg N_2O / t product	Sector-wide weighted average[3]
	0.790 t CO_2 / t product	Sector-wide weighted average[4]

Notes:
1. Default value from IPCC (2006)
2. Derived from IPCC (2006) data. See section 4.9.2 for details
3. Cheminfo Services (2010)
4. Cheminfo Services (2015); emission factors may vary if changes are made to the composition of feed.

A6.2.3. Metal Production

The range of the metallurgical coke emission factors and other parameters used for estimating emissions from iron and steel production are found in Table A6–18.

Tier 1-type emission factors for the category of Aluminium Production and the sources from which these emission factors were obtained are shown in Table A6–19.

A6.2.4. Non-Energy Products from Fuels and Solvent Use

The use of fossil fuels as feedstock or for other non-energy use (NEU) may result in emissions during the life of manufactured products. To estimate CO_2 emissions from NEU of natural gas, an emission factor of 38 g CO_2/m3 was used. This emission factor excludes the feedstock use of natural gas to produce ammonia, and it is derived from the NEU of natural gas data found in the 2005 Cheminfo Study (Cheminfo Services 2005). Table A6–20 shows the emission factors used to develop CO_2 emission estimates for non-energy applications

Table A6–17 Emission Factor for By-Product Emissions from Fluorochemical Production

Process	Emission Factor
HCFC-22 production	0.04 t HFC-23 emitted / t HCFC-22 produced[1]

Note:
1. IPCC (2000)

Table A6–18 CO_2 Emission Factors for Iron and Steel Industry

Parameter	Emission Factor	Unit
Iron ore reduction with coke	3.2–3.3[1]	t CO_2/t (tonne) coke used
Electrode consumption in electric arc furnaces	4.53[2]	kg CO_2/ t steel
Electrode consumption in basic oxide furnaces	0.23[2]	kg CO_2/ t steel

Notes:

1. Year-specific emission factors provided in Cheminfo Services (2010)
2. Provided by the Canadian Steel Producers Association. Chan K. 2009. Personal communication (email from Chan K to Pagé M, Environment Canada, dated July 21, 2009). Canadian Steel Producers Association.

Table A6–19 Tier 1 Emission Factors for Aluminium Production

Cell Technology Type	Emission Factors[1]		
	CO_2	Carbon Tetrafluoride (CF_4)	Carbon Hexafluoride (C_2F_6)
Side-worked pre-baked	1 600	1.6	0.4
Centre-worked pre-baked	1 600	0.4	0.04
Horizontal stud Söderberg	1 700	0.4	0.03
Vertical stud Söderberg	1 700	0.8	0.04

Note:

1. IAI (2006)

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Table A6–20 CO_2 Emission Factors for Non-energy Use of Natural Gas Liquids and Petroleum Products

Product	Fraction of Carbon Stored in Product	CO_2 Emission Factor (g CO_2/L)
Natural Gas Liquids		
Propane	0.8[1]	303[2]
Butane	0.8[1]	349[2]
Ethane	0.8[1]	197[2]
Petroleum Products		
Petrochemical Feedstocks[3]	0.8[1]	500[7]
Naphthas[4]	0.75[1]	625[7]
Lubricating Oils and Greases[5]	0.5[1]	1 410[7]
Petroleum Used for Other Products[6]	0.5[1]	1 450[7]

Notes:

1. IPCC/OECD/IEA (1997)
2. McCann (2000)
3. Carbon factor for Petrochemical Feedstocks is 680 g of carbon per litre (C/L) (Jaques 1992)
4. Carbon factor for Napthas is 680 g C/L (Jaques 1992)
5. Carbon factor for Lubricating Oils and Greases is 770 g C/L (Jaques 1992)
6. Carbon factor for Petroleum Used in Other Products is 790 g C/L (Jaques 1992)
7. The resulting CO_2 emission factor is calculated by multiplying the carbon factor for each product by the molecular weight ratio between CO_2 and Carbon (44/12) and by (1-fraction of carbon stored in product).

Table A6–21 Emission Factors for the use of PFCs, SF_6 and NF_3 in the Electronics Industry

Application	GHG Source	IPCC Tier	Emission Rate (%)	By-Product Emission Rate
Integrated Circuit or Semiconductor Manufacturing	CF_4	T2B - CVD	80[1]	N/A[1]
	CF_4	T2B - Etching	70[1]	N/A[1]
	C_2F_6	T2B - CVD	70[1]	0.1 kg CF_4 / kg C_2F_6[1]
	C_2F_6	T2B - Etching	40[1]	0.1 kg CF_4 / kg C_2F_6[1]
	c-C_4F_8	T2B - Etching	30[1]	N/A[1]
	SF_6	T2A	20[2]	N/A[2]
	NF_3	T2A	20[2]	0.09 kg CF_4 / kg NF_3[2]
	NF_3	T2B - Etching	20[3]	N/A[2]
Other Emissive Applications	PFCs	T2	50% first year / 50% second year[1]	N/A

Notes:

1. IPCC/OECD/IEA (1997)
2. IPCC (2006)
3. Cheminfo Services (2014)

of natural gas liquids and non-energy petroleum products, respectively. The emission factors for NEU petroleum coke are found in Table A6–5. The 2011 emission-factor value for Upgrading Facilities in Table A6–5 has been used for Ontario across the time series. For the other provinces, the 2011 emission-factor value for Refineries and Others is used across the time series. The emission factors associated with NEU of coal are referenced in Table A6–8.

A6.2.5. Electronics Industry

The use of perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) in integrated circuit or semiconductor manufacturing, electrical environmental testing, gross leak testing and thermal shock testing create GHG emissions of their respective source gases. The use of PFCs and NF_3 in the integrated circuit or semiconductor manufacturing industry can also lead to by-product PFC emissions. The emission factors used for the use of PFCs, SF_6 and NF_3 in the electronics industry is summarized in Table A6–21.

A6.2.6. Product Uses as Substitutes for Ozone Depleting Substances

The use of halocarbons in various applications, such as air conditioning (AC), refrigeration, aerosols, foam blowing, solvents and fire extinguishing, can result in hydrofluorocarbon (HFC) and PFC emissions.

Table A6–22 and Table A6–23 summarize emission rates used to estimate HFC and PFC emissions.

Table A6–22 HFC as ODS Substitute – Assembly, In-Service and End-of-Life Emission Factors (%)

Sub-category	Assembly (%)	In-Service (%)	End-of-Life (%)	Life Time (years)
Aerosols[1]	0	50% of orginal	-	2
Blowing agent in foams[1]				
Open cell foam	100	-	-	-
Closed cell foam	10	4.5	100	23
Air conditioning (Original Equipment Manufacture)[2]				
Air conditioner units in motor vehicles	0.5	10	75	13
Chillers (specify centrifugal or reciprocating)	1	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	1	4	20	17
Air conditioning (Service / Maintenance)[2]				
Air conditioner units in motor vehicles	-	10	75	13
Chillers (specify centrifugal or reciprocating)	-	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	-	4	20	17
Refrigeration (Original Equipment Manufacture)[2]				
Commercial transport	1	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	1	10	30	17
Industrial (warehouses, process equipment, etc.)	1	10	30	17
Residential (freezers, refrigerators)	0.6	0.5	30	15
Other equipment (specify)	1	10.8	30	15
Refrigeration (Service / Maintenance)[2]				
Commercial transport	-	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	-	10	30	17
Industrial (warehouses, processes, etc.)	-	10	30	17
Residential (refrigerators, freezers, etc.)	-	0.5	30	15
Other equipment (specify)	-	10.1	30	15
Solvent[1]	0	50% of orginal	-	2
Fire suppression / extinguishing systems (Original Equipment Manufacture)[1]				
Portable (mobile) systems	-	4	-	18
Total Fflooding (fixed) systems	-	2	-	18
Fire suppression / extinguishing systems (Service /Maintenance)[1]				
Portable (mobile) systems	-	4	-	18
Total flooding (fixed) systems	-	2	-	18
Miscellaneous[1]	-	50% of orginal	-	2
Other (specify)[1]	-	50% of orginal	-	2

Notes:
1. IPCC (2006)
2. Environment Canada (2015)

Table A6–23 PFC as ODS Substitute – Assembly, In-Service and End-of-Life Emission Factors (%)

Application	PFC Emission Rate (%)
Assembly	
Residential Refrigeration Equipment	3.5% (of charge)[1]
Commercial Refrigeration Equipment	
Stationary AC Equipment	3.5% (of charge)[1]
Mobile AC Equipment	4.5% (of charge)[2]
Operation	
Residential Refrigeration Equipment	17% (of stock in existing systems)
Commercial Refrigeration Equipment	17% (of stock in existing systems)
Stationary AC Equipment	17% (of stock in existing systems)
Mobile AC Equipment	30% (of stock in existing systems)
Other Applications	
Foam Blowing – open cell	100% (of use)
Foam Blowing – closed cell	10% of charge released during manufacturing and 4.5% of the original quantity charge released per year over the product's lifetime
Solvents	50% (of use) in the first year and the other 50% (of use) in the second year

Notes:

1. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* provide two ranges for values: 2–3% and 4–5%. The mid-point of the two ranges was used. (IPCC/OECD/IEA 1997).
2. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* provide a range of 4–5% as values. The average value was used. (IPCC/OECD/IEA 1997).

A6.3. Other Product Manufacture and Use

The uses of N_2O as an anaesthetic and as a propellant result in N_2O emissions. The emission factors used are shown Table A6–24

The use of PFCs in contained applications (such as electronic insulation and dielectric coolant for heat transfer) results in PFC emissions. The emission factors used are shown in Table A_6–26.

The use of urea-based diesel exhaust fluid (DEF) in diesel vehicles equipped with selective catalytic reduction (SCR) systems results in CO_2 emissions, the rate of which is dependent on the purity factor of urea in DEF as well as the dosing rate of urea to diesel consumption as per Table A_6–25.

Table A6–24 Emission Factors for N_2O Usage (Medical & Propellant)

Product	Application	N_2O Emission Rate (%)
N_2O Use	Anaesthetic Usage	100
	Propellant Usage	100

Source: IPCC (2006)

Table A6–25 Emission Factors for Use of Urea in SCR Vehicles

Product	DEF Purity	Dosing Rate
Urea use in SCR Vehicles	32.50%	2% of diesel consumption

Note:
Source: IPCC (2000)

Table A6–26 Emission Factors for PFC Emissions from Other Contained Product Uses

Process	PFC Emissions from Other Contained Sources
Assembly	1% (of charge)
Annual Leakage Rate	2% (of stock)
Disposal	98% (of remaining stock)

Note:
Source: IPCC (2000)

Table A6–27 Methane Emission Factors for Enteric Fermentation for Non-Cattle Animals

Non-cattle Animal Category	Enteric Fermentation Emission Factor[1] ($kg\ CH_4$/head/year)
Pigs	
Boars	1.5
Sows	1.5
Pigs < 20 kg	1.5
Pigs 20–60 kg	1.5
Pigs > 60 kg	1.5
Other Livestock	
Sheep	8
Lambs	8
Goats	5
Horses	18
Bison	55
Llamas & Alpacas	8
Elk & Deer	20
Wild Boars	1.5
Fox	N/A
Mink	N/A
Rabbits	N/A
Mules and Asses	10
Poultry	
Chickens	N/A
Hens	N/A
Turkeys	N/A

Notes:

1. Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Table 10.10

N/A = Not available

Table A6–28 Methane Emission Factors for Manure Management for Elk and Deer, Rabbits, Fox and Mink, Mules and Asses[1]

Livestock	CH_4 Emission Factor (kg CH_4 $head^{-1}$ yr^{-1})
Elk and Deer	0.22
Rabbits	0.08
Fox	0.68
Mink	0.68
Mules and Asses	0.76

1. Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Table 10.16

A6.4. Agriculture

The sources of agricultural GHGs are enteric fermentation, manure management, field burning of crop residues, agricultural soils, and agricultural use of lime, urea and other-carbon containing fertilizers. As a result of the implementation of the 2006 IPCC Guidelines, several new emission sources have been included in the Agriculture Sector. Nitrous oxide emissions from mineralization/immobilization associated with loss/gain of soil organic matter are now included, calculated using country-specific emission factors as derived in Annex 3.4 for direct emissions from agricultural soils. Carbon dioxide emissions from liming, urea application and other carbon-containing fertilizers are calculated based on the total quantity of C contained in these products. Ammonia emissions from synthetic N application are estimated using a country specific modelling method as noted in Annex 3.4. Finally, indirect emissions from ammonia volatilization and nitogen leaching are calculated based on the IPCC default emission factors of 0.01 kg N_2O-N kg-1 N and 0.0075 kg N_2O-N kg-1 N, respectively.

Methodologies for generating country-specific emission factors for enteric fermentation (cattle only), manure management, and agricultural soil emission estimates are detailed in Section A3.4. Certain default parameters used in Tier 2 calculations and Tier 1 emission factors are provided in Table A_6–27 to Table A6–31.

Table A6–29 Maximum Methane-Producing Potential (B_0) by Animal Category[1]

Animal Category	Maximum CH_4-Producing Potential (B_0) (m^3/kg VS)[4]
Dairy Cattle[2]	0.24
Non-dairy Cattle[3]	0.19
Sheep	0.19
Goats	0.18
Horses	0.3
Swine	0.48
Hens	0.39
Broilers	0.36
Turkeys	0.36

Notes:

1. Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9
2. Dairy cattle include dairy cows and dairy heifers.
3. The non-dairy cattle value is also used for bison.
4. VS = volatile solids

Table A6–30 Methane Conversion Factors (MCFs) by Animal Category and Manure Management System[1]

Animal Categories	Liquid Systems (MCF_L)	Solid Storage and Drylot (MCF_{SSD})	Pasture, Range and Paddock (MCF_{PRP})	Other Systems (MCF_O)
Dairy Cattle	0.2	0.02	0.01	0.01
Non-dairy Cattle[2]	0.2	0.02	0.01	0.01
Swine	0.2	0.02	0.01	0.01
Poultry	0.2	0.015	0.015	0.015
Horses	NA	0.01	0.01	0.01
Goats	NA	0.01	0.01	NA
Sheep	0.2	0.01	0.01	0.01
Lambs	0.2	0.01	0.01	0.01

Notes:

1. IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9 (cool climate, average annual temperature 12°C)
2. Non-dairy cattle values are also used for bison.

NA = Not applicable

Table A6–31 Emission Factors (EFs) for Manure Nitrogen (N) Lost as N_2O-N by Animal Category and Animal Waste Management Systems[1]

	Liquid Systems (EF_L)	Solid Storage and Drylot (EF_{SSD})	Other Systems (EF_O)
Non-dairy Cattle	0.001	0.02	0.005
Dairy Cattle	0.001	0.02	0.005
Poultry	0.001	0.02	0.005
Sheep and Lambs	0.001	0.02	0.005
Swine	0.001	0.02	0.005
Goats	0.001	0.02	0.005
Horses	0.001	0.02	0.005
Mules and Asses	0.001	0.02	0.005
Buffalo	0.001	0.02	0.005

Notes:

1. Source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Uses, Table 10.21

A6.5. Land Use, Land-Use Change and Forestry

The IPCC Tier 2 and Tier 3 methods and country-specific parameters are used for generating estimates for most of the LULUCF Sector. The CBM-CFS3 model is used for estimating growth, litter fall, tree mortality and decomposition, as well as the effects of natural disturbances for Forest Land. For Cropland, a process model (CENTURY) is used for estimating CO_2 emissions and removals as influenced by management activities, based on the National Soil Database of the Canadian Soil Information System. More detail on methods, emission factors and parameters for Forest Land and Cropland is provided in Annex 3.5.

As a result of the implementation of the 2006 IPCC Guidelines, new emission sources have been included in the LULUCF Sector. Notably, emissions from the use and disposal of Harvested Wood Products (HWP) were estimated and reported under the new LULUCF subsector (Harvested Wood Products, Chapter 6, Section 6.4). In addition, CO_2 emission estimates from the off-site decay of extracted peat are now reported in the Wetlands category and

CO_2 removal estimates were revised for the Settlements category due to the implementation of a country-specific methodology.

A6.6. Biomass Combustion

A6.6.1. CO_2

Emissions of CO_2 from the combustion of biomass (whether for energy use, from prescribed burning or from wildfires) are not included in National Inventory totals. These emissions are estimated and recorded as a loss of biomass stock in the Land Use, Land-use Change and Forestry (LULUCF) Sector.

The emissions related to energy use are reported as memo items in the common reporting format (CRF) tables as required by the United Nations Framework Convention on Climate Change (UNFCCC). The emissions related to energy use are reported as memo items in the common reporting format (CRF) tables as required by the United Nations Framework Convention on Climate Change (UNFCCC).

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The CO_2 emission factor (Table A6–32) for industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (one million British thermal units; U.S. EPA 2003). The U.S. EPA data were converted to kg/tonne at 50% moisture content (m.c.) using a higher heating value (HHV) of 10.47 MJ/kg at 50% m.c., which was developed from an internal review of available moisture content and heating value data. The emission factor for spent pulping

Table A6–32 Emission Factors for Biomass

Source[1]	Description	Emission Factor (g/kg fuel)		
		CO_2	CH_4	N_2O
Wood Fuel / Wood Waste	Industrial Combustion	840[4]	0.09[4]	0.06[4]
Forest Wildfires	Open Combustion	NA	NA[2]	NA[3]
Controlled Burning	Open Combustion	NA	NA[2]	NA[3]
Spent Pulping Liquor	Industrial Combustion	891[5]	0.02[6]	0.02[6]
Stoves and Fireplaces	Residential Combustion			
Conventional Stoves		1 539[6]	12.9[6]	0.12[6]
Conventional Fireplaces and Inserts		1 539[6]	12.9[6]	0.12[6]
Stoves/Fireplaces with Advanced Technology or Catalytic Control		1 539[6]	5.9[6]	0.12[6]
Pellet Stove		1 652[4]	4.12[6]	0.059[6]
Other Wood-burning Equipment		1 539[6]	4.12[6]	0.059[6]

Notes:

1. CO_2 emissions from biomass combusted for energy or agricultural purposes are not included in inventory totals, whereas CH_4 and N_2O emissions from these sources are inventoried under the Energy Sector. All greenhouse gas (GHG) emissions, including CO_2 emissions from biomass burned in managed forests (wildfires and controlled burning), are reported under Land-Use, Land-use Change and Forestry (LULUCF) and excluded from national inventory totals.
2. Emission ratio for CH_4 is 1/90th CO_2. See Section A3.4 in Annex 3.
3. Emission ratio for N_2O is 0.017% CO_2. See Section A3.4 in Annex 3.
4. Adapted from U.S. EPA (2003).
5. Adapted from NCASI (2010).
6. Adapted from IPCC (2006).

NA = not applicable

liquor is calculated from data collected by the National Council for Air and Stream Improvement (NCASI), based on carbon content assuming a 1% correction for unoxidized carbon (NCASI 2010). The NCASI emission factors were reported in units of kg/GJ HHV, which was converted to kg/tonne at 50% m.c. based on the same HHV vs. moisture content relationship used to convert wood waste.

CO_2 emission factor for residential combustion (Table A6–32) is based on the default 2006 IPCC guidelines. The IPCC data were converted to g/kg at 19% moisture content using a lower heating value (LHV) of 13.2 MJ/kg, which was calculated based on the assumption that LHV is 20% less than the HHV (FPL, 2004). The HHV was developed from an internal review of available moisture content and heating value data.

CO_2 emissions occur during forest wildfires and from controlled burning during forest conversion activities. The carbon emitted as CO_2 (CO_2-C) during forest fires is considered in the forest carbon balance, whereas the CO_2-C emitted during controlled burns is reported under the new land-use categories. There is no unique CO_2 emission factor applicable to all fires, as the proportion of CO_2-C emitted for each pool can be specific to the pool, the type of forest and disturbance, and the ecological zone (see Section A3.5).

A6.6.2. CH_4

Emissions of CH_4 from residential combustion of firewood are technology-dependent. The CH_4 emission factors are based on the default 2006 IPCC guidelines. The IPCC values were converted to g/kg at 19% m.c. using the same method used for the CO_2 conversion.

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The emission factor (Table A6–32) for CH_4 from industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA 2003) and converted to kg/tonne at 50% m.c. as discussed in Section A6.6.1 above. The emission factor for CH_4 from spent pulping liquor is adapted from the IPCC (2006). It is converted from the units reported in the IPCC (kg/TJ lower heating value [LHV]) to kg/tonne at 50% m.c. based on the assumption that the LHV is 20% lower than the HHV along with the same HHV vs. moisture content relationship discussed in Section A6.6.1.

Emission factors from landfill gas (Table A6–33) are adapted from the IPCC (2006).

Emissions of carbon as CH_4 (CH_4-C) from wildfires and controlled burning are always equal to 1/90th of CO_2-C emissions.

Table A6–33 Emission Factors for Landfill Gas Combustion

Source	Description	Emission Factor (kg /t)		
		CO_2	CH_4	N_2O
Landfill Gas	Industrial Combustion	2 752	0.05	0.005

Source: Adapted from IPCC (2006), Volume 2, Energy, Table 2.2

A6.6.3. N_2O

Emissions of N_2O from residential combustion of firewood are technology-dependent. The N_2O emission factors are based on the default 2006 IPCC guidelines. The IPCC values were converted to g/kg at 19% m.c. using the same method used for the CO_2 conversion.

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. Emission factors (Table A6–32) for industrial wood waste have been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA 2003) and converted to kg/tonne at 50% m.c. as discussed in Section A6.6.1 above. The emission factor for CH_4 from spent pulping liquor is adapted from the IPCC (2006). It is converted from the units reported in the IPCC (kg/TJ LHV) to kg/tonne at 50% m.c. based on the assumption that the LHV is 20% lower than the HHV along with the same HHV vs. moisture content relationship discussed in A6.6.1.

Emission factors for landfill gas (Table A6–33) are adapted from the IPCC (2006).

N_2O emissions from wildfires and controlled burning are equal to 0.017% vol/vol of CO_2 emissions. Since both gases have the same molecular weight, the same ratio can be applied on a mass basis (see Section A3.5.2).

A6.7. Waste

A6.7.1. Municipal Wastewater Handling – Wastewater

A6.7.1.1. CH_4

Emissions from municipal wastewater handling are dependent upon the organic loading of the effluent stream, population and the type of wastewater treatment provided. The emission factor in this case is the product of the methane correction factor (MCF), which is an estimate of the fraction of biological oxygen demand (BOD) that will ultimately degrade anaerobically (MCF) and the maximum methane producing capacity (B_0), which is expressed in terms of kg CH_4/kg BOD removed. On the basis of a recent study by AECOM Canada (2010), commissioned by Environment Canada, it is recommended that the following country-specific values be used: an MCF of 0.3, which is a blended category that represents the Canadian proportion of septic tanks, anaerobic lagoons and untreated effluents as well as the degree of degradation of the organics expected of the treatment or discharge; and a B_0 of 0.36 kg CH_4/kg BOD_5. Therefore, the emission factor is 0.108 kg CH_4/kg BOD_5.

The IPCC default emission factor of 0.6 kg CH_4/kg BOD was not used, as the AECOM study confirmed that its derivation from the 0.25 kg CH_4/kg COD was erroneous, where COD is the chemical oxygen demand.

A6.7.2. Municipal Wastewater Handling – Human Sewage

A6.7.2.1. N_2O

N_2O emissions from human sewage are a function of protein consumption per capita, population and the nitrogen content in protein. The emission factor used is the IPCC default value of 0.01 kg N_2O-N/kg sewage-N (IPCC/OECD/IEA 1997).

A6.7.3. Waste Incineration

A6.7.3.1. CH_4 from Sewage Sludge Incinerators

CH_4 emissions from sewage sludge incinerators are estimated from an emission factor of 1.6 kg CH_4/tonne of dry sludge, which is obtained from the U.S. EPA (1995).

A6.7.3.2. N_2O from MSW Incinerators

The emission estimates from municipal solid waste (MSW) incineration are calculated from an average IPCC default emission factor for MSW five-stoker facilities of 0.148 kg N_2O/tonne of waste (IPCC/OECD/IEA 1997). For wastewater sludge incineration, the emission factor is taken from the IPCC Good Practice Guidance and has the value of 0.8 kg N_2O/tonne of dry sludge.

A6.7.3.3. CH_4 from Hazardous and Clinical Waste Incinerators

In the absence of an IPCC default value, the emission factor used for the estimation of CH_4 from hazardous waste incinerators is based on country-specific measured emissions from data obtained from a facility in Canada that responded to a biennial survey conducted by Environment Canada on waste incineration (Environment Canada 2010). On the basis of the CH_4 emitted and the hazardous waste quantities incinerated in 2009, an emission factor of 1.695 x 10-4 kt CH_4/kt of hazardous waste was estimated. For clinical waste incinerators, the default CH_4 emission factors from Volume 5, Chapter 5, Table 5.3 of the 2006 IPCC Guidelines (IPCC 2006) for stoker type continuous and batch type incineration of 0.2 kg/Gg waste and 60 kg/Gg waste, respectively, were applied.

A6.7.3.4. N_2O from Hazardous and Clinical Waste Incinerators

In the absence of an IPCC default value, similarly to the description in Section A6.7.3.3 regarding the calculation of CH_4 from this source, the N_2O emission factor is based on the set of data from the same facility (Environment Canada 2010). On the basis of the N_2O emitted and the hazardous waste quantities incinerated in 2009, an emission factor of 3.164x 10-4 kt CH_4/kt of hazardous waste was estimated. For clinical incinerators, the default N_2O emission factors from Volume 5, Chapter 5, Table 5.6 of the 2006 IPCC Guidelines (IPCC 2006) for stoker type continuous and batch type incineration of 50 g N_2O/t waste and 60 g N_2O/t waste, respectively, were applied.

A6.7.3.5. CO_2 from Hazardous and Clinical Waste Incinerators

For the estimation of the emission factor for CO_2 emissions from hazardous waste incineration, the IPCC default values (IPCC 2000) are used for the carbon content of 50% and percent fossil carbon content over total carbon of 90% for hazardous waste. The emission factor is then 1.65 kt CO_2/kt hazardous waste. For clinical waste incineration, the emission factor is based on the IPCC default carbon content and fossil carbon percent of total carbon of 60% and 40%, respectively (IPCC 2006 Volume 5 Chapter 5 Table 5.2).

Annex 7

Ozone and Aerosol Precursors

Information on Canada's ozone and aerosol precursors, including carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO_x) is available on Environment and Climate Change Canada's website.[1] As recommended by the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (FCCC/CP/2013/10/Add.3 – UNFCCC 2013), Annex I Parties should provide information on indirect greenhouse gases (GHGs) such as CO, NO_x, NMVOC and SO_x in the National Inventory Report.

While these gases do not have a direct global warming effect, they either influence the creation and destruction of tropospheric and stratospheric ozone or affect terrestrial radiation absorption, as in the case of SO_x. These gases can impact the climate by acting as short-lived GHGs, alter atmospheric lifetimes of other GHGs and form GHGs, as in the case of CO reacting with a hydroxyl radical to form CO_2 in the atmosphere. These emissions are produced by a number of sources, such as fossil fuel combustion in the energy and transportation sectors, industrial production and biomass combustion.

National emission summaries for key air pollutants, along with historical national emission trends, are also available on Environment and Climate Change Canada's website.

1 Canada's Air Pollutant Emission Data can be found at http://ec.gc.ca/pollution/default. asp?1ang= ang=En&n=E9645OC4-1.

REFERENCES

Annex 1, Key Categories

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

Annex 2, Uncertainty

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

Annex 3.1, Methodology and Data for Estimating Emissions from Fossil Fuel Combustion

[AMS] Aircraft Movement Statistics. 2015. Ottawa (ON): Statistics Canada. Data base extracts from Conrad Ogrodnik from Statistics Canada for years Nov. 1, 1996 to 2014; Transport Canada personnel for years 1990 to Oct 31, 1996.

Alemdag IS. 1984. Wood density variation of 28 tree species from Ontario. Petawawa National Forestry Institute. Agriculture Canada. Canadian Forestry Service. Information Report PI-X-45. 12 pp.

[BADA] Base of Aircraft Data. 2009. Version 3.7. France. Eurocontrol Experimental Centre. Available online at: www.eurocontrol.int.

Cadieux JY. 2006. AMS Lookup Tables. Transport Canada.

Canadian Facts. 1997. Residential Fuelwood Combustion in Canada. Canadian Facts. Prepared for the National Emission Inventory and Project Task Group. Toronto (ON): CF Group Inc.

[CIEEDAC] Canadian Industrial Energy End-use Data Analysis Centre. 2013. Database on Energy, Production and Intensity Indicators for Canadian Industry. NAICS 327310 Cement Manufacturing. [cited 2013 Dec 16]. Available online at: http://www3.cieedac.sfu.ca/CIEEDACweb/mod.php?mod=NAICSPublic&menu=1602.

DesRosiers. Canadian Vehicles in Operation Census (CVIOC). Annual reports prepared by DesRosiers Automotive Consultants.

[EMEP/CORINAIR] European Monitoring and Evaluation Programme/The Core Inventory of Air Emissions in Europe. 2006. EMEP/CORINAIR Emission Inventory Guidebook. Group 8. Air Traffic. Version 2.3. European Environment Agency. Available online at: http://www.eea.europa.eu/publications/EMEPCORINAIR4/page017.html.

Environment Canada. 2014. Residential Fuelwood Consumption in Canada. Unpublished report. Prepared by K. Tracey, Pollutant Inventories and Reporting Division, Environment Canada. Gatineau (QC).

[FAA] Federal Aviation Administration. 2009. FAA Airports. Available online at: http://www.faa.gov/airports/airport_safety/airportdata_5010/.

Fleming G. 2008a. Canada OD Pairs grt10flts.xls. Federal Aviation Administration.

Fleming G. 2008b. SAGE Airport Codes and Locations. Federal Aviation Administration.

Fleming G. 2008c. $CAEP_8$ Goals Operations Round 1. Modelling and Database Task Force.

[FOCA] Federal Office of Civil Aviation. 2007. Aircraft Piston Engine Emissions Summary Report. Swiss Confederation: Federal Department of the Environment, Transport, Energy and Communications. 13 June 2007. Catalogue No. 0/3/33/33-05-003.022.

Gonzalez JS. 1990. Wood Density of Canadian Tree Species. Forestry Canada, Northwest Region. Northern Forestry Centre. Edmonton, AB. Information Report NOR-X-315. 130 pp.

Hagstrom M. 2010. TPengs FOI orig comp data 031105 corr 071129 Jason Hickey 13 June 2010. Stockholm (SE): Department of Systems Technology, Swedish Defence Research Agency.

[ICAO] International Civil Aviation Organization. 2008. ICAO Carbon Emissions Calculator. Report on Methodology.

[ICAO] International Civil Aviation Organization. 2009. ICAO Engine Emissions Databank. Version 16A. Civil Aviation Authority. Available online at: http://easa.europa.eu/document-library/icao-aircraft-engine-emissions-databank.

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, editors. Kanagawa (JP): Institute for Global Environmental Studies. Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

Jessome AP. 2000. Strength and Related Properties of Woods Grown in Canada. Forintek Canada Corp. Publication SP-114E. 37 pp.

Manning G. 2007. [Excel spreadsheet model]. From Gillian's work V_3. Version 3. Environment Canada.

Maples JD. 1993. The Light-Duty Vehicle MPG Gap: Its Size Today and Potential Impacts in the Future. Knoxville (TN): University of Tennessee, Transportation Centre.

McCann TJ. 2000. 1998 Fossil Fuel and Derivative Factors. Prepared by TJ McCann and Associates Ltd. and Clearstone Engineering Ltd. for Environment Canada.

[MOVES2014] Motor Vehicle Emission Simulator [Estimation Model]. 2014. Washington (DC): U.S. Environmental Protection Agency, Office of Transportation and Air Quality. Available online at: http://www3.epa.gov/otaq/models/moves/#downloading-2014a.

NAV Canada. 2009. Canada Flight Supplement. Ottawa (ON): NAV Canada.

[NRCan] Natural Resources Canada. 2010. Transportation End-Use Model (FCR Calculations). Natural Resources Canada.

[NRCan] Natural Resources Canada. 2015. CEUD 2014 Update [excel file], updated November 17, 2015.

Polk RL. 2013. Vehicles in Operation (VIO) Database. Compiled by R.L. Polk and Co., Southfield (MI).

Statistics Canada. 2015. Electric Power Thermal Generating Station Fuel Consumption Survey. CANSIM: tables 127-0004 to 127-0006. Available online at: http://www5.statcan.gc.ca/cansim/home-accueil?lang=eng.

Statistics Canada. 2013. Annual Industrial Consumption of Energy Survey. Questionnaire available online at: http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5047&Item_Id=44545&lang=en%20.

Statistics Canada. 1997. Household Facilities and Equipment (1990-1997). Household Surveys Division. Statistics Canada. #64-202 (discontinued).

Statistics Canada. 2009. Spending Patterns in Canada (1998-2009). Income Statistics Division. Statistics Canada. Catalogue No. 62-202 (discontinued).

Statistics Canada. CANSIM Database Table 405-0001: Road Motor Vehicle, Trailer and Snowmobile Registration, Terminated, Annual (number). Available online at: http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=4050001.

Statistics Canada. CANSIM Database Table 405-0004: Road Motor Vehicles, Registrations, Annual (number). Available online at: http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=4050004.

Statistics Canada. CANSIM Database Table 405-0002: Road Motor Vehicles, Fuel Sales, Annual (Litres). Available online at: http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=4050002&&pattern=&stByVal=1&p1=1&p2=31&tabMode=dataTable&csid=.

Statistics Canada. Canadian Vehicle Survey (CVS). (Annual). Catalogue No.53-223-XIE.

Statistics Canada. Report on Energy Supply and Demand in Canada (Annual). Catalogue No. 57-003-XIB.

Stewart Brown Associates. 2013. Kilometre Accumulation Rates in British Columbia and Ontario. Prepared for Environment Canada.

TFIS Inc. 2011. Canadian Liquid Transportation Biofuels Production and Consumption Information. Unpublished report prepared by TFIS Inc for the Greenhouse Gas Division, Environment Canada.

[TNS] TNS Canadian Facts. 2006. Residential Fuelwood Combustion in Canada. Presented to Environment Canada. Report C1077/BT. Toronto (ON): TNS Global.

[TNS] TNS Canada. 2012. Residential Fuelwood Combustion in Canada. Presented to Natural Resources Canada. Report 1381/BT. Toronto (ON): TNS Canada.

[U.S. EPA] United States Environmental Protection Agency. 2015. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2013. Washington (DC): U.S. Environmental Protection Agency.

[WBCSD] World Business Council for Sustainable Development. 2005. CO_2 Emissions Inventory Protocol. Version 2.0. Cement Sustainability Initiative.

Wiesen P, Kleffmann J, Kurtenbach R, Becker KH. 1994. Nitrous oxide and methane emissions from aero engines. Geophysical Research Letters 21(18):2027–2030.

Annex 3.2, Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution

[AER] Alberta Energy Regulator. 2016a. AER Compliance Dashboard – Incidents. [cited 2016 Aug 16]. Available online at: http://www1.aer.ca/compliancedashboard/incidents.html.

[AER] Alberta Energy Regulator. 2016b. Alberta's Energy Reserves 2015 and Supply/Demand Outlook 2016–2025: ST98-2016. Available online at: http://www.aer.ca/data-and-publications/statistical-reports/st98.

[AER] Alberta Energy Regulator. 2016c. Alberta Mineable Oil Sands Plant Statistics, Monthly Supplement December 2015: ST39-2015. Available online at: http://www.aer.ca/data-and-publications/statistical-reports/st39.

[BCOGC] British Columbia Oil and Gas Commission. 2016. Drilling Kicks and Blowouts by Area. Available online at: https://iris.bcogc.ca/generic_ogc/Ext_Accnt.Logon?p_ct=24102014110622.

[CAPP] Canadian Association of Petroleum Producers. 1999. CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry, Vols. 1 and 2. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering Ltd. Publication No. 1999-0010.

[CAPP] Canadian Association of Petroleum Producers. 2005a. A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emissions by the Upstream Oil and Gas Industry, Vols. 1–5. Calgary (AB): Clearstone Engineering Ltd.

[CAPP] Canadian Association of Petroleum Producers. 2005b. Extrapolation of the 2000 UOG Emission Inventory to 2001, 2002 and 2003. Calgary (AB): Clearstone Engineering Ltd.

[CAPP] Canadian Association of Petroleum Producers. 2006. An Inventory of GHGs, CACs, and H_2S Emissions by the Canadian Bitumen Industry: 1990 to 2003. Calgary (AB): Clearstone Engineering Ltd.

[CAPP] Canadian Association of Petroleum Producers. 2016. Statistical Handbook for Canada's Upstream Petroleum Industry.

[revised 2016 May; cited 2016 Aug 16]. Available online at: http://www.capp.ca/library/statistics/handbook/Pages/default.aspx.

[CGA] Canadian Gas Association. 1997. 1995 Air Inventory of the Canadian Natural Gas Industry. Calgary (AB): Radian International LLC.

Cheminfo Services Inc., and Clearstone Engineering Ltd. 2014. Compilation of a National Inventory of Greenhouse Gas and Fugitive VOC Emissions by the Canadian Coal Mining Industry. Final report submitted to the Energy Group, PIRD, Environment Canada.

[CNLOPB] Canada-Newfoundland and Labrador Offshore Petroleum Board. 2016a. Production Summary by Well – Hibernia. [cited 2016 Aug 16]. Available online at: http://www.cnlopb.ca/pdfs/hibstats/hib_oil_2015.pdf.

[CNLOPB] Canada-Newfoundland and Labrador Offshore Petroleum Board. 2016b. Production Summary by Well – Terra Nova. [cited 2016 Aug 16]. Available online at: http://www.cnlopb.ca/pdfs/tnstats/tn_oil_2015.pdf.

[CNLOPB] Canada-Newfoundland and Labrador Offshore Petroleum Board. 2016c. Production Summary by Well – White Rose. [cited 2016 Aug 16]. Available online at: http://www.cnlopb.ca/pdfs/wrstats/wr_oil_2015.pdf.

[CNLOPB] Canada-Newfoundland and Labrador Offshore Petroleum Board. 2016d. Production Summary by Well – North Amethyst. [cited 2016 Aug 16]. Available online at: http://www.cnlopb.ca/pdfs/nastats/na_oil_2016.pdf.

[CNLOPB] Canada-Newfoundland and Labrador Offshore Petroleum Board. 2016e. Environment Statistics – Spill Frequency and Volume Annual Summary. [cited 2016 Aug 16]. Available online at: http://www.cnlopb.ca/pdfs/spill/sumtab.pdf.

[CPPI] Canadian Petroleum Products Institute. 2004. Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production. Calgary (AB): Levelton Consultants Ltd. in association with Purvin & Gertz Inc.

Environment Canada. 2007. Bitumen-Oil Sands Extrapolation Model – Rev 3. Calgary (AB): Clearstone Engineering Ltd.

Environment Canada. 2014. Technical Report on Canada's Upstream Oil and Gas Industry. Vols. 1–4. Prepared for Environment Canada. Calgary (AB): Clearstone Engineering Ltd.

[GRI] Gas Research Institute. 2000. Vented Emissions from Maintenance at Natural Gas Distribution Stations in Canada. Austin (TX): Radian International LLC.

Hollingshead B. 1990. Methane Emissions from Canadian Coal Operations: A Quantitative Estimate. Devon (AB): Coal Mining Research Company. Report CI 8936.

[IPCC 2006] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, editors. Kanagawa (JP): Institute for Global Environmental Studies. Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

King B. 1994. Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options. Report prepared by Neill and Gunter for Environment Canada.

[NEB] National Energy Board. 2016. 2015 Estimated Production of Canadian Crude Oil and Equivalent. [revised 2016 Sep 23; cited 2016 Nov 1]. Available online at: http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/sttstc/crdlndptrlmprdct/stmtdprdctn-eng.html.

ORTECH Consulting Inc. 2013. Canadian Natural Gas Companies 2005 and 2011 Greenhouse Gas and Criteria Air Contaminant Inventory Report and Validation by Audit. Prepared for CEPEI. Guelph (ON).

Quenneville G. 2009. Inuvik Gas operators keep town flush with power. Northern New Services. Oil & Gas Drum, October 2009. Available online at: http://www.nnsl.com/business/pdfs/oilgas/pg6.

[SK MOE] Saskatchewan Ministry of Economy. 2016a. 2015 Crude Oil Volume and Value Summary. [revised 2016 Feb 29; cited 2016 Aug 24]. Available online at: http://economy.gov.sk.ca/oilgasstatreports.

[SK MOE] Saskatchewan Ministry of Economy. 2016b. Petroleum and Natural Gas Spill Report Directory. [revised 2016 Aug 9; cited 2016 Aug 16]. Available online at: http://www.publications.gov.sk.ca/details.cfm?p=70964.

Statistics Canada. 1999–2002. Coal and Coke Statistics. Catalogue No. 45-002-X. Available online at: http://www5.statcan.gc.ca/olc-cel/olc.action?objId=45-002-X&objType=2&lang=en&limit=0.

Statistics Canada. 2003– . Report on Energy Supply and Demand in Canada. Catalogue No. 57-003-X. Available online at: http://www5.statcan.gc.ca/olc-cel/olc.action?objId=57-003-X&objType=2&lang=en&limit=0.

Statistics Canada. 2016a. Table 131-0001 – Historical supply and disposition of natural gas, monthly (cubic metres). CANSIM. Available online at: http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=1310001&tabMode=dataTable&srchLan=-1&p1=-1&p2=9.

Statistics Canada. 2016b. Table 126-0001 – Historical supply and disposition of crude oil and equivalent, monthly (cubic metres). CANSIM. Available online at: http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=1260001&tabMode=dataTable&srchLan=-1&p1=-1&p2=9.

Annex 3.3, Methodology for Industrial Processes

AMEC. 2006. Identifying and Updating Industrial Process Activity Data in the Minerals Sector for the Canadian Greenhouse Gas Inventory. Unpublished report. Mississauga (ON): AMEC Earth & Environmental, a division of AMEC Americas Ltd.

Cheminfo Services. 2005a. Improvements to Canada's Greenhouse Gas Emissions Inventory Related to Non-Energy Use of Hydrocarbon Products. Unpublished report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2005b. Improving and Updating Industrial Process-Related Activity Data and Methodologies Used in Canada's Greenhouse Gas Inventory, Hydrofluorocarbons (HFCs). Unpublished report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2006. Improvements and Updates to Certain Industrial Process and Solvent Use-Related Sections in Canada's Greenhouse Gas Inventory. Unpublished report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2010. Study of Potential Additions and Updates to the Industrial Process Sources of GHGs in the Canadian GHG Inventory, and Development of Canadian-Specific Methodologies and Emission Estimates for such Sources. Final Report. Markham (ON): Cheminfo Services Inc.

[CSPA] Canadian Steel Producers Association. 2009. Industry-average pig iron content. Unpublished, confidential data.

[CSPA] Canadian Steel Producers Association. 2013–2015. Annual Canadian Iron and Steel Production and Disposition Data. Unpublished data.

[EHS] Environmental Health Strategies Inc. 2013. Report on Emission Factors for HFCs in Canada. Unpublished report. Toronto (ON): Environmental Health Strategies Inc. Prepared for Environment Canada.

Environment Canada. 2001. Environmental Code of Practice for Integrated Steel Mills. Available online at: https://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=30360F3C-1&offset=5&toc=hide#t1_1.

Environment Canada. 2011. Data collected under the *Canadian Environmental Protection Act, 1999*, section 71: *Notice with respect to certain aromatic amines and aromatic azo- and benzidine-based substances*. Canada Gazette, vol. 145, no. 51. December 22, 2014 version.

Environment Canada. 2015a. 2008 – 2012 HFC sales data collected under the *Canadian Environmental Protection Act, 1999,* section 71: *Notice with respect to hydrofluorocarbons*. Canada Gazette Part 1, vol. 148, no. 16, p. 920–930. Program Development and Engagement Division. Unpublished, confidential data.

Environment Canada. 2015b. Review of Country-specific HFCs Emission Estimations in the Refrigeration and Air Conditioning Sectors. Edalatmanesh M, Niemi D. Unpublished report. Ottawa (ON).

Environment and Climate Change Canada (ECCC). 2016a. 2013 – 2014 HFC sales data collected under the *Canadian Environmental Protection Act*, 1999, section 71: *Notice with respect to hydrofluorocarbons in bulk*. Canada Gazette Part 1, vol. 150, no. 1, p 7–13. Program Development and Engagement Division. Unpublished, confidential data.

Environment and Climate Change Canada (ECCC). 2016b. 2015 HFC sales data collected under under the *Canadian Environmental Protection Act*, 1999, section 71: *Notice with respect to hydrofluorocarbons in bulk*. Canada Gazette Part 1, vol. 150, no. 24, p. 1816–1823. Program Development and Engagement Division. Unpublished, confidential data.

Environment Canada (GHG Division) and Canadian Electricity Association. 2008. SF_6 Emission Estimation and Reporting Protocol for Electric Utilities. Available online at: http://www.publications.gc.ca/site/eng/454401/publication.html.

[IAI] International Aluminum Institute. 2006. The Aluminum Sector Greenhouse Gas Protocol (Addendum to the WRI/WBCSD Greenhouse Gas Protocol). International Aluminum Institute.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: http://www.ipcc-nggip.iges.or.jp/public/gp/english/.

[IPCC] Intergovernmental Panel on Climate Change. 2006. Guidelines for National Greenhouse Gas Inventories. Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Jaques AP. 1992. Canada's Greenhouse Gas Emissions: Estimates for 1990, Environmental Protection, Conservation and Protection, Environment Canada. Report EPS 5/AP/4.

McCann TJ. 2000. 1998 Fossil Fuel and Derivative Factors. Unpublished report. Prepared by TJ McCann and Associates for Environment Canada.

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

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

Statistics Canada. 1990–2003. Primary Iron and Steel. Monthly. Catalogue No. 41-001-XIB (discontinued).

Statistics Canada. 1990–2004. Cement. Catalogue No. 44-001-XIB. Available online at: http://www5.statcan.gc.ca. (discontinued).

Statistics Canada. 1990–2007. Industrial Chemicals and Synthetic Resins. Catalogue No. 46-002-XIE. Available online at: http://www5.statcan.gc.ca. (discontinued).

Statistics Canada. 1990–2015. Report on Energy Supply and Demand in Canada. Catalogue No. 57-003-XIB. Available online at: http://www5.statcan.gc.ca.

Statistics Canada. 2004. Industrial Consumption of Energy Survey: The 1990 NAICS based estimates. Catalogue No. 57-505-XIE.

Statistics Canada. 2004–2012. Steel, Tubular Products and Steel Wire. Monthly. Catalogue No. 41 019-X (discontinued).

Statistics Canada. 2005–2014. CANSIM database. Table 303-0060: Production, Shipments and Stocks of Cement, Monthly (Metric Tonnes). Available online at: http://www5.statcan.gc.ca.

Statistics Canada. 2005–2014. CANSIM database. Table 303-0061 Destination of Shipments of Cement, Monthly (Metric Tonnes). Available online at: http://www5.statcan.gc.ca.

Annex 3.4, Methodology for the Agrculture Sector

[AAFRD] Alberta Agriculture, Food and Rural Development. 2001. Alberta Cow-Calf Audit, 1997/1998 Production Indicators and Management Practices Over the Last 10 Years. Edmonton, Alberta, Canada.

[AAFRD and University of Alberta] Alberta Agriculture, Food and Rural Development and University of Alberta. 2003. Development of a Farm-Level Greenhouse Gas Assessment: Identification of Knowledge Gaps and Development of a Science Plan. Alberta Agricultural Research Institute (AARI) Project No. 2001J204. Available online at: http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/cl9706/$FILE/ghgreport.pdf. [accessed 2015 December 4].

Agriculture and Agri-Food Canada. 1990–2011. Annual Livestock and Meat Report. Available online at: www.agr.gc.ca/redmeat-vianderouge/index_eng.htm. [accessed 2015 September 3].

Arrouays D, Saby N, Walter C, Lemercier B, Schvartz C. 2006. Relationships between particle-size distribution and organic carbon in French arable topsoils. Soil Use and Management 22:48–51.

Beauchemin KA, McGinn SM. 2005. Methane emissions from feedlot cattle fed barley or corn diets. Journal of Animal Science 83:653–661.

Beauchemin KA, McGinn SM. 2006. Enteric methane emissions from growing beef cattle as affected by diet and level of intake. Canadian Journal of Animal Science 86(3):401–408.

Beauchemin KA, McGinn SM, Benchaar C, Holtshausen L. 2009. Crushed sunflower, flax, or canola seeds in lactating dairy cow diets: Effects on methane production, rumen fermentation, and milk production. Journal of Dairy Science 92:2118–2127.

Boadi DA, Wittenberg KM. 2002. Methane production from dairy and beef heifers fed forages differing in nutrient density using the sulphur hexafluoride (SF_6) tracer gas technique. Canadian Journal of Animal Science 82:201–206.

Boadi DA, Wittenberg KM, McCaughey WP. 2002. Effects of grain supplementation on methane production of grazing steers using the sulphur (SF_6) tracer gas technique. Canadian Journal of Animal Science 82:151–157.

Boadi DA, Ominski KH, Fulawka DL, Wittenberg KM. 2004a. Improving Estimates of Methane Emissions Associated with Enteric Fermentation of Cattle in Canada by Adopting an IPCC (Intergovernmental Panel on Climate Change) Tier-2 Methodology. Final report submitted to the Greenhouse Gas Division, Environment Canada, by the Department of Animal Science, University of Manitoba, Winnipeg, MB, Canada.

Boadi DA, Wittenberg KM, Scott SL, Burton D, Buckley K, Small JA, Ominski KH. 2004b. Effect of low and high forage diet on enteric and manure pack greenhouse gas emissions from a feedlot. Canadian Journal of Animal Science 84:445–453.

Bouwman AF. 1996. Direct emission of nitrous oxide from agricultural soils. Nutrient Cycling in Agroecosystems 46:53–70.

Bouwman AF, Boumans LJM, Batjes NH. 2002a. Estimation of global NH_3 volatilization loss from synthetic fertilizers and animal manure applied to arable lands and grassland. Global Biogeochemical Cycles 16:8.1–8.15.

Bouwman AF, Boumans LJM, Batjes NH. 2002b. Emissions of N_2O and NO from fertilized fields: Summary of available data. Global Biogeochemical Cycles 16:6-1–6-13.

BPR-Infrastructure inc. 2008. Suivi 2007 du Portrait agroenvironnemental des fermes du Québec : rapport présenté au ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, à l'Union des producteurs agricoles et à Agriculture et Agroalimentaire. Available online at: http://www.mapaq.gouv.qc.ca/fr/md/Publications/Pages/Details-Publication.aspx?guid=%7B3fcc5e09-ea9f-4cfa-a4db-91beff2a993b%7D. [accessed 2015 December 4].

Canfax Research Services. 2009. Trends, Cycles and Seasonality in the Cattle Industry. Calgary (AB): Canadian Cattlemen's Association. 36 pp.

Chadwick DR, Sneath RW, Phillips VR, Pain BF. 1999. A UK inventory of nitrous oxide emissions from farmed livestock. Atmospheric Environment 33:3345–3354.

Chang C, Janzen HH. 1996. Long-term fate of nitrogen from annual feedlot manure applications. Journal of Environmental Quality 25:785–790.

Chaves AV, Thompson LC, Iwaasa AD, Scott SL, Olson ME, Benchaar C, Veira DM, McAllister TA. 2006. Effect of pasture type (alfalfa vs. grass) on methane and carbon dioxide production by yearling beef heifers. Canadian Journal of Animal Science 86(3):409–418.

Christensen DA, Steacy G, Crowe WL. 1977. Nutritive value of whole crop cereal silages. Canadian Journal of Animal Science 57:803–805.

Coote DR, Liang BC, Huffman EC. 2008. Crop residue burning in Canada. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Corre MD, Van Kessel C, Pennock DJ. 1996. Landscape and seasonal patterns of nitrous oxide emissions in a semiarid region. Soil Science Society of America Journal 60:1806–1815.

Corre MD, Pennock DJ, Van Kessel C, Elliott DK. 1999. Estimation of annual nitrous oxide emissions from a transitional Grassland–Forest region in Saskatchewan, Canada. Biogeochemistry 44:29–49.

[CRAAQ] Centre de référence en agriculture et agroalimentaire du Québec. 1999. Chèvres laitières—Budget: Production laitière. Centre de Référence en Agriculture et Agroalimentaire du Québec. Agdex 435/821. Comité de références économiques en agriculture du Québec. Group GRÉAGRI inc.

da Sylva AP, Kay BD. 1997. Estimating the least limiting water range of soils from properties and management. Soil Science Society of America Journal 61:877–883.

Decisioneering. 2000. Crystal Ball®, Decisioneering Inc., Denver, Colorado, U.S.A. Available online at: http://www.crystalball.com. [accessed 2015 December 4].

Dobbie KE, McTaggart IP, Smith KP. 1999. Nitrous oxide emissions from intensive agricultural systems: Variations between crops and seasons, key driving variables and mean emission factors. Journal of Geophysical Research 104:26891–26899.

Ellis JL, Kebreab E, Odongo NE, McBride BW, Okine EK, France J. 2007. Prediction of methane production from dairy and beef cattle. Journal of Dairy Science 90:3456–3467.

Ellis JL, Kebreab E, Odongo NE, Beauchemin K, McGinn S, Nkrumah JD, Moore SS, Christopherson R, Murdoch GK, McBride BW, et al. 2009. Modeling methane production from beef cattle using linear and nonlinear approaches. Journal of Animal Science 87:1334–1345.

Ellis JL, Bannink A, France J, Kebreab E, Dijkstra J. 2010. Evaluation of enteric methane prediction equations for dairy cows used in whole farm models. Global Change Biology 16:3246–3256.

Environment Canada. 2002. Canadian Climate Normals—Precipitation. Available online at: http://climate.weather.gc.ca/climate_normals/index_e.html. [accessed 2015 December 4].

Eugène M, Massé D, Chiquette J, Benchaar C. 2008. Meta-analysis on the effects of lipid supplementation on methane production in lactating dairy cows. Canadian Journal of Animal Science 88:331–334.

Flynn HC, Smith JO, Smith KA, Wright J, Smith P, Massheder J. 2005. Climate- and crop-responsive emission factors significantly alter estimates of current and future nitrous oxide emissions from fertilizer use. Global Change Biology 11:1522–1536.

Freibauer A. 2003. Regionalized inventory of biogenic greenhouse gas emissions from European agriculture. European Journal of Agronomy 19:135–160.

Godbout S, Verma M, Larouche JP, Potvin L, Chapman AM, Lemay SP, Pelletier F. Brar SK. 2010. Methane production potential (B_0) of swine and cattle manures – A Canadian perspective. Environmental Technology 31:1371–1379.

Goss MJ, Goorahoo D. 1995. Nitrate contamination of groundwater: measurement and prediction. Fertilizer Research 42:331–338.

Grant R, Pattey E. 1999. Mathematical modeling of nitrous oxide emissions from an agricultural field during spring thaw. Global Biogeochemical Cycles 13:679–694.

Gregorich EG, Rochette P, VandenBygaart AJ, Angers DA. 2005. Greenhouse gas contributions of agricultural soils and potential mitigation practices in eastern Canada. Soil & Tillage Research 76:1–20.

Hao X. 2007. Nitrate accumulation and greenhouse gas emissions during compost storage. Nutrient Cycling in Agroecosystems 78:189–195.

Hao X, Chang C, Carefoot JM, Janzen HH, Ellert BH. 2001a. Nitrous oxide emissions from an irrigated soil as affected by fertilizer and straw management. Nutrient Cycling in Agroecosystems 60:1–8.

Hao X, Chang C, Larney FJ, Travis GR. 2001b. Greenhouse gas emissions during cattle feedlot manure composting. Journal of Environmental Quality 30:376–386.

Hao X, Xu S, McAllister TA, Larney FJ. 2008. Antibiotics in cattle diet affect greenhouse gas emissions from manure composting. Australian Journal of Experimental Agriculture 48:342–355.

Hao X, Stanford K, McAllister TA, Larney FJ, Xu S. 2009. Greenhouse gas emissions and final compost properties from co-composting bovine specified risk material and mortalities with manure. Nutrient Cycling in Agroecosystems 83:289–299.

Hao X, Benke M, Larney FJ, McAllister TA. 2010a. Greenhouse gas emissions when composting manure from cattle fed wheat dried distillers' grains with solubles. Nutrient Cycling in Agroecosystems 89:105–114.

Hao X, Xu S, Larney FJ, Stanford K, Cessna AJ, McAllister TA. 2010b. Inclusion of antibiotics in feed alters greenhouse gas emissions from feedlot manure during composting. Nutrient Cycling in Agroecosystems 89:257–267.

Hénault C, Devis X, Page S, Justes E, Reau R, Germon J-C. 1998. Nitrous oxide emissions under different soil and land management conditions. Biology and Fertility of Soils 26:199–207.

Hutchings NJ, Sommer SG, Andersen JM, Asman WAH. 2001. A detailed ammonia emission inventory for Denmark. Atmospheric Environment 35:1959–1968.

Hybrid. 2001. Hybrid Converter—Commercial Hens and Toms. Available online at: http://www.hybridturkeys.com/en/Hybrid%20Products/Mainstream%20Products/Converter.aspx. [accessed 2015 December 4].

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: http://www.ipcc-nggip.iges.or.jp/public/gp/english/. [accessed 2015 December 4].

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change. Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm. [accessed 2015 December 4].

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for Greenhouse Gas Inventories. Available online at: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm. [accessed 2015 December 4].

Izaurralde RC, Lemke RL, Goddard TW, McConkey B, Zhang Z. 2004. Nitrous oxide emissions from agricultural toposequences in Alberta and Saskatchewan. Soil Science Society of America Journal 68:1285–1294.

Jambert C, Delmas R, Serça D, Thouron L, Labroue L, Delprat L. 1997. N_2O and CH_4 emissions from fertilized agricultural soils in southwest France. Nutrient Cycling in Agroecosystems 48:105–114.

Janzen HH, Beauchemin KA, Bruinsma Y, Campbell CA, Desjardins RL, Ellert BH, Smith EG. 2003. The fate of nitrogen in agroecosystems: an illustration using Canadian estimates. Nutrient Cycling in Agroecosystems 67:85–102.

Jayasundara S, Wagner-Riddle C. 2014. Greenhouse gas emissions intensity of Ontario milk production in 2011 compared with 1991. Canadian Journal of Animal Science 94:155–173.

Kaharabata SK, Schuepp PH, Desjardins RL. 1998. Methane emissions from above ground open manure slurry tanks. Global Biogeochemical Cycles 12:545–554.

Karimi-Zindashty Y, Macdonald JD, Desjardins RL, Worth D, Hutchinson JJ, Vergé XPC. 2012. Sources of uncertainty in the IPCC Tier 2 Canadian livestock model. The Journal of Agricultural Science 150(5):556–569.

Karimi-Zindashty Y, Macdonald JD, Desjardins RL, Worth D, Liang BC. 2014. Determining the uncertainty in agricultural nitrous oxide emissions for Canada. Internal report. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Kebreab E, Clark K, Wagner-Riddle C, France J. 2006. Methane and nitrous oxide emissions from Canadian animal agriculture: A review. Canadian Journal of Animal Science 86:135–158.

Kononoff PJ, Mustafa AF, Christensen DA, McKinnon JJ. 2000. Effects of barley silage particle length and effective fiber on yield and composition of milk from dairy cows. Canadian Journal of Animal Science 80:749–752.

Kopp JC, Wittenberg KM, McCaughey WP. 2004. Management strategies to improve cow–calf productivity on meadow bromegrass pastures. Canadian Journal of Animal Science 84(3):529–535.

Koroluk R, Bourque L. 2003. Manure storage in Canada. Statistics Canada. Catalogue No. 21-021-$MIE_{2003001}$, Vol. 1, No. 1.. Available on line at http://www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=21-021-MIE2003001&lang=eng. [accessed 2010 May].

Laguë C, Gaudet É, Agnew J, Fonstad TA. 2005. Greenhouse gas emissions from liquid swine manure storage facilities in Saskatchewan. Transactions of the American Society of Agricultural Engineers 48:2289–2296.

Lemke RL, Izaurralde RC, Nyborg M, Solberg ED. 1999. Tillage and N-source influence soil-emitted nitrous oxide in the Alberta Parkland Region. Canadian Journal of Soil Science 79:15–24.

Lemke RL, Baron V, Iwaasa A, Farrell R, Schoenau J. 2012. Quantifying nitrous oxide emissions resulting from animal manure on pasture, range and paddock by grazing cattle in Canada. Final report submitted to the Greenhouse Gas Division, Environment Canada, by Agriculture and Agri-Food Canada, Saskatoon, SK, Canada.

Liang BC. 2014. Estimating ammonia emissions from synthetic nitrogen fertilizer application in Canada. Gatineau (QC): Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

Liang BC, Padbury G, Patterson G. 2004. Cultivated organic soils in Canada. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Liebig MA, Morgan JA, Reeder JD, Ellert BH, Gollany HT, Schuman GE. 2005. Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. Soil & Tillage Research 83:25–52.

MacDonald JD, Liang BC. 2011. Analysis of Canadian Quantification Methodologies of Greenhouse Gas emissions from Livestock: IPCC Tier 2 Quality Control Documentation 2011 submission. Internal report submitted to Dominique Blain. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

MacMillan RA, Pettapiece WW. 2000. Alberta Landforms: Quantitative Morphometric Descriptions and Classification of Typical Alberta Landforms, Semiarid Prairie Agricultural Research Centre, Research Branch, Agriculture and Agri-Food Canada, Swift Current, Saskatchewan, Canada, Technical Bulletin No. 2000-2E.

Manitoba Agriculture and Food. 2000. Manitoba Cattle on Feed 1999/2000. Market Analysis and Statistics Section, Program and Policy Analysis Branch, Manitoba Agriculture and Food.

Marinier M, Clark K, Wagner-Riddle C. 2004. Improving Estimates of Methane Emissions Associated with Animal Waste Management Systems in Canada by Adopting an IPCC Tier-2 Methodology. Final report submitted to the Greenhouse Gas Division, Environment Canada, by the Department of Land Resource Science, University of Guelph, Guelph, Ontario, Canada.

Marinier M, Clark K, Wagner-Riddle C. 2005. Determining manure management practices for major domestic animals in Canada. Final report submitted to the Greenhouse Gas Division, Environment Canada, by the Department of Land Resource Science, University of Guelph, Guelph, Ontario, Canada.

Massé DI, Croteau F, Patni NK, Masse L. 2003. Methane emissions from dairy cow and swine manure slurries stored at 10°C and 15°C. Canadian Biosystems Engineering 45:6.1–6.6.

Massé DI, Masse L, Claveau S, Benchaar C, Thomas O. 2008. Methane emissions from manure storages. Transactions of the ASABE 51:1775–1781.

McCaughey WP, Wittenberg K, Corrigan D. 1997. Methane production by steers on pasture. Canadian Journal of Animal Science 77:519–524.

McCaughey WP, Wittenberg K, Corrigan D. 1999. Impact of pasture type on methane production by lactating beef cows. Canadian Journal of Animal Science 79:221–226.

McGinn SM, Beauchemin KA, Coates T, Colombatto D. 2004. Methane emissions from beef cattle: Effects of monensin, sunflower oil, enzymes, yeast, and fumaric acid. Journal of Animal Science 82:3346–3356.

McGinn SM, Chen D, Loh Z, Hill J, Beauchemin KA, Denmead OT. 2008. Methane emissions from feedlot cattle in Australia and Canada. Australian Journal of Experimental Agriculture 48:183–185.

McGinn SM, Chung YH, Beauchemin KA, Iwaasa AD, Grainger C. 2009. Use of corn distillers' dried grains to reduce enteric methane loss from beef cattle. Canadian Journal of Animal Science 89:409–413.

Milne AE et al. 2014. Analysis of uncertainties in the estimates of nitrous oxide and methane emissions in the UK's greenhouse gas inventory for agriculture. Atmospheric Environment 82:94–105.

Minasny B, McBratney AB, Bristow KL. 1999. Comparison of different approaches to the development of pedotransfer functions for water-retention curves. Geoderma 93:225–253.

Monni S, Perälä P, Regina K. 2007. Uncertainty in agricultural CH_4 and N_2O emissions from Finland - Possibilities to increase accuracy in emission estimates. Mitigation and Adaptation Strategies for Global Change 12:545–571.

[NRC] National Research Council (U.S.). 1981. Nutrient Requirements of Goats. Washington (DC): National Research Council, National Academy Press.

[NRC] National Research Council (U.S.). 1985. Nutrient Requirements of Sheep, 6th Revised Edition. Washington (DC): National Research Council, National Academy Press.

[NRC] National Research Council (U.S.). 1989. Nutrient Requirements of Horses, 5th Revised Edition. Washington (DC): National Research Council, National Academy Press.

[NRC] National Research Council (U.S.). 1998. Nutrient Requirements of Swine, 10th Revised Edition. Washington (DC): National Research Council, National Academy Press.

[NRC] National Research Council (U.S.). 2001. Nutrient Requirements of Dairy Cattle, 7th Revised Edition. Washington (DC): National Research Council. National Academy Press.

Nyborg M, Solberg ED, Izaurralde RC, Malhi SS, Molina-Ayala M. 1995. Influence of long-term tillage, straw and N fertilizer on barley yield, plant-N uptake and soil-N balance. Soil & Tillage Research 36:165–174.

Odongo NE, Bagg R, Vessie G, Dick P, Or-Rashid MM, Hook SE, Gray JT, Kebreab E, France J, McBride BW. 2007. Long-term effects of feeding monensin on methane production in lactating dairy cows. Journal of Dairy Science 90:1781–1788.

Okine EK, Mathison GW. 1991. Effects of feed intake on particle distribution, passage of digesta, and extent of digestion in the gastrointestinal tract of cattle. Journal of Animal Science 69:3435–3445.

Ominski KH, Boadi DA, Wittenberg KM. 2006. Enteric methane emissions from backgrounded cattle consuming all-forage diets. Canadian Journal of Animal Science 86:393–400.

Park KH, Thompson AG, Marinier M, Clark K, Wagner-Riddle C. 2006. Greenhouse gas emissions from stored liquid swine manure in a cold climate. Atmospheric Environment 40:618–627.

Park KH, Wagner-Riddle C, Gordon RJ. 2010. Comparing methane fluxes from stored liquid manure using micrometeorological mass balance and floating chamber methods. Agricultural and Forest Meteorology 150:175–181.

Pattey E, Trzcinski MK, Desjardins RL. 2005. Quantifying the reduction of greenhouse gas emissions as a result of composting dairy and beef cattle manure. Nutrient Cycling in Agroecosystems 72:173–187.

Paul JW, Zebarth BJ. 1997. Denitrification and nitrate leaching during the fall and winter following dairy cattle slurry application. Canadian Journal of Soil Science 77:231–240.

Pennock DJ, Corre MD. 2001. Development and application of landform segmentation procedures. Soil & Tillage Research 58:151–162.

Petit HV, Dewhurst RJ, Proulx JG, Khalid M, Haresign W, Twagiramungu H. 2001. Milk production, milk composition, and reproductive function of dairy cows fed different fats. Canadian Journal of Animal Science 81:263–271.

Rochette P, Janzen HH. 2005. Towards a revised coefficient for estimating N_2O from legumes. Nutrient Cycling in Agroecosystems 73:171–179.

Rochette P, Chantigny MH, Ziadi N, Angers, DA, Bélanger G, Charbonneau E, Pellerin D, Liang BC, Bertrand N. 2014. Soil nitrous oxide emissions after deposition of dairy cow excreta in eastern Canada. Journal of Environmental Quality 43:829–841.

Rochette P, Worth DE, Lemke RL, McConkey BG, Pennock DJ, Wagner-Riddle C, Desjardins RL. 2008. Estimation of N_2O emissions from agricultural soils in Canada. I. Development of a country-specific methodology. Canadian Journal of Soil Science 88:641–654.

Rotz CA. 2004. Management to reduce nitrogen losses in animal production. Journal of Animal Science 82(Suppl.):E119–E137.

Rypdal K, Winiwarter W. 2001. Uncertainties in greenhouse gas emission inventories – Evaluation, comparability and implications. Environmental Science and Policy 4:107–116.

Sheppard SC, Bittman S, Tait J. 2009. Monthly NH_3 emissions from poultry in 12 Ecoregions of Canada / Émissions mensuelles de NH_3 par les exploitations avicoles dans 12 écorégions du Canada. Canadian Journal of Animal Science 89:21–35.

Sheppard SC, Bittman S, Bruulsema TW. 2010. Monthly ammonia emissions from fertilizers in 12 Canadian ecoregions. Canadian Journal of Soil Science 90:113–127.Sheppard SC, Bittman S, Swift ML, Tait J. 2010. Farm practices survey and modelling to estimate monthly NH_3 emissions from swine production in 12 Ecoregions of Canada. Canadian Journal of Animal Science 90:145–158.

Sheppard SC, Bittman S, Swift ML, Beaulieu M, Sheppard MI. 2011. Ecoregion and farm size differences in dairy feed and manure nitrogen management: A survey. Canadian Journal of Animal Science 91:459–473.

Sheppard SC, Bittman S. 2011. Farm survey used to guide estimates of nitrogen intake and ammonia emissions for beef cattle, including early season grazing and piosphere effects. Animal Feed Science and Technology 166-167:688–698.

Sheppard, S. C., and S. Bittman. 2012. Farm practices as they affect NH_3 emissions from beef cattle. Incidence des pratiques agricoles sur les émissions de NH_3 des bovins de boucherie Canadian Journal of Animal Science 92:525–543.

Small JA, McCaughey WP. 1999. Beef cattle management in Manitoba. Canadian Journal of Animal Science 79:539–544.

Statistics Canada. 1987. Agriculture, Census Canada 1986. Statistics Canada. Catalogue No. 96-102.

Statistics Canada. 1992. Agricultural Profile of Canada in 1991. Census of Agriculture. Catalogue No. 93350.

Statistics Canada. 1997. Agricultural Profile of Canada in 1996. Census of Agriculture. Catalogue No. 93356.

Statistics Canada. 2002. Agricultural Profile of Canada in 2001. Census of Agriculture. Catalogue No. $95F_{0301}$XIE.

Statistics Canada. 2007a. 2006 Census of Agriculture. Catalogue No. 95-629. Available online at: http://www.statcan.gc.ca/ca-ra2006/index-eng.htm. [accessed 2015 December 4].

Statistics Canada. 2007b. Selected Historical Data from the Census of Agriculture. Catalogue No. 95-632. Available online at: http://www.statcan.gc.ca/pub/95-632-x/2007000/4129763-eng.htm. [accessed 2015 December 4].

Statistics Canada. 2008. Alternative Livestock on Canadian Farms. Census years 1981, 1986, 1991, 1996, 2001 and 2006. Catalogue No. 23-502-X.

Statistics Canada. 2012a. Table 95-640-XWE - 2011 Farm and farm operator data (database). Available online at: http://www5.statcan.gc.ca/olc-cel/olc.action?objId=95-629-X&objType=2&lang=en&limit=0. [accessed 2015 December 4].

Statistics Canada. 2014a. Fertilizer Shipments Survey. Statistics Canada Catalogue No. 21-022-X. http://www.statcan.gc.ca/pub/21-022-x/21-022-x2014003-eng.pdf. [accessed 2015 December 4].

Statistics Canada. 2014b. Table 001-0010 – Estimated areas, yield, production and average farm price of principal field crops, in metric units. CANSIM (database). Available online at: http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0010010&tabMode=dataTable&srchLan=-1&p1=-1&p2=9. [accessed 2015 December 4].

Statistics Canada. Table 003-0032 - Number of cattle, by class and farm type, annual (head), CANSIM (database). Available online at: http://www5.statcan.gc.ca/cansim/a05?lang=eng&id=0030032&pattern=0030032&searchTypeByValue=1&p2=35. [accessed 2015 December 4].

Statistics Canada. Table 003-0031 - Number of sheep and lambs on farms, annual (head), CANSIM (database). Available online at: http://www5.statcan.gc.ca/cansim/a05?lang=eng&id=0030031&pattern=0030031&searchTypeByValue=1&p2=35. [accessed 2015 December 4].

Statistics Canada. Table 003-0004 - Number of hogs on farms at end of semi-annual period (head), CANSIM (database). Available online at: http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0030100&pattern=Livestock&tabMode=dataTable&srchLan=-1&p1=1&p2=-1. [accessed 2015 December 4].

[U.S. EPA] United States Environmental Protection Agency. 2004. National Emission Inventory—Ammonia Emissions from Animal Husbandry Operations. Draft report. January 30. Washington (DC): U.S. Environmental Protection Agency.

Valacta Dairy Services/CanWest DHI. 2016. Stats from milk recording data. Vision 2000 [database].

VanderZaag AC, Gordon RJ, Jamieson RC, Burton DL, Stratton GW. 2009. Gas emissions from straw covered liquid dairy manure during summer storage and autumn agitation. Transactions of the ASABE 52:599–608.

VanderZaag AC, Gordon RJ, Jamieson RC, Burton DL, Stratton GW. 2010. Effects of winter storage conditions and subsequent agitation on gaseous emissions from liquid dairy manure. Canadian Journal of Soil Science 90:229–239.

Van Haarlem RP, Desjardins RL, Gao Z, Flesch TK, Li X. 2008. Methane and ammonia emissions from a beef feedlot in western Canada for a twelve-day period in the fall. Canadian Journal of Animal Science 88:641–649.

Wagner-Riddle C, Thurtell GW. 1998. Nitrous oxide emissions from agricultural fields during winter and spring thaw as affected by management practices. Nutrient Cycling in Agroecosystems 52:151–163.

Wagner-Riddle C, Park KH, Thurtell GW. 2006. A micrometeorological mass balance approach for greenhouse gas flux measurements from stored animal manure. Agricultural and Forest Meteorology 136:175–187.

Wagner-Riddle C, Furon A, McLaughlin NL, Lee I, Barbeau J, Jayasundara S, Parkin G, von Bertoldi P, Warland J. 2007. Intensive measurement of nitrous oxide emissions from a corn soybean wheat rotation under two contrasting management systems over 5 years. Global Change Biology 13:1722–1736.

Western Canadian Dairy Herd Improvement Services. 2002. 2002 Herd Improvement Report. Edmonton (AB). Canada. 16 pp.

Weston RH. 2002. Constraints on feed intake by grazing sheep. In Freer M, Dove H, editors. Sheep Nutrition. Collingwood (AU): CSIRO Publishing.

Xu S, Hao X, Stanford K, McAllister T, Larney FJ, Wang J. 2007. Greenhouse gas emissions during co-composting of cattle mortalities with manure. Nutrient Cycling in Agroecosystems 78:177–187.

Yang JY, De Jong R, Drury CF, Huffman E, Kirkwood V, Yang XM. 2007. Development of a Canadian agricultural nitrogen model (CANB v2.0): simulation of the nitrogen indicators and integrated modeling for policy scenarios. Canadian Journal of Soil Science 87:153–165.

Zebarth BJ, Hii B, Liebscher H, Chipperfield K, Paul JW, Grove G, Szeto SY. 1998. Agricultural land use practices and nitrate contamination in the Abbotsford aquifer, British Columbia, Canada. Agriculture, Ecosystems & Environment 69:99–112.

Annex 3.5, Methodology for Land Use, Land-Use Change and Forestry

Bailey AW, Liang BC. 2013. Burning of managed grassls in Alberta, Saskatchewan and British Columbia. Western Rangeland Consultants Inc., Edmonton (AB); Pollutant Inventories and Reporting Division, Environment Canada, Gatineau (QC).

Baron VS, Mapfumo E, Dick AC, Naeth MA, Okine EK, Chanasyk DS. 2002. Grazing intensity impacts on pasture carbon and nitrogen flow. Journal of Range Management 55(6):535–541.

Bartelink HH. 1998. A model of dry matter partitioning in trees. Tree Physiology 18(2):91–101.

Biederbeck VO, Campbell CA, Zentner RP. 1984. Effect of crop rotation and fertilization on some biological properties of a loam in southwestern Saskatchewan. Canadian Journal of Soil Science 64:355–367.

Biondini ME, Manske L. 1996. Grazing frequency and ecosystem processes in a northern mixed prairie, USA. Ecological Applications 6(1):239–256.

Blain D, Seed E, Lindsay M, Hayne S, McGovern M. 2015. Forest Land and Other Land Conversion to Wetlands (Reservoirs) Estimation and Reporting of CO_2 Emissions. Unpublished report. Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

Bolinder MA. 2004. Contribution aux connaissances de la dynamique du C dans les systèmes sol-plante de l'est du Canada. PhD thesis, Université Laval, Sainte-Foy (QC).

Boudewyn P, Song X, Magnussen S, Gillis M. 2007. Model-based, volume-to-biomass conversion for forested and vegetated land in Canada. Natural Resources Canada, Canadian Forest Service. Information Report – BC-X-411.

Bremer E, Janzen HH, Johnston AM. 1994. Sensitivity of total, light fraction and mineralizable organic matter to management practices in a Lethbridge soil. Canadian Journal of Soil Science 74:131–138.

Bruce JP, Frome M, Haites E, Janzen H, Lal R, Paustian K. 1999. Carbon sequestration in soils. Journal of Soil Water Conservation 54:382–389.

Butson C, Fraser R. 2005. Mapping land cover change and terrestrial dynamics over northern Canada using multi-temporal Landsat imagery. In: Proceedings of the Third International Workshop on the Analysis of Multi-temporal Remote Sensing Images: MultiTemp 2005, May 16-18, 2005. Biloxi (MS): Institute of Electrical and Electronics Engineers.

Campbell CA, McConkey BG, Zentner RP, Dyck RP, Selles F, Curtin D. 1995. Carbon sequestration in a Brown Chernozem as affected by tillage and rotation. Canadian Journal of Soil Science 75:449–458.

Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D. 1996a. Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. Canadian Journal of Soil Science 76:395–401.

Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D. 1996b. Tillage and crop rotation effects on soil organic matter in a coarse-textured Typic Haploboroll in southwestern Saskatchewan. Soil & Tillage Research 37:3–14.

Campbell CA, Selles F, LaFond GP, McConkey BG, Hahn D. 1998. of crop management on C and N in long-term crop rotations after adopting no-tillage management: Comparison of soil sampling strategies. Canadian Journal of Soil Science 78:155–162.

Campbell CA, Zentner RP, Liang BC, Roloff G, Gregorich EG, Blomert B. 2000. Organic C accumulation in soil over 30 years in semiarid southwestern Saskatchewan—Effect of crop rotations and fertilizers. Canadian Journal of Soil Science 80:179–192.

Campbell CA, Janzen HH, Paustian K, Gregorich EG, Sherrod L, Liang BC, Zentner RP. 2005. Carbon storage in soils of the North American Great Plains: Effect of cropping frequency. Agronomy Journal 97:349–363.

Carter MR, Kunelius HT, Sanderson JB, Kimpinski J, Platt HW, Bolinder MA. 2003. Trends in productivity parameters and soil health under long-term two-year potato rotations. Soil & Tillage Research (Special issue) 72:153–168.

Cerkowniak D. 2014. National Inventory Report – 2015: Results, methodological changes and updates to LULUCF reporting for agriculture. Report submitted to the Pollutant Inventories and Reporting Division, Environment Canada, by the Research Branch of Agriculture and Agri-Food Canada, Saskatoon (SK).

Chen W, Blain D, Li J, Fraser R, Zhang Y, Leblanc S, Keohler K, Butson C, Olthof I, Orazietti J, et al. 2005. Estimation of Greenhouse Gas Removals/Emissions Due to Land Use Changes over Canada's North during 1985–1990 and 1990–2000. Summary report. Submitted to the Greenhouse Gas Division, Environment Canada.

Chen W, Blain D, Li J, Fraser R, Zhang Y, Leblanc S, Keohler K, Olthof I, Wang J, McGovern M. 2009. Estimating carbon release caused by land use changes over Canada's north during 1985–1990 and 1990–2000 using satellite Earth observation. Journal of Geophysical Research 114: G_{01017}.

Cleary J. 2003. Greenhouse gas emissions from peat extraction in Canada: A Life Cycle Perspective. MSc thesis, McGill University, Montreal (QC). C_2GCR Report No. 2003-1.

Cleary J, Roulet N, Moore T. 2005. Greenhouse gas emissions from Canadian peat extraction, 1990–2000: A life-cycle analysis. Ambio 34:456–461.

Cofer WR, Winstead EL, Stocks BJ, Goldammer JG, Cahoon DR. 1998. Crown fire emissions of CO_2, CO, H_2, CO_4, and TNMHC from a dense jack pine boreal forest fire. Geophysical Research Letters 25:3919–3922.

Duchemin É. 2002. Canadian Reservoir Database / Répertoire des réservoirs canadiens [Computer file]. Environment Canada and DREXenvironment (distributor).

Duchemin É. 2006. Émissions de gaz provoquant l'effet de serre à partir des terres inondées au Canada. Final report submitted to the Greenhouse Gas Division, Environment Canada.

Dyk A, Leckie D, Tinis S, Ortlepp S. 2015. Canada's National Deforestation Monitoring System: System Description. Natural Resources Canada, Canadian Forest Service. 30 pp. Report BC-X-439.

Eichel F. 2006. Review of Environment Canada Reservoir Flooding Dates on Hydro Reservoirs 2007 Sub Nov24.xls. Canadian Forest Service, Natural Resources Canada. 6 pp.

Ellert B, Bettany JR. 1995. Calculation of organic matter and nutrients stored in soils under contrasting management regimes. Canadian Journal of Soil Science 75:529–538.

[FAO] Food and Agriculture Organization. 2010. Forest Product Conversion Factors for the UNECE Region. Geneva Timber and Forest Discussion Paper 49. Food and Agricultural Organization of the United Nations.

Fraser R, Olthof I, Girouard G, Pavlic G, Clouston A, Pouliot D, Chen W. 2005. Remote Sensing Based Estimate of Land Use Change Area in Canada's Arctic/Sub-Arctic. Final report to the Greenhouse Gas Division, Environment Canada.

Garcia Bravo T. 2015. Picea mariana (Mill.) B.S.P plantation on cutover peatland in Alberta (Canada): Evaluating the effect of fertilization and resulting carbon stocks. MSc Thesis. University of Calgary. Calgary, Alberta, 103 pp.

Glatzel S, Kalbitz K, Dalva M, Moore T. 2003. Dissolved organic matter properties and their relationship to carbon dioxide efflux from restored peat bogs. Geoderma 113:397–411.

González E, Rochefort L. 2014. Drivers of success in 53 cutover bogs restored by a moss layer transfer technique. Ecological Engineering 68:279–290.

Gorham E. 1991. Northern peatlands: role in the carbon cycle and probable responses to climatic warming. Ecological Applications 1:182–195.

Hayne S, Verbicki M. 2011. Aboveground biomass density of Canadian peatlands. Unpublished report. Pollutant Inventories and Reporting Division, Environment Canada.

Hayne S, Jenkins C, Garneau M. 2014. Off-site GHG emissions from Canadian peat products. Unpublished report. Pollutant Inventories and Reporting Division, Environment Canada.

Huffman T, Leckie D, McGovern M, Olesen M, Green M, Hill DA, Rounce T, Churchill J, Liu J. 2015. Integration of multiple spatial datasets in the development of a temporal series of high-accuracy, high-resolution land use maps. Proceedings of the 35th EARSeL Symposium, Stockholm, Sweden, June 15-19, 2015.

[IPCC] Intergovernmental Panel on Climate Change. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry, Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm.

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use, Intergovernmental Panel on Climate Change. Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm.

[IPCC] Intergovernmental Panel on Climate Change. 2010. Revisiting the use of managed land as a proxy for estimating national anthropogenic emissions and removals. Eggleston HS, Srivastava N, Tanabe K, Baasansuren J, editors. IGES, Japan, IPCC Expert Meeting Report.

[IPCC] Intergovernmental Panel on Climate Change. 2014. 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Hiraishi T, Krug T, Tanabe K, Srivastava N, Baasansuren J, Fukuda M, Troxler TG, editors. IPCC, Switzerland. Available online at: http://www.ipcc-nggip.iges.or.jp/public/wetlands/.

Janzen HH, Campbell CA, Gregorich EG, Ellert BH. 1997. Soil carbon dynamics in Canadian agroecosystems. In: Lal R, Kimble JM, Follett RF, Stewart BA, editors. Soil Processes and Carbon Cycles. Boca Raton (FL): CRC Press. p. 57–80.

Janzen HH, Campbell CA, Izaurralde RC, Ellert BH, Juma N, McGill WB, Zentner RP. 1998. Management effects on soil C storage in the Canadian prairies. Soil & Tillage Research 47:181–195.

Johnson RD, Kasischke ES. 1998. Change vector analysis: a technique for the multispectral monitoring of land cover and condition. International Journal of Remote Sensing 19:411–426.

Kasischke ES, Bruhwiler LP. 2003. Emissions of carbon dioxide, carbon monoxide, and methane from boreal forest fires in 1998. Journal of Geophysical Research Atmospheres 108(D_1):8146.

Kurz WA, Apps MJ, Webb TM, McNamee PJ. 1992. The Carbon Budget of the Canadian Forest Sector: Phase 1. Edmonton (AB): Northern Forestry Centre, Forestry Canada. Information Report NOR-X-326.

Kurz WA, Dymond CC, Stinson G, Rampley GJ, Neilson ET, Carroll AL, Ebata T, Safranyik L. 2008a. Mountain pine beetle and forest carbon feedback to climate change. Nature 452:987–990.

Kurz WA, Stinson G, Rampley GJ, Dymond CC, Neilson ET. 2008b Risk of natural disturbances makes future contribution of Canada's forests to the global carbon cycle highly uncertain. Proceedings of the National Academy of Sciences 105:1551–1555.

Kurz WA, Dymond CC, White TM, Stinson G, Shaw CH, Rampley GJ, Smyth C, Simpson BN, Neilson ET, Trofymow JA, et al. 2009. CBM-CFS_3: A model of carbon-dynamics in forestry and land-use change implementing IPCC standards. Ecological Modelling 220:480–504.

Kurz WA, Shaw CH, Boisvenue C, Stinson G, Metsaranta J, Leckie D, Dyk A, Smyth C, Neilson ET. 2013. Carbon in Canada's boreal forest – A synthesis. Environmental Reviews 21:260–292.

Leckie D. 2006a. Deforestation Monitoring Pilot Project Reports v 1.0. Canadian Forest Service, Natural Resources Canada. 199 pp. Report DRS-Q-004.

Leckie D. 2006b. NIR 2006 Records of Decision for Canada's National Deforestation Estimate 2006. Canadian Forest Service, Natural Resources Canada. 56 pp. Report DRS-N-011.

Leckie D. 2011. Deforestation Area Estimation Uncertainty for Canada's National Inventory Report Greenhouse Gas Sources and Sinks 2011. Canadian Forest Service, Natural Resources Canada. 12 pp. Report DRS-N-030.

Leckie DG, Gillis MD, Wulder MA. 2002. Deforestation estimation for Canada under the Kyoto Protocol: A design study. Canadian Journal of Remote Sensing 28(5):672–678.

Leckie D, Paradine D, Burt W, Hardman D, Tinis S. 2006. NIR 2006 Deforestation Area Estimation for Canada: Methods Summary. Victoria (BC): Canadian Forest Service, Natural Resources Canada. 13 pp. Report DRS-Q-001.

Leckie D, Dyk A, Paradine D, Tammadge D, Tinis S. 2010a. Deforestation Interpretation Guide (Version NIR 2011). Canadian Forest Service, Natural Resources Canada. 85 pp. Report DRS-M-016.

Leckie D, Dyk A, Ortlepp S, Tinis S. 2010b. Records of Decision for Canada's National Deforestation Estimate. Canadian Forest Service, Natural Resources Canada. 20 pp. Report DRS-N-029.

Leckie D, Paradine D, Kurz W, Magnussen S. 2015. Deforestation mapping sampling designs for Canadian landscapes. Canadian Journal of Forestry Research 45:1564–1576.

Li Z, Kurz WA, Apps MJ, Beukema SJ. 2003. Belowground biomass dynamics in the Carbon Budget Model of the Canadian Forest Sector: recent improvements and implications for the estimation of NPP and NEP. Canadian Journal of Forest Research 33:126–136.

Liang BC, Gregorich EG, MacKenzie AF. 1996. Modelling the effects of inorganic and organic amendments on organic matter in a Quebec soil. Soil Science 161:109–114.

Liang BC, Padbury G, Patterson G. 2004. Cultivated organic soils in Canada. Gatineau (QC): Greenhouse Gas Division, Environment Canada.

Liang BC, Campbell CA, McConkey BG, Padbury B, Collas P. 2005. An empirical model for estimating carbon sequestration on the Canadian prairies. Canadian Journal of Soil Science 85:549–556.

Liebig MA, Morgan JA, Reeder JD, Ellert BH, Gollany HT, Schuman GE. 2005. Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. Soil & Tillage Research 83(1):25–52.

Litton CM, Ryan MG, Tinker DB, Knight DH. 2003. Belowground and aboveground biomass in young postfire lodgepole pine forests of contrasting tree density. Canadian Journal of Forest Research 33(2):351–363.

Magnuson JL, Robertson DM, Benson BJ, Wynne RH, Livingstone DM, Arai T, Assel TA, Barry RG, Card V, Kuusisto E, et al. 2000. Historical trends in lake and river ice cover in the northern hemisphere. Science 289:1743–1746.

Mailvaganam S. 2002. 2001 Ontario Grape Vine Survey. Ontario Ministry of Agriculture and Food. Available on request from stats.omafra@ontario.ca.

Marshall IB, Schut PH, Ballard M. 1999. A National Ecological Framework for Canada: Attribute Data. Prepared by Environment Canada and Agriculture and Agri-Food Canada. Available online at: http://sis.agr.gc.ca/cansis/nsdb/ecostrat/1999report/index.html.

McConkey BG, Liang BC, Campbell CA, Curtin D, Moulin A, Brandt SA, Lafond GP. 2003. Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. Soil & Tillage Research 74:81–90.

McConkey B, Angers D, Bentham M, Boehm M, Brierley T, Cerkowniak D, Liang BC, Collas P, de Gooijer H, Desjardins R, et al. 2007a. CanAG-MARS Methodology and Greenhouse Gas Estimates for Agricultural Land in the LULUCF Sector for NIR 2006. Report submitted to the Greenhouse Gas Division, Environment Canada, by the Research Branch of Agriculture and Agri-Food Canada.

McConkey BG, VandenByGaart B, Hutchinson J, Huffman T, Martin T. 2007b. Uncertainty Analysis for Carbon Change—Cropland Remaining Cropland. Report submitted to Environment Canada by the Research Branch of Agriculture and Agri-Food Canada.

McCrae T, Smith CAS, Gregorich LJ. 2000. Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. Ottawa (ON): Agriculture and Agri-Food Canada. Publication 2022/E.

McGovern M. 2014. GHG Spatial Reporting Structure for Canada's Land Use, Land-Use Change and Forestry Sector – Reporting Zones and Reconciliation Units. Pollutant Inventory and Reporting Division, Environment Canada.

McGovern M, Pasher J. 2016. Canadian urban tree canopy cover and carbon sequestration status and change 1990-2012. Urban Forestry & Urban Greening 20:227–232.

McKenney DW, Hutchinson MF, Kestevan JL, Vernier LA. 2001. Canada's plant hardiness zones revisited using modern climate interpolation techniques. Canadian Journal of Plant Science 81:129–143.

Metsaranta J, Morken S, Hafer M. 2014. Uncertainty Estimates: National Forest GHG Inventory Reporting for the 2014 National Inventory Report. Unpublished manuscript.

Metsaranta J, Morken S, Hafer M. 2016. Uncertainty Estimates: National Forest GHG Inventory Reporting for the 2016 National Inventory Report. Unpublished manuscript.

Monreal CM, Zentner RP, Robertson JA. 1997. An analysis of soil organic matter dynamics in relation to management, erosion and yield of wheat in long-term crop rotation plots. Canadian Journal of Soil Science 77:553–563.

[NRCan] Natural Resources Canada. 1974. Lakes – Ice Free Period [map], 1:35,000,000. In: National Atlas of Canada, 4th Edition. Available online at http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/5c2581ff-1c35-5310-b31a-7960ca892d0b.html.

[NRCan] Natural Resources Canada. 2016. Preliminary Estimate of the Mineral Production of Canada, by Province, 2015. Natural Resources Canada. Available online at http://sead.nrcan.gc.ca/prod-prod/ann-ann-eng.aspx.

Nendel C, Kersebaum KC. 2004. A simple model approach to simulate nitrogen dynamics in vineyard soils. Ecological Modelling 177:1–5.

Nowak DJ, Greenfield EJ, Hoehn RE, Lapoint E. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution 178:229–236.

Olthof I, Butson C, Fraser R. 2005. Signature extension through space for northern landcover classification: a comparison of radiometric correction methods. Remote Sensing of Environment 95:290–302.

Parton WJ, Schimel DS, Cole CV, Ojima DS. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Science Society of America Journal 51:1173–1179.

Parton WJ, Stewart JWB, Cole CV. 1988. Dynamics of C, N, P and S in grassland soils: a model. Biogeochemistry 5:109–131.

Pasher J, McGovern M, Khoury M, Duffe J. 2014. Assessing carbon storage and sequestration by Canada's urban forest using high resolution earth observation data. Urban Forestry and Urban Greening 13(3):484–494.

Paul KI, Polglase PJ, Nyakuengama JG, Khanna PK. 2002. Change in soil carbon following afforestation. Forest Ecology and Management 168(1–3):241–257.

Pennock DJ, Frick AH. 2001. The role of field studies in land-scape-scale applications of process models: an example of soil redistribution and soil organic carbon modeling using CENTURY. Soil & Tillage Research 58(3/4):183–191.

Petrone RM, Waddington JM, Price JS. 2001. Ecosystem scale evapotranspiration and net CO_2 exchange from a restored peatland. Hydrological Processes 15:2839–2845.

Petrone RM, Waddington JM, Price JS. 2003. Ecosystem-scale flux of CO_2 from a restored vacuum harvested peatland. Wetlands Ecology and Management 11:419–432.

Poulin M, Rochefort L, Quinty F, Lavoie C. 2005. Spontaneous revegetation of mined peatlands in eastern Canada. Canadian Journal of Botany 83:539–557.

Power K, Gillis MD. 2006. Canada's forest inventory 2001. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia. Information Report BC-X-408E. 100 p. Available online at http://cfs.nrcan.gc.ca/publications/?id=26795.

Rochefort L, Quinty F, Campeau S, Johnson K, Malterer T. 2003. North American approach to the restoration of Sphagnum dominated peatlands. Wetlands Ecology and Management 11:3–20.

Saarnio S, Morero M, Shurpali N, Tuittila E, Makila M, Alm J. 2007. Annual CO_2 and CH_4 fluxes of pristine boreal mires as a background for the lifecycle analyses of peat energy. Boreal Environmental Research 12(2):101–113.

Schuman GE, Janzen HH, Herrick JE. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. Environmental Pollution 116:391–396.

Skog KE. 2008. Sequestration of carbon in harvested wood products for the United States. Forest Products Journal 58:56–72.

Smith WN, Rochette P, Monreal C, Desjardins RL, Pattey E, Jaques A. 1997. The rate of carbon change in agricultural soils in Canada at the landscape level. Canadian Journal of Soil Science 77:219–229.

Smith WN, Desjardins RL, Pattey E. 2000. The net flux of carbon from agricultural soils in Canada 1970–2010. Global Change Biology 6(5):558–568.

Smith WN, Desjardins RL, Grant B. 2001. Estimated changes in soil carbon associated with agricultural practices in Canada. Canadian Journal of Soil Science 81:221–227.

Smoliak S. 1965. Effects of manure, straw and inorganic fertilizers on Northern Great Plains ranges. Journal of Range Management 18:11–14.

Statistics Canada. 1992. 1991 Digital Boundary Files User Guide and digital files. Statistics Canada.

Statistics Canada, 2010. Introducing a New Concept and Methodology forDelineating Settlement Boundaries: a Research Project on CanadianSettlements. Technical Paper, http://www.statcan.gc.ca/pub/16-001-m/16-001-m2010011-eng.htm (accessed November, 4th, 2016).

Statistics Canada. 2011. 2011 Census Profiles. Available online at http://www12.statcan.gc.ca/census-recensement/2011/dp-pd/prof/index.cfm?Lang=E&MM.

Stinson G, Zhang G, Rampley G, Dymond C, White T, Kurz WA. 2006a. Forest Inventory Rollback Tool for CBM-CFS3. Internal report.

Ottawa (ON): Greenhouse Gas Division, Environment Canada.

Stinson G, White T, Kurz WA, Dymond C. 2006b. Delineating Canada's Managed Forest for NIR 2007. Internal report. Ottawa (ON): Greenhouse Gas Division, Environment Canada.

Stinson G, Kurz WA, Smyth CE, Neilson ET, Dymond CC, Metsaranta JM, Boisvenue C, Rampley GJ, Li Q, White TM, and Blain D. 2011. An inventory-based analysis of Canada's managed forest carbon dynamics, 1990 to 2008. Global Change Biology 17(6):2227–2244.

Strack M, Zuback Y. 2013. Annual carbon balance of a peatland 10 yr following restoration. Biogeosciences 10:2885–2896.

Strack M, Keith A, Xu B. 2014. Growing season carbon dioxide and methane exchange at a restored peatland on the Western Boreal Plain. Ecological Engineering 64:231–239.

Tarnocai C. 1997. The amount of organic carbon in various soil orders and ecological provinces in Canada. In: Lal R, Kimble JM, Follett RF, Stewart BA, editors. Soil Processes and the Carbon Cycle. Boca Raton (FL): CRC Press. p. 81–92.

[TNS] TNS Canadian Facts. 2006. Residential Fuelwood Combustion in Canada. Presented to Environment Canada. Report C1077/BT. Toronto (ON): TNS Global.

[TNS] TNS Canada. 2012. Residential Fuelwood Combustion in Canada. Presented to Natural Resources Canada. Report 1381/BT.Toronto (ON): TNS Canada.

[U.S. EPA] United States Environmental Protection Agency. 2013. Inventories of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010. EPA Report 430-R-12-001.

VandenBygaart AJ, Gregorich EG, Angers DA. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. Canadian Journal of Soil Science 83:363–380.

VandenBygaart AJ, McConkey BG, Angers DA, Smith W, De Gooijer H, Bentham M, Martin T. 2008. Soil carbon change factors for the Canadian agriculture national greenhouse gas inventory. Canadian Journal of Soil Science 88:671–680.

Voroney RP, Angers DA. 1995. Analysis of the short-term effects of management on soil organic matter using the CENTURY model. In: Lal R, Kimble J, Levine E and Stewart BA, editors. Soil Management and the Greenhouse Effect. New York (NY): Springer-Verlag. p. 113–120.

Waddington JM, Price JS. 2000. Effect of peatland drainage, harvesting, and restoration on atmospheric water and carbon exchange. Physical Geography 21(5):433–451.

Waddington JM, Warner KD. 2001. Atmospheric CO_2 sequestration in restored mined peatlands. Ecoscience 8(3):359–368.

Waddington JM, Warner KD, Kennedy GW. 2002. Cutover peatlands: A persistent source of atmospheric CO_2. Global Biogeochemical Cycles 16:1–7.

Waddington JM, Day SM. 2007. Methane emissions from a peatland following restoration. Journal of Geophysical Research 112:1–11.

Waddington JM, McNeil P. 2002. Peat oxidation in an abandoned cutover peatland. Canadian Journal of Soil Science 82:279–286.

Waddington JM, Toth K, Bourbonniere R. 2008. Dissolved organic carbon export from a cutover and restored peatland. Hydrological Processes 22:2215–2224.

Waddington JM, Strack M, Greenwood MJ. 2010. Toward restoring the net carbon sink function of degraded peatlands: Short-term response in CO_2 exchange to ecosystem-scale restoration. Journal of Geophysical Research 115:1–13.

White T, Kurz WA. 2005. Afforestation on private land in Canada from 1990 to 2002 estimated from historical records. The Forestry Chronicle 81(4):491–497.

White T, Luckai N, Larocque GR, Kurz WA, Smyth C. 2008. A practical approach for assessing the sensitivity of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS_3). Ecological Modelling 219(3–4):373–382.

Xiao CW, Ceulemans R. 2004. Allometric relationships for below- and aboveground biomass of young Scots pines. Forest Ecology and Management 203(1–3):177–186.

Annex 3.6, Methodology for Waste Sector

AECOM Canada. 2011. Improved Methodology for the Estimation of Greenhouse Gases from Canadian Municipal Wastewater Treatment Facilities.

AECOM Canada. 2012. Evaluation of Canada's Estimation Methodology of Nitrous Oxide Emissions from Human Sewage Final Report.

American Public Works Association. 1964. Characteristics of Municipal Refuse. In: Proceedings of the National Conference on Solid Waste Research.

Anon. 1967a. World Survey Finds Less Organic Matter. Refuse Removal Journal 10:26.

Anon. 1967b. Can Garbage Become a National Asset? Compost Science 8(1):3.

Canadian Council of Ministers of the Environment. 2006. Review of Dioxins and Furans from Incineration in Support of a Canada-wide Standard Review. A Report Prepared for The Dioxins and Furans Incineration Review Group Through a Contract Associated with CCME Project #390-2007. Prepared by A.J. Chandler & Associates Ltd.

Canadian Council of Ministers of the Environment. 2007. Canada-Wide Standards for Mercury. A Report on Compliance and Evaluation – Mercury from Dental Amalgam Waste. A Report on Progress – Mercury Emissions and Mercury-Containing Lamps.

Canadian Council of Ministers of the Environment. 2010. Canada-Wide Standard for Mercury Emissions (Incineration & Base Metal Smelting). 2010 Progress Report.

Climate Action Reserve. 2009. Table B.6 Organic Waste Digestion Project Protocol. [accessed 2010 Oct 12]. p. 66. Available online at: http://www.climateactionreserve.org/how/protocols/organic-waste-digestion/dev/#version_1.0.

[CRA] Conestoga-Rovers & Associates. 2011. Estimation of Greenhouse gas (GHG) Emissions from Canadian Unmanaged Municipal Solid Waste (MSW) Landfills and MSW Incinerators and Validation of MSW Landfill Model Methane Generation Rate Constant. Prepared by Conestoga-Rovers & Associates.

CRC Press. 1973. National Waste Composition (1967), Table 1.1-9: Summary of International Refuse Composition of the CRC Handbook of Environmental Control, Volume II: Solid Waste; Table 1.1-10: Composition of Household Garbage and Table 1.1-28: Composition and Analysis of Average Municipal Refuse. Bond R, Straub CP, editors. Cleveland (OH): CRC Press.

Environment Canada. 1840– . Historical Precipitation Data. Available online at: http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html. [accessed 2010 Jun 15].

Environment Canada. 1986. Water Use in Canadian Industry. Prepared by Tate DM, Scharf D, Environmental Economics Branch, Environment Canada.

Environment Canada. 1991. Water Use in Canadian Industry. Prepared by Tate DM, Scharf D, Environmental Economics Branch, Environment Canada.

Environment Canada. 1994a. Options for Managing Emissions from Solid Waste Landfills. Prepared by Hickling for Environment Canada in association with Emcon Associates.

Environment Canada. 1994b. Study of Greenhouse Gas Emissions from Non-Fossil Fuel Sources. Prepared by Senes Consultants for Environment Canada.

Environment Canada. 1995a. Estimation of the Effects of Various Municipal Waste Management Strategies on Greenhouse Gas Emissions. Report EPS 2/AP/1.

Environment Canada. 1995b. Waste Analysis, Sampling, Testing and Evaluation (WASTE) Program: The Effect of Waste Stream Characteristics on Municipal Solid Waste Incineration: The Fate and Behaviour of Trace Metals, Vol. I. Report EPS 3/HA/10.

Environment Canada. 1996a. Water Use in Canadian Industry. Prepared by Tate DM, Scharf D. Environmental Economics Branch, Environment Canada.

Environment Canada. 1996b. Perspectives on Solid Waste Management in Canada: An Assessment of the Physical, Economic and Energy Dimensions of Solid Waste Management in Canada. Vol. I. Prepared by Resource Integration Systems Ltd., for Hazardous Waste Branch, Environment Canada.

Environment Canada. 1997. Telephone survey conducted by Environment Canada.

Environment Canada. 1999. Municipal Solid Waste Incineration in Canada: An Update on Operations 1997–1998. Prepared by Compass Environmental Inc. for Environment Canada and Federal Panel on Energy Research Development.

Environment Canada. 2003a. Inventory of Landfill Gas Recovery and Utilization in Canada. National Office of Pollution Prevention, Environment Canada.

Environment Canada. 2003b. Municipal Solid Waste Incineration in Canada: An Update on Operations 1999–2001. Prepared by A.J. Chandler & Associates in conjunction with Compass Environmental Inc. for Environment Canada.

Environment Canada. 2007. An Inventory of Landfill Gas Recovery and Utilization in Canada 2005. Unpublished report prepared by the Greenhouse Gas Division of Environment Canada with the support of the University of Manitoba.

Environment Canada. 2009. An Inventory of Landfill Gas Recovery and Utilization in Canada 2006 and 2007. Unpublished report prepared by the Greenhouse Gas Division of Environment Canada.

Environment Canada. 2010. Waste Incineration in Canada 1990-2009 – A Summary of Findings from Surveys Conducted in 2006, 2008 and 2010. Unpublished internal Environment Canada Report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

Environment Canada. 2011. An Inventory of Landfill Gas Recovery and Utilization in Canada 2008 and 2009. Unpublished report prepared by the Greenhouse Gas Division of Environment Canada.

Environment Canada. 2013a. Canadian Waste Export Data to the United States. Unpublished internal Environment Canada Report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

Environment Canada. 2013b. An Inventory of Landfill Gas Recovery and Utilization in Canada 2010 and 2011. Greenhouse Gas Division, Environment Canada.

Environment Canada. 2013c. An Inventory of the 2012 Waste Incineration Survey in Canada 2010 and 2011. Unpublished internal Environment Canada Report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

Environment Canada 2014a. A Review of Canadian Non-Hazardous Waste Export Quantities to the United States. Unpublished internal Environment Canada Report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

Environment Canada. 2014b. An Inventory of Landfill Gas Recovery and Utilization in Canada 2012 and 2013. Greenhouse Gas Division, Environment Canada.

Environment Canada. 2014c. An Inventory of the 2014 Waste Incineration Survey in Canada 2012 and 2013. Unpublished internal Environment Canada Report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

Environment Canada. 2014d. An Inventory of the 2012 Industrial Wastewater Survey in Canada – 2010 and 2011. Unpublished internal Environment Canada Report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

Environment Canada. 2014e. An Inventory of the 2014 Industrial Wastewater Survey in Canada – 2012 and 2013. Unpublished internal Environment Canada Report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

[ECCC] Environment and Climate Change Canada. 2016a. A Review of Canadian Non-Hazardous Waste Export Quantities to the United States. Unpublished internal Environment Canada Report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

[ECCC] Environment and Climate Change Canada. 2016b. Étude nationale de la composition des déchets solides 2014-2015. A study commissioned by Environment Canada and conducted by Les Consultants S.M. inc.

[ECCC] Environment and Climate Change Canada. 2016c. An Inventory of the 2014 Industrial Wastewater Survey in Canada – 2014 and 2015. Unpublished internal Environment Canada Report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

Golder Associates Ltd. 2008. Inventory of Greenhouse Gas Generation from Landfills in British Columbia. Prepared for the Ministry of Environment – Community Waste Reduction Section, Victoria (BC).

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change, Organisation for Economic Co-operation and Development, and International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at http://www.ipcc-nggip.iges.or.jp/public/gp/english/.

[IPCC] Intergovernmental Panel on Climate Change. 2002. Background Papers - IPCC Expert Meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at http://www.ipcc-nggip.iges.or.jp/public/gp/gpg-bgp.html.

[IPCC] Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme. Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

Levelton BH. 1991. Inventory of Methane Emissions from Landfills in Canada. Unpublished report prepared for Environment Canada by Levelton & Associates.

McCarthy JE. 1993. Interstate Shipment of Municipal Solid Waste. Environment and Natural Resources Policy Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

McCarthy JE. 1995. Interstate Shipment of Municipal Solid Waste: 1995 Update. Environment and Natural Resources Policy Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

McCarthy JE. 1996. Interstate Shipment of Municipal Solid Waste: 1996 Update. Environment and Natural Resources Policy Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

McCarthy JE. 1997. Interstate Shipment of Municipal Solid Waste: 1997 Update. Environment and Natural Resources Policy Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

McCarthy JE. 1998. Interstate Shipment of Municipal Solid Waste: 1998. Update. Environment and Natural Resources Policy Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

McCarthy JE. 2000. Interstate Shipment of Municipal Solid Waste: 2000 Update. Resources, Science, and Industry Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

McCarthy JE. 2001. Interstate Shipment of Municipal Solid Waste: 2001 Update. Resources, Science, and Industry Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

McCarthy JE. 2004. Interstate Shipment of Municipal Solid Waste: 2004 Update. Resources, Science, and Industry Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

McCarthy JE. 2007. Interstate Shipment of Municipal Solid Waste: 2007 Update. Resources, Science, and Industry Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

McCarthy JE, Hardenbergh AL. 2002. Interstate Shipment of Municipal Solid Waste: 2002 Update. Resources, Science, and Industry Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

McCarthy JE, Reisch M, Davis G. 1990. Interstate Shipment of Municipal Solid Waste. Environment and Natural Resources Policy Division, CRS Reports for Congress, Library of Congress, Congressional Research Service.

Michigan. 1996–2011. Annual Reports of Solid Waste Landfilled in Michigan. Department of Environmental Quality, State of Michigan. Available online at: http://www.michigan.gov/deq/0,1607,7-135-3312_4123-47581--,00.html.

Maurice C, Lagerkvist A. 2003. LFG emission measurements in cold climatic conditions: seasonal variations and methane emissions mitigation. Cold Regions Science and Technology 36:37–46.

MWA Consultants Paprican. 1998. Increased Use of Wood Residue for Energy: Potential Barriers to Implementation. Final draft. Prepared for the Canadian Petroleum Producers Association (confidential internal document).

[NCASI] National Council for Air and Stream Improvement. 2003. Calculation Tools for Estimating Greenhouse Gas Emissions from Wood Products Manufacturing Facilities. National Council for Air and Stream Improvement, Inc.

[NRCan] Natural Resources Canada. 1997. National Wood Residue Data Base. Natural Resources Canada (printouts from J. Roberts).

[NRCan] Natural Resources Canada. 1999. Canada's Wood Residues: A Profile of Current Surplus and Regional Concentrations. Prepared by the Canadian Forest Service, Industry, Economics and Programs Branch, Natural Resources Canada for the National Climate Change Process Forest Sector Table.

[NRCan] Natural Resources Canada. 2005. Estimated Production, Consumption and Surplus Mill Wood Residues in Canada—2004. Prepared by the Forest Products Association of Canada for Natural Resources Canada.

[NRCan] Natural Resources Canada. 2006. Provincial/Territorial Disposal Waste Compositions (2002), an Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications. Natural Resources Canada.

Ontario Ministry of the Environment. 1991. Residential Waste Composition Study: Volume 1 of the Ontario Waste Composition Study. Prepared by Gore and Storrie Limited., Decima Research Limited for the Ontario Ministry of the Environment, Toronto.

Peavy HS, Rowe DR, Tchobanoglous G. 1985. Environmental Engineering. New York (NY): McGraw Hill Book Company.

Rose K, Steinbüchel A. 2005. Biodegradation of natural rubber and related compounds: recent insights into a hardly understood catabolic capability of microorganisms. Applied and Environmental Microbiology 71(6):2803–2812.

[RTI] Research Triangle Institute. 2004. Documentation for Changes to the Methodology for the Inventory of Methane Emissions from Landfills.

Statistics Canada. 2000. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts, Statistics Canada. Catalogue No. 16F0023XIE.

Statistics Canada. 2003. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts, Statistics Canada. Catalogue No. 16F0023XIE.

Statistics Canada. 2004. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts, Statistics Canada. Catalogue No. 16F0023XIE.

Statistics Canada. 2006. Annual Demographic Statistics. Catalogue No. 91-213-XIB.

Statistics Canada. 2007a. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts, Statistics Canada. Catalogue No. 16F0023XIE.

Statistics Canada. 2007b. Food Statistics. Catalogue No. 21-020-XIE.

Statistics Canada. 2008a. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts, Statistics Canada. Catalogue No. 16F0023XIE.

Statistics Canada. 2008b. Food Statistics. Catalogue No. 21-020-XIE.

Statistics Canada. 2010a. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts, Statistics Canada. Catalogue No. $16F_{0023}$XIE.

Statistics Canada. 2010b. Food Statistics. Catalogue No. 21-020-XIE.

Statistics Canada. 2013. Waste Management Industry Survey: Business and Government Sectors. System of National Accounts, Statistics Canada. Catalogue No. $16F_{0023}$XIE.

Statistics Canada. 2014. Annual Demographic Estimates: Canada, Provinces and Territories. Catalogue No. 91-215-X, September 2014 release.

Statistics Canada. 2015a. Annual Demographic Estimates: Canada, Provinces and Territories. Catalogue No. 91-215-X, September 2015 release.

Statistics Canada. 2015b. Disposal and Diversion of Waste, by Province and Territory. Summary Table from CANSIM Table 153-0041, Catalogue No. 16F0023X. [revised 2015 Jun 19; cited 2015 Nov 19]. Available online at: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/envir32a-eng.htm.

Statistics Canada, 2016a. Disposal of waste, by source, Canada, provinces and territories, Summary Table from CANSIM Table 153-0041. [revised 2016-09-22, cited 2016 Dec 10]. Available online at: http://www5.statcan.gc.ca/cansim/a26?id=1530041&retrLang=eng&lang=eng.

Statistics Canada. 2016b. Annual Demographic Estimates: Canada, Provinces and Territories. Catalogue No. 91-215-X, September 2016 release.

Stericycle, ULC. 2014. Environmental Assessment Registration – Stericycle Waste Transfer Facility. Submitted to Minister of Environment and Conservation – Director of Environmental Assessment, Government of Newfoundland and Labrador.

Tchobanoglous G, Theisen H, Vigil S. 1993. Integrated Solid Waste Management: Engineering Principles and Management Issues. New York (NY): McGraw Hill.

Thompson S, Tanapat S. 2005. Waste management options for greenhouse gas reduction. Journal of Environmental Informatics 6(1):16–24.

Thompson S, Sawyer J, Bonam RK, Smith S. 2006. Recommendations for Improving the Canadian Methane Generation Model for Landfills. Winnipeg (MB): Natural Resources Institute. University of Manitoba.

Tsuchii A, Suzuki T, Takeda K. 1985. Microbial degradation of natural rubber vulcanizates. Applied and Environmental Microbiology 50:965–970.

[U.S. EPA] United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors. Vol. I—Stationary Point and Area Sources. AP 42, 5th Edition. Chapter 2, Solid Waste Disposal. U.S. Environmental Protection Agency. Available online at: http://www.epa.gov/ttn/chief/ap42/ch02.

Annex 4, Comparison of Sectoral and Reference Approaches and the National Energy Balance

Environment Canada. 2016. Updated Coal Emission, Energy Conversion and Oxidation Factors.

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, editors. Kanagawa (JP): Institute for Global Environmental Studies. Available online at www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

Jaques AP. 1992. *Canada's Greenhouse Gas Emissions: Estimates for 1990, Environmental Protection*. Conservation and Protection. Environment Canada. Report No. EPS 5/AP/4.

McCann TJ. 2000. *1998 Fossil Fuel and Derivative Factors*. Report prepared by T.J. McCann and Associates for Environment Canada.

Statistics Canada. *Report on Energy Supply–Demand in Canada* (Annual). #57-003-X.

Annex 5, Assessment of Completeness

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme*. Available online at http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Annex 6, Emission Factors

AECOM Canada. 2010. *Improved Methodology for the Estimation of Greenhouse Gases from Canadian Municipal Wastewater Treatment Facilities*.

AMEC Earth & Environmental. 2006. *Identifying and Updating Industrial Process Activity Data in the Minerals Sector for the Canadian Greenhouse Gas Inventory*. AMEC Earth & Environmental.

Barton P, Simpson J. 1994. *The Effects of Aged Catalysts a*nd Cold Ambient Temperatures on Nitrous Oxide Emissions. Mobile Sources Emissions Division, Environment Canada. MSED Report No. 94-21.

BioMer. 2005. *Biodiesel Demonstration and Assessment for Tour Boats in the Old Port of Montreal and Lachine Canal National Historic Site*. Final report.

[CAC] Cement Association of Canada, 2016. *Unpublished data on Canadian clinker production*.

[CAPP] Canadian Association of Petroleum Producers. 1999. *CH_4 and VOC Emissions from the Canadian Upstream Oil and Gas Industry*. Vols. 1 and 2. Prepared for the Canadian Association of Petroleum Producers. Calgary (AB): Clearstone Engineering. Publication No. 1999-0010.

Cheminfo Services. 2005. *Improvements to Canada's Greenhouse Gas Emissions Inventory Related to Non-Energy Use of Hydrocarbon Products*. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2010. *Study of Potential Additions and Updates to the Industrial Process Sources of GHGs in the Canadian GHG Inventory, and Development of Canadian-Specific Methodologies and Emission Estimates for such Sources*. Final Report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2014. *Chemical Management Plan 2 (CMP_2) Scoping Project for Substance Information on Nitrogen Trifluoride (NF_3)*. Confidential Final Report. Markham (ON): Cheminfo Services Inc.

Cheminfo Services. 2015. *Petrochemical Production Study: Carbon Flows and GHG Emissions*. Confidential Final Report. Markham (ON): Cheminfo Services Inc.

[CIEEDAC] Canadian Industrial Energy End-Use Data Analysis Centre. 2003. *A Review of Energy Consumption in Canadian Oil Sands Operations, Heavy Oil Upgrading 1990, 1994 to 2001*. Burnaby (BC): Simon Fraser University.

[CIEEDAC] Canadian Industrial Energy End-Use Data Analysis Centre. 2014. *Energy Use and CO_2 Emissions in Canadian Oil Refineries 1990, 1994 to 2012*. Burnaby (BC): Simon Fraser University.

[CRA] Conestoga-Rovers and Associates. 2014. *Characterization of Coking Coal, Coke, and Coke By-Products for the Purpose of Developing Updated Carbon Dioxide Combustion Emission Factors*. Final report submitted to the Energy Group, PIRD, Environment Canada.

Environment Canada. 2006. *ERMD Report 04-44: Greenhouse Gas Emissions from 1997-2005 Model Year Light Duty Vehicles*. Unpublished Environment Canada internal report. Ottawa (ON): Emissions Research and Measurement Division, Environment Canada.

Environment Canada. 2009. *ERMS Report 07-14A: N_2O Emissions from In-Use Canadian Tier 1 Vehicles, Report A: Greenhouse Gas Emission Rates*. Unpublished Environment Canada internal report. Ottawa (ON): Emissions Research and Measurement Section, Environment Canada.

Environment Canada. 2010. *Waste Incineration in Canada 1990-2009 – A summary of findings from surveys conducted in 2006, 2008 and 2010*. Unpublished Environment Canada internal report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

Environment Canada. 2015. Review of Country-specific HFCs Emission Estimations in the Refrigeration and Air Conditioning Sectors. Edalatmanesh M, Niemi D. Unpublished report. Ottawa (ON).

Environment and Climate Change Canada. 2016. *Updated Coal Emission, Energy Conversion and Oxidation Factors*. Unpublished Environment Canada internal report. Ottawa (ON): Pollutant Inventories and Reporting Division.

[FPL] Forest Products Laboratory. 2004. *Fuel Value Calculator*. 5th Ed. USDA Forest Service: Arlington, Virginia.

Graham L, Rideout G, Rosenblatt D, Hendren J. 2008. *Greenhouse Gas Emissions from Heavy-Duty Vehicles, Atmospheric Environment 42:4665–4681*.

Graham L, Belisle S L, Rieger P. 2009. *Nitrous Oxide Emissions from Light Duty Vehicles, Atmospheric Environment 43:2031–2044*.

[IAI] International Aluminum Institute. 2006. *The Aluminum Sector Greenhouse Gas Protocol* (Addendum to the WRI/WBCSD Greenhouse Gas Protocol). International Aluminum Institute.

ICF Consulting. 2004. *Update of Methane and Nitrous Oxide Emission Factors for On-Highway Vehicles*. Prepared by ICF Consulting for the U.S. Environmental Protection Agency. Report No. 420-P-04-16.

[IPCC] Intergovernmental Panel on Climate Change. 2000. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme*. Available online at http://www.ipcc-nggip.iges.or.jp/public/gp/english/.

[IPCC] Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme*. Available online at http://www.ipcc-nggip.iges.or.jp/public/2006gl/.

[IPCC/OECD/IEA] Intergovernmental Panel on Climate Change / Organisation for Economic Co-operation and Development / International Energy Agency. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available online at http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Jaques AP. 1992. Canada's Greenhouse Gas Emissions: Estimates for 1990. Ottawa (ON): *Environmental Protection Publications, Conservation and Protection, Environment Canada*. Report No. EPS 5/AP/4.

McCann TJ. 2000. *1998 Fossil Fuel and Derivative Factors*. Prepared by T.J. McCann and Associates for Environment Canada.

[NCASI] National Council for Air and Stream Improvement. 2010. *ICFPA/NCASI Spreadsheets for Calculating GHG Emissions from Pulp and Paper Manufacturing*. Version 3.2. National Council for Air and Stream Improvements. [revised 2010 March; cited 2010 Dec 3].

Radovan R, Hassani N. et al. 2012. *A Statistical Approach to Carbon Dioxide Emission Factors for Coal Consumed in Canada*. Unpublished Report. Gatineau (QC): Environment Canada, Pollutant Inventories and Reporting Division.

SGA Energy. 2000. *Emission Factors and Uncertainties for CH_4 & N_2O from Fuel Combustion*. Unpublished report prepared by SGA Energy Limited for the Greenhouse Gas Division, Environment Canada.

Statistics Canada. 2014. *Report on Energy Supply and Demand in Canada (Annual)*. Catalogue No. 57-003-X

[U.S. EPA] United States Environmental Protection Agency. 1995. *Compilation of Air Pollutant Emission Factors*. 5th Edition. Vol. 1, Chapter 2.2, Sewage Sludge Incineration. U.S. Environmental Protection Agency. Available online at www.epa.gov/ttn/chief/ap42/ch02.

[U.S. EPA] United States Environmental Protection Agency. 1996a. *Compilation of Air Pollutant Emission Factors—Vol. I: Stationary Point and Area Sources, AP 42, 5th Edition, Supplement B*. Washington (DC): U.S. Environmental Protection Agency.

[U.S. EPA] United States Environmental Protection Agency. 1996b. *Compilation of Air Pollutant Emission Factors—Vol. 1: Stationary Point and Area Sources, AP 42, 5th Edition, Supplement B, Section 1.9 and 1.10*. Washington (DC): U. S. Environmental Protection Agency.

[U.S. EPA] United States Environmental Protection Agency. 2003. *Compilation of Air Pollutant Emission Factors—Vol. 1: Stationary Point and Area Sources, AP 42, 5th Edition, Section 1.6*. Washington (DC): U.S. Environmental Protection Agency.

[U.S. EPA] United States Environmental Protection Agency. 2010. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*. Washington (DC): U.S. Environmental Protection Agency.

[WBCSD] World Business Council for Sustainable Development. 2005. CO_2 *Accounting and Reporting Standard for the Cement Industry, Version 2.0*. Switzerland.

Annex 7, Ozone and Aerosol Precursors

[UNFCCC] United Nations Framework Convention on Climate Change. 2014. *Report of the Conference of the Parties on its nineteenth session, held in Warsaw from 11 to 23 November 2013, Decision* 24/CP.19. FCCC/CP/2013/10/Add.3. Available online at unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf